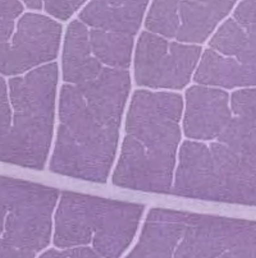
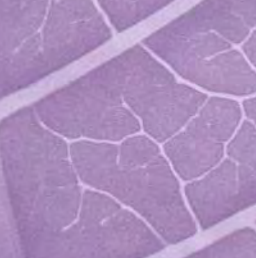
Forest Research Annual Report and Accounts 1999–2000





Forest Research
An agency of the Forestry Commission

HC99

Advisory Committee on Forest Research

Membership at 31 March 2000

Chairman

PROFESSOR H.G. MILLER, OBE
Professor of Forestry,
University of Aberdeen

Secretary

DR P.H. FREER-SMITH
Chief Research Officer,
Forest Research

Members

DR A.R. GRIFFIN
Renewable Resources Division,
Shell International

PROFESSOR M.J. JEGER
Sainsbury Professor of
Horticulture, Wye College,
University of London

R.A. KEMPTON, FRSE
Director, Biomathematics
and Statistics Scotland

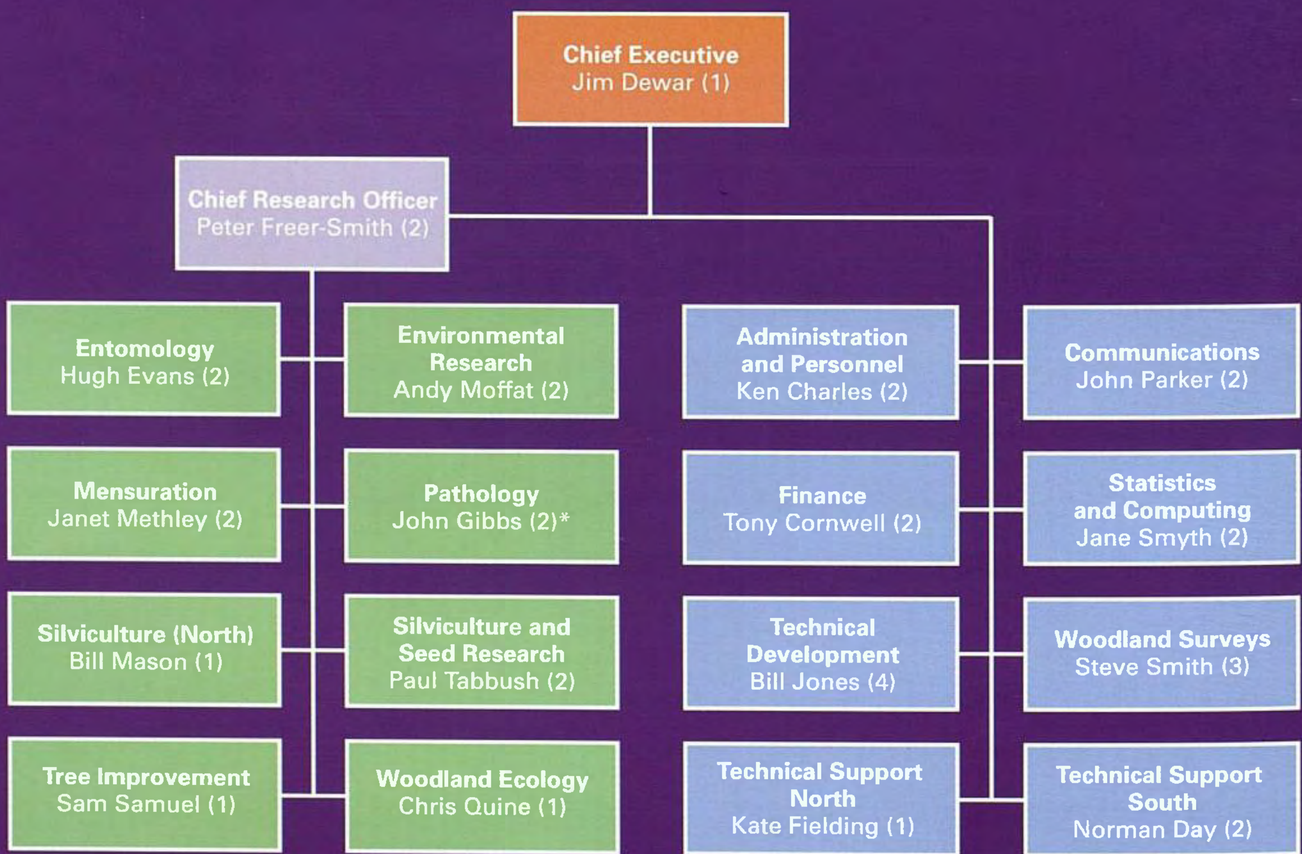
PROFESSOR B.R. KERRY
Head of Entomology and
Nematology Department,
Rothamsted Experimental Station

DR P.S. SAVILL
Reader in Forestry,
Oxford Forestry Institute

PROFESSOR M.B. USHER
Chief Scientist,
Scottish Natural Heritage

Forest Research Organisation

at 31 March 2000



Location

1 Northern Research Station
2 Alice Holt Research station
3 Forestry Commission Headquarters
4 Ae Village
* Joan Webber from 1 April 2000

Forest Research Annual Report and Accounts 1999–2000

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

Forest Research ARA 1999–2000

Ordered by the House of Commons to be printed 31 January 2000

Contents

HC99

ISBN 010-298-500-6

Edinburgh: The Stationery Office

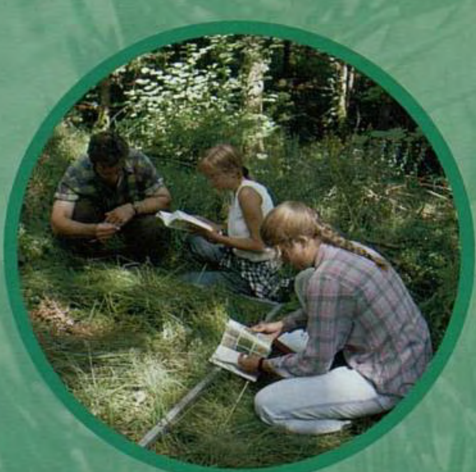
£16.30

Forest Research

An agency of the Forestry Commission

About Forest Research

Forest Research (FR) is an agency of the Forestry Commission (FC) and is the principal organisation in the UK engaged in forestry and tree related research. The agency was launched on 1 April 1997 and comprises the former Research Division, Technical Development Branch and parts of the former Surveys Branch of the Forestry Commission.



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 Ministry of Agriculture, Fisheries and Food, the Department of Trade and Industry, the Department of the Environment, Transport and the Regions, the European Union, commercial organisations, private individuals, landowners 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. An increasing proportion of the research effort is directed at developing the non-market 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 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 approximately 280 staff, not including visiting scientists and sandwich students. A copy of the agency's Business Plan is available from the Library at Alice Holt Lodge.

Chief Executive's Introduction

I am pleased to present the Agency's Annual Report and Accounts for the year ended March 2000. Forest Research has now been an agency for three years. An important feature in the management of agencies is the setting of performance measures and targets for each of the core objectives. While achievement against targets do not tell the whole story the performance over three years shows a clear trend of improvement in customer satisfaction, an increasing output of peer-reviewed papers,reductions in unit costs, progress in reviewing our work by visiting groups of scientists and an increasing income from non-Forestry Commission sources. But for most readers it is our achievements in providing policymakers and practitioners with soundly based advice and new techniques which are the more significant indicators of performance.

Research highlights

The pine weevils *Hylobius abietis* and *Hylastes* species are a major cause of losses when restocking after felling. The weevils lay their eggs in the stumps of felled conifers and emerge to feed on the stem of young trees. This bark feeding can completely girdle the stem resulting in death of the tree. A variety of insecticides and application methods have been effective in preventing losses. Concerns over operator safety and environmental impacts and the limited size of the market have led to notices of withdrawal of dipping in permethrin as a method of plant protection.

Six alternative insecticides have been tested for efficacy and of these three are showing promise. Large scale trials have also been carried out using nematodes raised in a new production facility at our Alice Holt Research Station. Preliminary results have shown the practicality of the method. The cost per hectare of using nematodes for control remains significantly higher than the cost of using insecticides but better assessment of risk and selective treatment of sites is expected to reduce the overall cost.

Our entomologists continue to deal with a range of exotic insects which pose threats to trees in Britain including Asian longhorn, Asian gypsy moth, *Ips typographus* and *Dendroctonus micans*. Fortunately the control methods in place are proving effective in preventing any of these species causing significant losses.

The discovery of pinewood nematode in pine trees in Portugal confirmed earlier assessments that this species, a native of China and a pest in North America, could pose a threat to trees in Europe. Our Head of Entomology Branch, through participation in an EC mission, is advising on control measures.

Meticulous research on *Fomes* butt rot *(Heterobasidion annosus)* has refined our assessment of the risks and created the opportunity to reduce chemical usage and costs. Stump treatment against Fomes is now no longer recommended on soils with a peat depth of greater than 15 cm in areas where the rainfall exceeds 1600 mm a year.

Researchers at Sheffield University have developed an immuno-contraceptive vaccine as a means of controlling grey squirrels. Small-scale field trials conducted by Forest Research staff show that the technique is promising but there is still much work to be done to produce a fully developed system.

Although Britain's climate is very suitable for the growth of trees, regular winter gales and occasional storms can cause significant windthrow. A new risk model, ForestGALES, incorporates the most recent research findings on the interaction between stand management and wind damage. A CD-rom and training package is now available.

Calibration of Sitka spruce yield models for a wide range of initial spacings and thinning treatments has been successfully completed. Release of the software package to allow interactive modelling of Sitka spruce is planned for early 2001.

A survey of log straightness in southern Scotland has shown that Sitka spruce planted at higher elevation and in later decades are less straight than crops planted at lower elevation and in earlier decades. The causes are a combination of greater wind damage on more exposed sites and changes in silvicultural practices. This quantitative information confirms anecdotal evidence and will be incorporated into production forecasts to give an indication of how the quality of future log supplies is likely to change through time. Surveys are being extended to cover all of Scotland and the north of England.

Continuous cover forestry systems are being promoted as a means of avoiding the dramatic changes in the landscape caused by harvesting trees by clearfelling. Experience in other parts of Europe shows that cost-effective use of continuous cover forestry depends upon the successful use of natural regeneration. During the year, we published a Bulletin summarising our current understanding of natural regeneration in British conifer forests. In addition, ongoing investigations of the light regime within Sitka spruce stands indicate that the light intensity in typical Sitka spruce stands is too low for successful establishment of natural regeneration. This has implications for the management of these stands if natural regeneration is to succeed.

We hosted a conference on 'The Transformation of Plantation Forests' attended by over one hundred delegates from 12 countries. At the conference the Chief Executive of Forest Enterprise announced an intention to increase the role of continuous cover forestry in the management of the publicly owned forest estate.

Modelling of tree growth under different climate conditions has lead to predictions of a general increase in growth rates for trees across the UK as a result of climate change though summer droughts could limit productivity in parts of the south of England. A four-year EU funded study at Coalburn in Northern England has concluded that conifer afforestation poses little threat to low flows in upland rivers. Previous research had shown that the original ploughing of the peaty catchment prior to planting in 1973 had resulted in a doubling of low flows, but that this effect had tailed off over the subsequent 20 years.

The new work has demonstrated that the longer-term decline was caused by the gradual in-filling of the plough furrows through subsidence and *Sphagnum* growth, and was not due to an increased water use by the developing forest. Low flows are predicted to remain above pre-afforestation levels for the complete forest rotation.

Lowland raised bogs are an endangered habitat and there is pressure to remove trees planted on such sites but with limited evidence that the raised bog habitat would be recreated. Initial results from an experiment at Flanders Moss in Central Scotland show that removal of the tree cover leads to a rapid rise in the water table even without blocking drainage ditches and that a raised bog vegetation will quickly re-establish. However under some conditions a problem could be created by natural regeneration of tree species.

Tree breeding by phenotypic selection is a slow and laborious process involving extensive field trials and long delays between initial selection and the production of improved genetic material. A programme has been initiated to shorten the cycle and increase the degree of selection of desirable traits. This involves identification of genetic markers which are closely correlated with desired characteristics and selectively breeding from individuals carrying these genetic markers.

Much planting stock used in Britain is imported. This is particularly the case for broadleaved species where seed production in Britain is irregular and seed cannot be readily stored for use in subsequent years. There is concern that unless planting material is locally sourced it will be ill adapted to the local climate and site. This argument ignores the potential benefits of tree breeding and selection from across a species' natural distribution. However, the latest results from ash provenance trials confirm that GB and French sourced material performs much better than material from elsewhere in Europe.

There is a desire to conserve the genetic diversity of Britain's much diminished native woodland resource. Past work on terpenes in Scots pine recognised broad differences between populations and developed a zonation which became the basis for seed selection in expanding the native pinewoods of Scotland. DNA analysis is a more reliable means of identifying related populations and is now being used on a number of native species as an aid to genetic conservation.

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 the Tree Improvement Branch and the Mensuration Branch.

The Visiting Group to Tree Improvement Branch was lead by Dr David Thompson of the Genetics and Tree Improvement Research Section of Coillte Teoranta, the Irish Forestry Board, supported by Professor Steve McKeand of the Department of Forestry at North Carolina State University and Dr Kornel Burg of the Biotechnology Department of Austrian Research. The group found the research was of high scientific merit but proposed changes in the direction of some projects.

Specifically they recommended that:

- a more aggressive approach be adopted to the Sitka spruce Breeding Programme with multiple trait selection, accelerated breeding and clonal forestry;
- with the resources at our disposal the Broadleaved Tree Breeding Programme be confined to just 2 or 3 species;
- investment in equipment be made to allow marker aided selection.

Decisions have since been taken to begin a marker aided selection programme to accelerate Sitka spruce breeding and to invest in gene sequencing equipment. However, concerns over the risks associated with clonal forestry and selection from a smaller breeding population argues for continuing with the conservative approach to selection. Broadleaved tree breeding has much support from other organisations, most notably the Hardwood Tree Breeders' Association. This is the subject of a Forestry Research Co-ordination Committee workshop in September 2000.

The Visiting Group to Mensuration was lead by Mr Graham Hamilton, formerly of the Forestry Commission, and Dr Pekka Kauppi of the University of Helsinki. The group complimented the Branch on their current work on growth and yield modelling. Specifically they recommended that:

- publication of revised yield models should remain top priority;
- key data analysis and implications be published;
- datasets be made more readily available to other researchers;
- greater emphasis be given to investigating improved timber measurement techniques.

Revised yield models remain a key priority. We are in discussion with funders on the cost implications of the other recommendations.

Targets and Achievements

Performance measure		1997/1998	1998/1999	1999/2000	
Customer satisfaction	Target	85%	92%	95%	
	Achieved	90%	94%	96%	Target met
Peer-reviewed papers	Target	29	35	38	
	Achieved	33	40	43	Target met
Unit cost/researcher day	Target	98	96	94	
96/97 = 100	Achieved	98	94	94	Target met
Unit cost of support services	Target	–	–	98	
	Achieved	–	100	98	Target met
Cost recovery	Target	100%	100%	100%	
	Achieved	101%	103%	101%	Target met

Professor J.P. Blakeman and Professor R.M. Cormack stood down from the Advisory Committee having served for 4 years and 12 years respectively. Mr Rob Kempton and Professor Mike Jeger have been appointed to the Committee.

We are grateful to the members of the Advisory Committee and the Visiting Groups for their valuable advice.

Finance

Income through the service level agreement with Policy and Practice Division increased by 1.9% to £9985k. Income from other parts of the FC including Forest Enterprise increased by 4.4%. Income from non-FC sources increased by 9.0%. Total expenditure increased by 5.1%. The target operating surplus of £520k was exceeded by £126k.

Visitors

Forestry Minister Elliot Morley and Deputy Minister for Rural Affairs John Home Robertson visited the Northern Research Station and expressed strong support for the work of the agency. Mr Morley is the first minister to have visited both Research Stations. James Paice MP visited Alice Holt Lodge, which is within his North Hampshire parliamentary constituency.

Members of the Timber Growers' Association and the Institute of Chartered Foresters attended research update seminars at Abergavenny and the Northern Research Station. GIS (geographical information systems) open days were held at both Research Stations and attracted a good number of participants with an interest in the development of GIS technology for storage and analysis of spatial data.

The agency hosted groups of visitors from Austria, Canada, Estonia, France, India, Latvia and Sweden and individual visitors from a further 21 countries thereby maintaining links with forestry organisations around the world.

People

Total staff numbers employed by the agency at year end, excluding sandwich students and visiting scientists, was 282 full-time equivalents, an increase of 2 on last year.

I am pleased to record the award of an OBE to Dr John Gibbs for his work on fungal pathogens. Dr David Lonsdale received the Arboricultural Association's 1999 Annual Award for services to arboriculture. Chris Quine, Dr Jonathan Humphrey and Dr Richard Ferris received the ICF Silvicultural Prize for their paper on 'Should the wind disturbance patterns observed in natural forests be mimicked in planted forests in the British uplands?'

Mr Harry Pepper retired after more than 40 years service with the Forestry Commission. For the past 30 years he has been engaged in research on tree protection against mammal pests and became the acknowledged expert on red and grey squirrel management. We wish him well in his retirement.

New appointments to the agency included Kate Fielding, Head of Technical Support Unit (North), on transfer from the FC, Professor Sam Evans to work on tree growth modelling, Dr Helen Armstrong to work on grazing and deer management and Dr Roger Dunham to work on the application of the ForestGALES software package.

The success of the agency in providing advice to policymakers, in equipping forest managers with improved methods and technical services and in meeting key targets could not have been achieved without the skills, enthusiasm and commitment of the staff of the agency.

Jim Dewar
Chief Executive, Forest Research

Pests and Diseases

Pests and Diseases

by John Gibbs and Hugh Evans

The causes of damage to trees are often hard to determine. There are many reasons for this. Symptoms may not be specific to a particular cause and may be complex in origin. If micro-organisms are involved, they are often not easy to see and identify. In addition, the causal organisms may disappear quickly from the damaged tissue and be replaced by secondary organisms of little or no significance. Awareness of these points has led to a lively debate among scientists concerned with forest protection as to the extent to which diagnostic guides should be placed in the hands of non-specialist staff. Some would argue that 'a little knowledge is a dangerous thing', and it cannot be denied that there is a danger that an important new cause of damage may be misidentified and, hence, disregarded. However, the balance of opinion around the world is that it is helpful for diagnostic guides to be made available to practitioners and this is a view that we in Forest Research share.

It therefore seems appropriate to summarise what is available from past and present staff of Forest Research. The book *Diseases and disorders of forest trees* by Steve Gregory and Derek Redfern (1998) is aimed firmly at the manager or owner of woods and plantations. By contrast *Diagnosis of ill-health in trees* by Robert Strouts and Tim Winter is principally directed at those concerned with the ornamental or 'amenity' tree. An expanded second edition of this book has just been published (Strouts and Winter, 2000). A more specialised audience is catered for in the Field Book *Christmas tree pests* by Clive Carter and Tim Winter (1998). In addition, the current year saw a warm welcome for David Lonsdale's *Principles of tree hazard assessment and management.* Among other things, this book provides information on the recognition and evaluation of tree hazards due to structural defects and decay (Lonsdale, 1999).

However, the existence of these books does not reduce the need for the practitioner to make direct contact with suitably qualified experts to whom causes of damage can be reported and by whom detailed investigations can be made. This process brings two-fold benefits: firstly, the non-specialist can gain in terms of relevant first-hand advice; and secondly, the expert can increase in experience while, at the same time, gaining information on the behaviour of a pest or disease under a particular set of conditions.

Threats from abroad

An Asian longhorn beetle, *Anoplophora glabripennis*

This insect is described in some detail in Evans and Gibbs (1999). During 1999, and in conjunction with FC Plant Health Service staff, a publicity campaign and a programme of directed surveys were conducted to determine if the Asian longhorn beetle (ALB) was established in Britain. A poster illustrating the key identification points was distributed widely within the Forestry Commission, and also to local authorities, arboriculturalists, tree wardens, universities, etc. Particular emphasis was placed on informing importers of goods from China of the risks from the beetle and on ensuring that they were aware of the new legislation, passed in February 1999, to reduce the risks of beetle importation. Several radio and TV interviews were given during the initial publicity phase in the spring, and these brought responses from the general public as well as the targeted audience.

The number of confirmed sightings of ALB was lower than in 1998, and this could be attributed to the higher standards of debarking and 'grub-hole control' which were brought about by the new legislation. However, linkage to packaging material used for heavy items from China was confirmed; such items included ceramic magnets, decorative tiles, cast iron manhole covers and flooring slates. In most cases, it was adult ALB that were discovered, highlighting the risk that the insects might be able to disperse from depots and warehouses by flying.

In the USA, attempts are being made to control established infestations in New York and Chicago, and one of us (HFE) was able to attend the USDA Interagency Meeting in January 2000 at which ALB was discussed in depth. It is apparent from experience in the USA that ground-based surveys to determine the presence of ALB are very difficult to carry out because of the cryptic nature of the beetle attacks. This is especially true early in an infestation when there will be little external sign, such as branch death, of beetle activity. Research into a potential attractant for monitoring and managing populations of the adult beetles has identified chemicals that elicit a response in electro-antennogram tests. However, field tests did not show any attraction and, therefore, there is currently no 'remote sensing' method of surveying for the presence of ALB.

The infestations in New York and Chicago continue to spread, despite the sanitation felling regime that is in place.

Although it appears that ALB has not established breeding colonies in the UK, the threat remains and it is important that vigilance is maintained. The highest probability of detecting the beetle is through casual observation of the very striking adult stage (shiny black with white spots and very long antennae, body length of beetle up to 30 mm). The public are asked to report any suspected sightings immediately to the Forestry Commission.

Exotic bark beetles

Pheromone traps, baited with the attractant for the eight-toothed spruce bark beetle, *Ips typographus,* have been in use since 1985. Data from these traps have provided a measure of the total risk from continental Europe and, in the process, have reflected changes in trading patterns. Results for the 15-year period are shown in Figure 1. The leap in numbers in 1994 and, particularly, in 1995 can largely be attributed to increased trade with the Baltic States and to the fact that, initially, the standard of debarking was poor. This has now been rectified, although the numbers of interceptions are still higher than before 1994. The devastating gales experienced in much of Northern Europe at the turn of the year will have provided enormous quantities of breeding material for a range of bark beetles and, in consequence, there is an increasing risk of bark beetle importation for the next few years.

Other bark beetle species are also attracted to the lures in the pheromone traps, and captures have included *Dryocoetes* sp. (1), *Dryocoetinus villosus* (3), *Hylastes* spp. (22), *Hylurgops* sp.(1), *Ips sexdentatus* (34), *Pityogenes bidentatus* (17), *Pityogenes trepanatus* (1), *Tomicus piniperda* (2+) and *Trypodendron* spp. (11). All are on the British list and, thus, do not necessarily represent new incursions on imported wood. However, the presence of *I. typographus* among these beetles, suggesting that some may have been imported from continental Europe, indicates an inadequacy in the debarking process. Direct interceptions on dunnage and other wood packing material of a range of bark and wood-boring beetles, including *Monochamus sartor,* a potential vector of pinewood nematode (see below), indicates that there are many pathways for entry of exotic pests to Britain.

Pinewood nematode in Portugal

The threat from the pinewood nematode (PWN), *Bursaphelenchus xylophilus,* has been recognised for some time, and measures such as heat treatment of wood have been in place for several years (Evans *et al.,* 1996). Hitherto, surveys for PWN in various EU Member States have been negative but during 1999 the nematode was found in the Setubal region of Portugal. The Portuguese authorities reported this important new finding to the EU Standing Committee on Plant Health in May 1999 and then carried out further extensive surveys. The nematode was found in association with wilting pines at a number of other locations in the same region.

Figure 1 Numbers of *Ips typographus* caught in pheromone traps over the period 1985–1999.

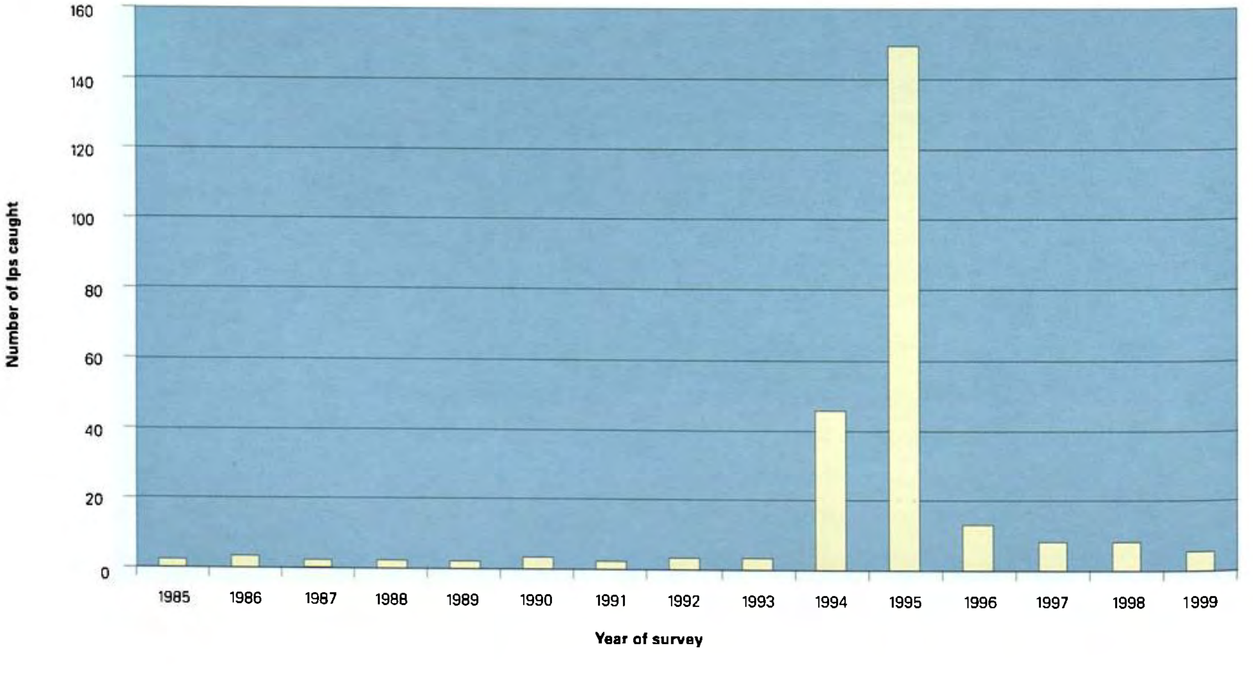
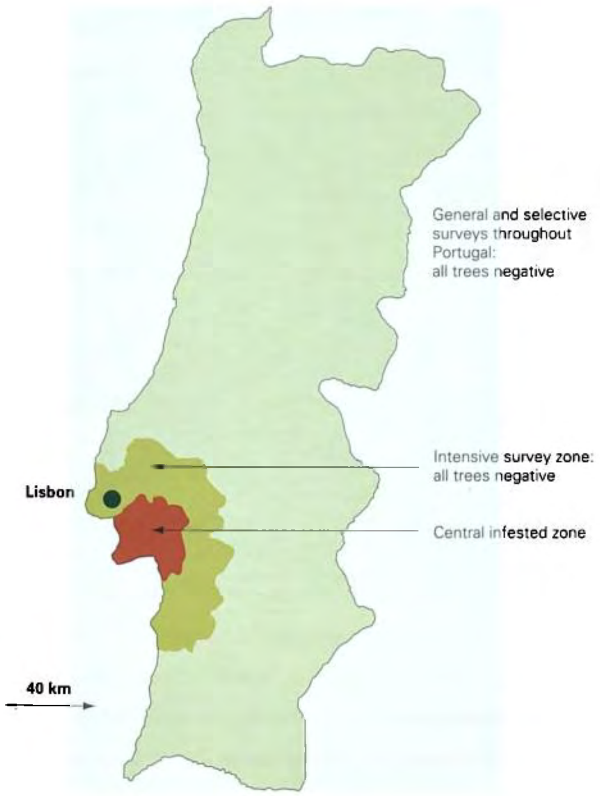


Figure 2 shows the known infested area and also indicates a zone in which, despite very intensive surveys, no trees with PWN have been found.

Figure 2 Area of Portugal known to be infested with the pine wilt nematode.



All trees showing wilt symptoms have been felled and destroyed as part of a strategy to reduce the scale of the infestation and to minimise the risks of further spread. During the coming year, all EU Member States will carry out surveys for the possible presence of the nematode in order to determine whether the pest has already spread beyond the known infested area.

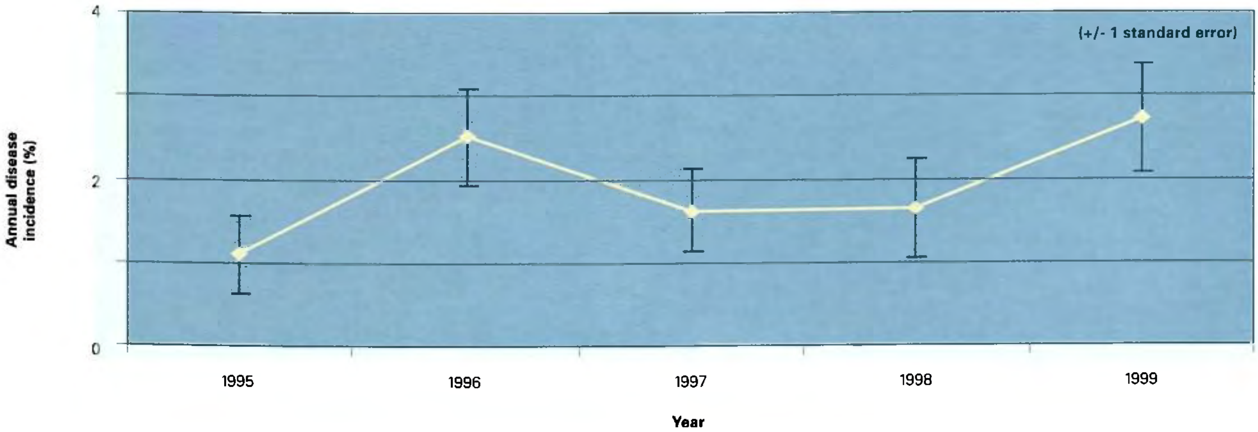
Established pest and disease problems

Phytophthora disease of alder

During the year the first definite records of Phytophthora disease were made in Cumbria. It was found on the River Leven near the point where it enters Morecombe Bay, on the River Kent just south of Kendal and on the River Eamont near Penrith.

Surveys of riparian plots across some 70 000 km² of southern England and east Wales have now been conducted for six years. Symptomatic and dead trees now comprise 11.4% of the current population, with dead trees comprising 34% of these. From the data, an 'Annual Incidence of Disease' (AID) can be calculated (Gibbs *et al.,* 1999). The 1999 AID of 2.73% was the highest yet recorded (Figure 3). Although significant numbers of trees killed by the disease have collapsed or been washed away, it is now evident that dead trees can remain standing for many years. Typically there is a progressive shedding of branches until the trunk alone remains.

Figure 3 Phytophthora disease of alder: the annual disease rate.



Dieback of alder in Scotland

A new project has been initiated on the dieback of riparian alder in Scotland (Plate 1). This condition differs from Phytophthora disease in that it develops from the crown downwards. The first symptoms of the condition are the presence of branches with dead or dying leaves, or the presence of leafless branches bearing fine twigs during the growing season. These symptoms are associated with dead patches or strips of bark (lesions) on the branches, and a number of separate branches on the same tree are often similarly affected. Lesions frequently extend from dead or dying branches into their supporting limbs, and major limbs bearing several affected branches can thereby be killed. Likewise, lesions extending from major limbs into the main stem may result in the death of the tree. Trees suffering from dieback take on a skeletal appearance, but dead shoots and branches disintegrate rapidly so that evidence of the condition can soon vanish. The death of affected trees is common, but some may survive if the bark on their stems is not completely killed. In such cases, new shoots can develop from the base of the trunk to form a new crown beneath the dead, disintegrating top. The condition was first noted in northwest Scotland during the early 1980s, but within the last decade it appears to have become widespread throughout the Highlands, with a few outbreaks also being recorded in the south of Scotland. Study plots are being established at sites where differences in the severity and longevity of dieback are apparent and which offer opportunities for a detailed investigation of diseased material.

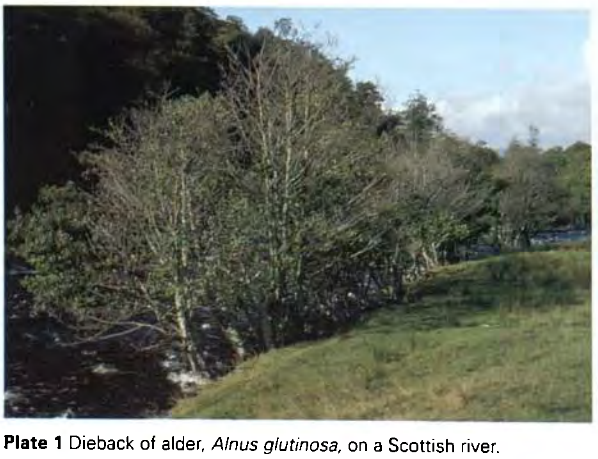


Plate 1 Dieback of alder, *Alnus glutinosa*, on a Scottish river.

Bluestain in pine logs: potential for biological control

In recent years there has been considerable interest in the idea of preventing the development of bluestain in pine by treating freshly cut long-ends with competitive but non-damaging fungi. Much attention has been focused on an albino strain of the bluestain fungus, *Ophiostoma piliferum*, marketed as Cartapip®, which has already been shown to be of significant benefit to the pulping industry in North America. When applied to green wood chips prior to pulping, the Cartapip® reduces the pulp extractive content; it also increases pulp brightness, presumably by excluding other colonists that discolour the wood chips. For some years Pathology Branch has been engaged in a study to determine if Cartapip® shows the same ability to exclude bluestain fungi when applied to Scots pine logs under British conditions. Gorton *et al.* (2000) report that as part of the study, the growth and colonising characteristics of Cartapip® were compared with a range of other bluestain fungi common to pine, both in culture and in freshly felled logs. Cartapip® was fast growing, even at 30°C, an effective coloniser, and did not cause any bluestain although colonised wood sometimes took on a yellowish tinge. When applied to ends of freshly felled logs, it significantly reduced the amount of bluestain that developed over a three-month period. Thus in one trial the mean percent stain development was 92% in control (untreated logs) as compared to 21% in Cartapip®-treated logs. However, at least one species, *Sphaeropsis sapinea*, was still able to invade and cause significant amounts of stain in some Cartapip®-treated logs. In subsequent trials, an isolate of *Ophiostoma piceae* was also included to explore the ability of this fungus to act as a bio-protectant. Although *O. piceae* did cause slight discoloration at the log ends, it gave a similar level of protection to that conferred by Cartapip® (Plate 2).

Plate 2 Extent of colonisation by bluestain fungi in control and Cartapip®-treated logs of Scots pine. Discs cut from the exposed end and 18 cm in from the end of a Cartapip®-treated log (a and b respectively); comparable discs cut from a control log (c and d).

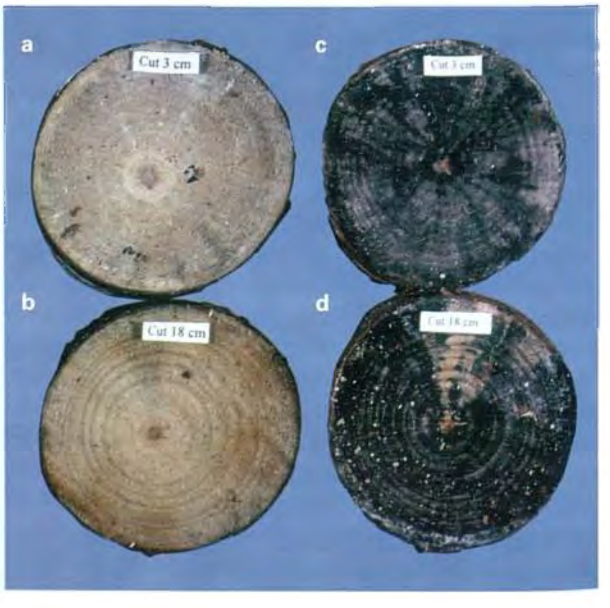


Table 1 Annual survey data on pine looper moth populations: maximum number of pupae per m².

Forest District	Unit	1994	1995	1996	1997	1998	1999
North York Moors	Cropton	0.0	0.4	4.4	revised transects		
	Dalby	0.0	0.8	1.2	no. 1 3.6	1.2	1.2
	Hambledon	2.0	3.2	6.4	no. 2 0.0	0.8	0.4
	Langdale	1.6	0.0	4.4	no. 3 1.2	1.2	2.0
	Wykeham	0.4	1.6	7.6	no. 4 2.8	2.0	1.6
Midlands	Cannock	1.2	1.6	4.0	6.0	0.8	0.4
	Swynnerton	0.8	2.0	8.8	2.0	0.0	0.4
Sherwood	Sherwood III	0.4	0.8	2.0	0.8	0.4	0.0
	Sherwood IV	0.8	2.8	2.4	1.6	1.2	0.4
Inverness	Culloden	0.0	0.0	0.4	0.4	3.6	0.8
Moray	Culbin	2.4	10.6	18.0	6.0	2.0	3.6
	Lossie	6.8	21.6	18.4	0.4	1.6	6.8
	Roseisle	2.8	11.2	14.8	4.4	1.2	2.8
	Speymouth	4.4	10.0	24.0	30.0	20.4	4.0
Tay	Montreathmont	n/s	n/s	22.4	23.2	1.2	2.4
Aberfoyle	Edensmuir	0.4	0.8	2.4	0.0	0.0	0.4
	Tentsmuir	1.6	6.0	14.0	32.8	2.8	1.2

n/s = not surveyed.

Pine looper moth, *Bupalus piniaria*

Annual survey data on pine looper moth populations have continued and are summarised in Table 1. The upward trend noted in *Report on Forest Research 1996* has, thankfully, not been sustained and populations are currently at low levels. However, there has been a slight increase at various sites in Morayshire, which is one of the areas in which regular population cycles tend to be found. Overall, there is no current cause for concern, although, on the basis of past results, populations can be expected to rise during the period 2001–02.

Weather-related and periodic damage

In 1999, every month apart from June was warmer than the long-term average. Trees flushed early but, in contrast to many recent years, there were few reports of damage due to spring frosts. However, a severe gale affected Scotland on 21–22 May causing widespread foliage browning, particularly in the north and west; species affected included Scots pine, alder, oak and birch. Damage was more severe at high elevation but there was also noticeable directional browning of beech and birch at low elevation.

The winter and the following spring were both very wet and this led to waterlogging problems on certain soils. As a consequence there were numerous deaths among newly planted trees. Species involved included yew, beech, Scots pine, Douglas fir and cherry. Even in a relatively well-drained nursery soil Sitka spruce seedlings suffered stunting and death. The wet winter also provoked an outbreak of *Phytophthora ilicis* on holly with extensive defoliation being reported on some trees. Active disease continued much later in the year than has been seen previously, with leaf and shoot killing still occurring at the end of April.

The wet soil conditions followed by hot dry weather in July and August favoured the development of Phytophthora diseases. The most notable cases concerned yew, involving a range of host material from recently planted trees to some planted seven years previously. The pathogen in these cases was mostly *Phytophthora citricola* but some *P cinnamomi* was also isolated. A combination of waterlogged soil conditions and root killing by Phytophthora was also associated with death and crown dieback of established *Prunus avium* in Scotland. In Scotland also, the wet spring conditions may have favoured development of bacterial canker of cherry at another site where some trees had girdling stem lesions.

Whether the wet start to 1999 was a factor in the cases involving bleeding canker caused by *Phytophthora cactorum* is not clear but this was the first year for some time that this disease was widely reported. The species affected was horse chestnut and the damage was unusually severe with many trees being killed outright.

Leaf damage due to feeding by the oak slugworm, *Caliroa annulipes*, a sawfly (Hymenoptera: Tenthredinidae), was common. The larvae feed gregariously on the undersides of leaves, removing the entire epidermis and leaving skeletonised leaves that turn brown in patches (Plate 3). There are two generations of larvae so that feeding is normally noted in May to June and again in August. Occasionally, there may be a partial third generation in the autumn. The sawfly will attack a number of tree genera including *Tilia* (most frequent), *Betula, Crataegus, Fagus, Prunus* and *Quercus*. Although the damage to the foliage of young trees can be conspicuous, effects on tree growth seem to be negligible (Strouts and Winter, 2000).

There were also many records of the great black spruce bark aphid *Cinara piceae* on garden spruce. During May and June, these large (6 mm in length), long-legged aphids can build up to very high numbers on the trunk and branches (Plate 4), producing copious amounts of honeydew. Unlike the majority of aphids, *C. piceae* often move quickly over the trunk and from a distance can be mistaken for other insects such as beetles. Despite the numbers, they appear to cause little damage to the health of the infested tree. However, the production of large quantities of honeydew can cause indirect problems: other insects such as ants and wasps can be attracted to the tree and the growth of sooty moulds can render it unsightly. The colonies may persist until September and then disappear quite suddenly.

In most of England the late summer was hot and dry and there was premature defoliation on some broadleaf species, notably birch, sycamore, lime and whitebeam *(Sorbus aria)*. Some late season diseases were also conspicuous. Cherry leaf scorch, caused by *Apiognomonia errabunda*, was very disfiguring to wild cherry *(Prunus avium)* through much of England and Wales.

Plate 3 Leaf damage due to feeding by the oak slugworm *Caliroa annulipes*.

It was also noted in Scotland, but was not as widespread as in 1997. Scab contributed to early leaf-fall on various ornamental apples and rowan. Poplar rust, caused by *Melampsora larici-populina*, was again widespread and caused severe defoliation on the clones Beaupré and Boelare. These are among several relatively new clones that had remained unaffected by *M. larici-populina* until 1994, when a previously unknown form of the fungus (pathotype E4) appeared in Europe. Although none of the currently registered clones is now totally resistant to rust, many of them remain suitable for cultivation, owing to a valuable degree of partial resistance or tolerance to rust. Candidate clones with these characteristics are being assessed for possible inclusion in the registered list.

In the autumn, there was a report of unusually severe needle browning in a 10-year-old crop of Scots pine caused by *Lophodermella sulcigena*, with a high percentage of trees affected, and in February 2000 extensive infection on Corsican pine was reported at Culbin in Morayshire.

In December in Scotland there was an unusual instance of stem splitting in 5–8 m Norway spruce trees that had been cut in November and used as part of a civic Christmas display. The trees had split from the base upwards, with the cracks extending to the pith and spiralling up the stem as in a drought crack. A visit to the forest, from which the trees had come, revealed that other trees, cut at the same time but not yet sold, showed the same symptoms. The moisture content of the wood was low compared to levels found in freshly felled spruce and it seems probable that the cracking was a consequence of the excessive loss of moisture suffered by the cut trees during the high winds that were prevalent in late November and early December.

Plate 4 The great black spruce bark aphid *Cinara piceae*.

New or unusual records

The rarely recorded *Taphrina amentorum* was found on alder catkins in Scotland and northern England. The resulting disease is conspicuous, with some infected scales producing reddish-coloured outgrowths, but it has no damaging effects on the tree.

There were reports of dieback in birch in Northern England, Scotland and Wales. On trees with dieback symptoms in Scotland, the fungus *Marssonina betulae* was found both in leaf spots and shoot lesions. However, it is unlikely to have been responsible for the extensive mortality of older branches. In a number of cases, the condition has been found to affect planted trees while naturally regenerated birch has been unaffected; this suggests that the provenance of the planting stock may be important.

Canker and dieback of *Robinia pseudoacacia* was reported from Northumberland and the fungi isolated from shoot lesions are still under investigation.

In Surrey, extensive infection of a medium-sized Wellingtonia by *Ganoderma australe* (synonym *G. adspersum*) had caused death of bark in strips up the stem. Several of the lower branches were dead. This type of damage is very unusual, as is the host, and the fate of this tree will be followed over the coming years. *Ganoderma lucidum* was found infecting a pollard *Carpinus betulus* in Hainault Forest, Essex. This appears to be a first record for this host in the UK.

In Northumberland, there were two records of damage due to pollution. One involved foliage damage to a range of pine species and broadleaves, and was probably caused by sulphur dioxide or fluorine emanating from a nearby smelter. The other involved foliage browning on *Crataegus* hedges. In this case the damage was associated with adjacent straw bales which had been injected with ammonia to enrich the straw for use as animal feed. Gaps in the polythene covering had allowed the gas to escape and these corresponded to patches of damage on the hedges.

References

Carter, C. and Winter, T.G. (1998). *Christmas tree pests.* Forestry Commission Field Book 17. The Stationery Office, London.

Evans, H.F. and Gibbs, J.N. (1999). Pests and diseases. In, *Forest Research annual report and accounts 1998–1999,* 10–19. The Stationery Office, London.

Evans, H.F., McNamara, D.G., Braasch, H., Chadoeuf, J. and Magnusson, C. (1996). Pest Risk Analysis (PRA) for the territories of the European Union (as PRA area) on *Bursaphelenchus xylophilus* and its vectors in the genus *Monochamus. EPPO Bulletin* **26,** 199–249.

Gibbs, J.N., Lipscombe, M.A. and Peace, A.J. (1999). The impact of Phytophthora disease on riparian populations of common alder *(Alnus glutinosa)* in southern Britain. *European Journal of Forest Pathology* **29,** 39–50.

Gorton, C., Webber, J.F. and Dickinson, D.J. (2000). The potential for biological control of bluestain in Britain. *International Research Group Paper.* IRG Secretariat, Stockholm, Sweden.

Gregory S.G. and Redfern, D.B. (1998). *Diseases and disorders of forest trees.* Forestry Commission Field Book 16. The Stationery Office, London.

Lonsdale, D. (1999). *Principles of tree hazard assessment and management.* The Stationery Office, London.

Strouts, R.G. and Winter, T.G. (2000). *Diagnosis of ill-health in trees* (2nd edtn). The Stationery Office, London.

Fomes Decay in Sitka Spruce – New Perceptions of Risk

Fomes Decay in Sitka Spruce – New Perceptions of Risk

by Derek Redfern

Introduction

The danger presented by the wood-rotting fungus *Heterobasidion annosum* first became widely appreciated in Britain in the early 1950s when John Rishbeth showed that air-borne spores could establish the pathogen in previously unaffected woodlands by colonising freshly-cut conifer stumps (see for example Rishbeth, 1949; 1950). Initially the problem was seen largely as one of killing of pines. On high pH soils in south-east England losses can be high and mortality may continue throughout the life of a crop, although the rate at which trees die tends to decline with time. Elsewhere, soils are predominantly acidic and death of pines is rarely significant. In most other species, killing is generally unimportant and usually ceases when crops reach a height of 3–5 m; loss is principally caused by decay (Plate 1). However, due to the absence of obvious symptoms the extent of loss is more difficult to appreciate than in the case of pines, even with high levels of disease.

Large-scale planting of Sitka spruce and other introduced conifers began in the 1920s. The bulk took place on ground with no previous forest history and these plantations were disease-free, at least until the time of first thinning. However, a small proportion of plantations was established on severely infested sites formerly occupied by coniferous woodland, and surveys on sites like this by Anderson (1924) and Peace (1938) showed that most commonly planted species are highly susceptible to decay. Later work provided additional information, particularly for Sitka spruce, which had been poorly represented earlier (Greig, 1962; Gladman and Low, 1963).

Plate 1 Decayed Sitka spruce. Note area of dead bark on the upper side of the section, which was taken at stump height. The presence of dead bark indicates severe decay. In the field this would have been evident as slight resinosis at the base of the tree.

This work established the potential for serious losses in all the most important coniferous species used in British forestry and led to the introduction of control by means of stump protection in about 1960.

No formal data are available either on the distribution of disease or on the overall loss caused to British forestry by *H.annosum*. Records from small-scale surveys, and casual observations, suggest that less than 5% of the coniferous forest area is affected and disease may be serious on only 1% (Redfern and Ward, 1998). However, the present distribution of disease may primarily reflect the history of conifer planting and the use of chemical stump protection, rather than the biological potential of *H.annosum*. Severe infection is generally confined to sites that were woodland before about 1940, and the highest levels of disease are usually found in places with a history of conifer woodland extending for two rotations or more (Low and Gladman, 1960; Pratt, 1979). Consequently sites associated with serious disease have tended to be on mineral soils in the lowlands, whereas upland sites in Wales, northern England and Scotland are virtually disease-free. The potential for disease in these upland areas has been investigated in a major, long-term research project.

In order to determine the risk of disease in Sitka spruce on acidic soils in the uplands, thinning stumps in first rotation plantations on a range of site types were either allowed to become infected naturally or deliberately infected with the pathogen. By this means, estimates have been made firstly of the likelihood that stumps might become infected by spores, and secondly of the ability of *H.annosum* to colonise stumps and cause infection in surrounding trees. Information on these processes, combined with available casual observations, was used to construct a model of disease development and thus to estimate losses over several rotations under various management regimes.

The biology of H. annosum in Sitka spruce

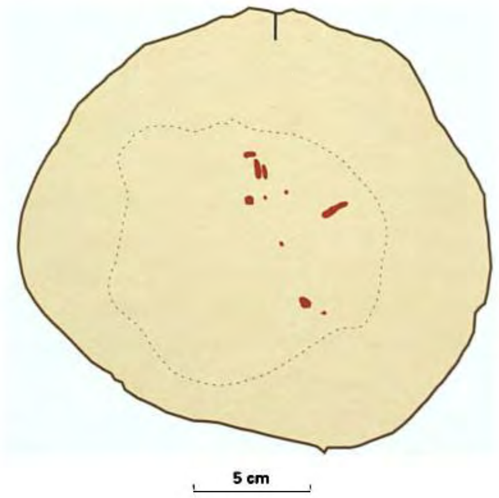
Stump infection and colonisation

Sitka spruce stumps are much less susceptible to spore infection than those of all three pines commonly grown in Britain (Rishbeth, 1951, 1957; Meredith, 1959, 1960; Greig, 1962; Redfern, 1982). They may also be less susceptible than those of Norway spruce, since although serious disease has arisen from spore-infected Norway spruce stumps (Pratt and Greig, 1988; Swedjemark and Stenlid, 1993) there have been no similar reports for Sitka spruce. Significant disease in Sitka spruce is invariably associated with the presence of other species: most frequently Scots pine or larch, either in an earlier crop or in mixture with the spruce. Nevertheless, spore-infected Sitka spruce stumps can give rise directly to decay in adjacent trees (Morrison and Redfern, 1994; Redfern, personal observation).

While high levels of stump infection can be achieved by inoculation with spores, the likelihood of Sitka spruce stumps becoming infected naturally (in the absence of stump protection) has been established only recently (Redfern *et al.*, in press). Previously, only limited information was available from experiments conducted for other purposes on single sites, in which the frequency of natural infection varied from 1.7% to 13.3% (Redfern, 1993; Redfern *et al.*, 1997; Woods *et al.*, 2000). In this recent work, the risk of infection in unprotected stumps was investigated in a large-scale trial on 48 sites in Scotland and north England. Stumps were either inoculated or exposed only to infection from natural sources. Among inoculated stumps, between-site variation was surprisingly large, implying a strong environmental effect, and infection was significantly lower on peat soils than on mineral soils. As might be expected, the level of natural infection was equally variable, ranging from 0% to 58%, with a mean of 10.5% across all sites, but more significantly there was no infection at all on 17 sites. Infection was less frequent where the annual rainfall exceeded 1600 mm (5.7%) than in drier areas (15.5%), but this may have been associated more with lower spore loads in the more recently established forests of the west, than with rainfall *per se*.

In stumps in upland Britain, *H.annosum* typically establishes scattered colonies in the heartwood; sapwood is colonised much less readily (Figure 1). Wood moisture content appears to be an important factor determining this pattern, which contrasts with that recorded for Sitka spruce in warmer and drier environments in Britain and elsewhere, and also with that for Norway spruce and the pines (Redfern, 1993). In natural infections, individual colonies in the upper part of the stump rarely exceed 1 cm^2 in area after two years; many colonies are far smaller, and *H.annosum* generally occupies <5% of the total stump cross-sectional area. Much more extensive colonisation has been recorded for individual stumps, but this is rare (Redfern *et al.*, 1997).

Figure 1 Location of colonies in a naturally infected Sitka spruce stump two years after cutting. Colonies are shown in red and the position of the boundary between heartwood and sapwood is indicated by a dotted line.

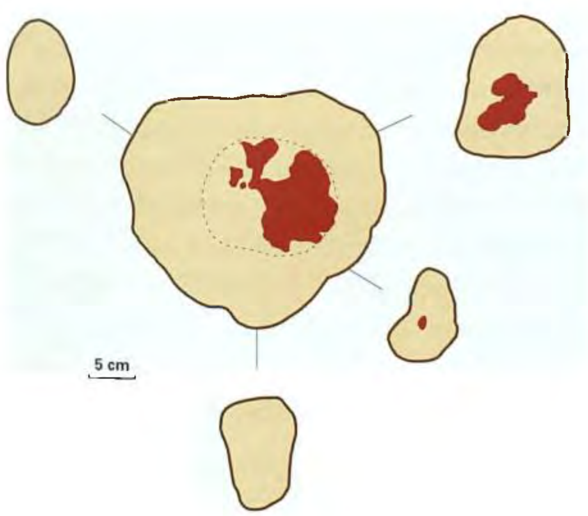


Survival in spore-infected stumps

In the large-scale trial just referred to, a proportion of the stumps found to be infected two years after cutting was resampled six years later to determine long-term survival. The future of single, very small colonies in the heartwood was of particular interest. There was a substantial decline in the number of stumps containing viable *H.annosum*, which implied an overall level of incidence of only 2.8% eight years after felling. Insufficient information is available to allow an accurate description of colony development, but there is evidence from other work that some colonies expand and others decline. Much of the decline in the trial was due to the failure of small colonies to survive, but some large colonies also died.

By contrast, a few small colonies expanded to occupy almost the entire stump. Among those stumps in which it survived *H.annosum* entered roots only in stumps that were colonised substantially, so that only one-third of the available roots on infected stumps were occupied. It is likely that the infective potential of the fungus would be attenuated even further before reaching points of root contact with adjacent live trees, since the success with which it can be recovered from infected roots declines with increasing distance from the stump (Redfern, 1984; Morrison and Redfern, 1994). The preference for colonisation in heartwood may also have implications for spread, since even where *H.annosum* extended to the upper roots it was frequently confined to the central tissue and was surrounded by uncolonised wood (Figure 2).

Figure 2 Location of *H. annosum* in the stump and upper roots of a naturally infected Sitka spruce stump on peat soil eight years after cutting. The largest outline, in the centre, represents a section through the stump and the smaller outlines represent sections through the proximal portions of the four major roots. Areas containing *H. annosum* are shown in red and the dotted line shows the position of the boundary between heartwood and sapwood.

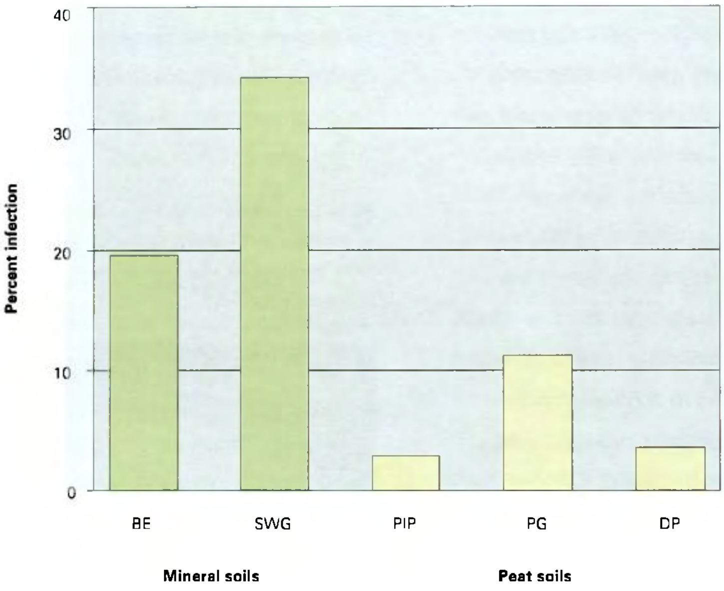


Below-ground spread and infection

In an experiment set up to study the effect of soil on infection, thinning stumps in crops growing on five of the commonest soils in British forests were inoculated with wooden dowels containing *H.annosum*. Adjacent trees were subsequently excavated and examined for infection over a 10-year period (Plate 2). Both survival of the fungus in stumps and infection of surrounding trees were greater on mineral soils than on peaty soils (Redfern, 1998; Figure 3). By contrast, soil appeared to have little effect on growth of the fungus in the tree once infection had taken place.

Plate 2 (a) Infected Sitka spruce root and the early stage of decay extending into the stem. **(b)** Close-up of lesion on infected root in (a). Note 'pustules' of *H. annosum* on dead bark and resin bleeding at the lesion margin.

Figure 3 Effect of soil on infection of Sitka spruce trees by *H. annosum* 10 years after inoculation of adjacent stumps. The soils are: brown earth (BE), surface-water gley (SWG), peaty ironpan (PIP), peaty gley (PG) and deep peat (DP).



Predicting potential losses

Use of a model has shown that losses in Sitka spruce are principally dependent on two factors: the soil on which the trees are growing and the frequency of stump infection by spores (Pratt *et al.*, 1989; Redfern *et al.*, 1994a and b). Soil is of overriding importance in disease development through its effect on below-ground spread, and predictions suggest that in thinned crops the incidence of disease on peat soils is likely to be much lower than on mineral soils, irrespective of the frequency of stump infection. As a general principle, infection levels rise in successive rotations, so that in time the incidence of disease on peat soil might be expected to approach that on mineral soils. However, modelled data suggest that after a number of rotations disease incidence may reach a maximum and thereafter remain constant, so that differences induced by soil effects are likely to be maintained (Pratt *et al.*, 1989).

When the model was devised, probabilities of successful development at various stages in the life cycle of the fungus were established from observations or from experiments. At that time, no information was available either on the frequency of stump infection or on the ability of the fungus to colonise stumps and survive long enough to cause infection. Various probabilities were therefore assumed for these two stages. The information on stump infection now available, and referred to above, confirms that the figures of 5% and 50% assumed for stump infection were realistic for the purpose of establishing broad principles, though the lower one is clearly closer to the levels current in northern Britain. However, the assumption previously made for the probability that stumps would become infective (0.40), i.e. capable of transmitting disease, seems to have been too high in view of the substantial failure of *H.annosum* both to exploit stumps that initially become infected, or even to survive in them. Loss predictions based on lower probabilities for these initial stages in the life cycle would therefore be lower than earlier estimates, and in turn this would decrease the economic benefit of stump protection (Redfern *et al.*, 1994b).

Discussion and conclusions

The threat posed by Fomes root and butt rot to forests in Britain can now be evaluated with some confidence. There is much to support the view that it should be seen essentially as a disease of 'lowland' forests, though the distinction between lowland and upland in this context would differ somewhat from that defined for the purpose of vegetation classification (Rodwell and Patterson, 1994). The risk of disease in Sitka spruce, and possibly in other butt-rot susceptible species, is greatest on well-drained mineral soils in the east and south, particularly where pine or larch is present, either in the current crop or as stumps from an earlier one. Risk is lowest on peaty soils in the north and west, and in the absence of any association with pine or larch.

Sandy soils with a high pH present an extreme risk, although Sitka spruce is rare on this soil type. The importance of *H. annosum* in pines on high-pH soils at Thetford is well known. However this may have biased perceptions of the disease. In species other than pine, pH is a relatively unimportant risk factor, and even in pines quite serious losses can sometimes occur on soils with a pH below 5.0. The overwhelming majority of our forest estate is on acidic soils and serious disease can readily develop in butt-rot susceptible species where the pH is well below 5.0 (Stenlid and Redfern, 1998).

From a strictly commercial point of view, stump treatment is not justified on peaty soils or where there is a low risk that stumps will become sufficiently colonised to cause infection in nearby trees. However, several important questions about the biology of *H. annosum* in Sitka spruce remain to be answered including the following three principal ones. Can ploughing, mounding or other forms of cultivation and soil disturbance increase the risk of below-ground-spread on shallow peats? Does the pattern of colonisation and survival by *H. annosum* that has been established for thinning stumps apply also to stumps created by clear-felling? In the absence of stump protection can spore loads be expected to increase in upland forests in the west? For this reason, the choice of site types on which stump protection can be safely discontinued should be conservative, and for the time being involve only those with the least risk. Practical considerations may necessitate the acceptance of more risk when no-treatment areas are delimited in the field.

To some extent the disease in Sitka spruce presents a paradox. Despite the well-established susceptibility of trees to decay, stumps apparently provide a much less hospitable substrate for colonisation by spores. Thus, whereas infected stumps arising from decayed trees are usually heavily colonised and are likely to provide inoculum for many years, those infected by spores are often poorly colonised, and in many stumps the fungus fails to persist. However, rare stumps appear to be highly susceptible to spore infection and the extent of colonisation in these rivals that in stumps from decayed trees. Three species of *Heterobasidion* are now recognised in Europe: *H.annosum* (Fr.) Bref., *H.parviporum* Niemela & Korhonen and *H.abietinum* Niemela & Korhonen (Niemela and Korhonen, 1998). These species were formerly recognised as intersterile groups, known as the 'P' (pine), 'S' (spruce) and 'F' (fir) groups respectively, after the genera with which they are most closely associated, though the 'P' group has a much wider host range than the other species (Korhonen *et al.*, 1998).

Tests on isolates obtained from basidiocarps throughout Britain suggest that only *H.annosum* is present here. This offers an intriguing explanation for the difference in stump colonisation and survival between Sitka spruce and the pines. Both this, and the extreme variation between stumps on the same site, might reflect the poor adaptation of *H.annosum* to Sitka spruce, at least as a saprotroph, so that only rare genets may be successful colonists.

Important questions remain unanswered, but the evidence so far available suggests that in pure Sitka spruce on peat soils in the wetter parts of the uplands, the risk of successful stump colonisation and spread is so low that *H.annosum* is unlikely to become permanently established. This will probably remain the case even if spore loads increase. On mineral soils in these areas, without the barrier to spread provided by peat, the risk would be higher. Some disease could be expected, but with present levels of stump infection the incidence is likely to be low.

References

Anderson, M.L. (1924). Heart rot in conifers. *Transactions of the Royal Scottish Arboricultural Society* **38,** 37–45.

Gladman, R.J. and Low, J.D. (1963). Conifer heart rots in Scotland. *Forestry* **36,** 227–244.

Greig, B.J.W. (1962). *Fomes annosus* (Fr.) Cke. and other root-rotting fungi in conifers on ex-hardwood sites. *Forestry* **35,** 164–182.

Korhonen, K., Capretti, P., Karjalainen, R. and Stenlid, J. (1998). Distribution of *Heterobasidion annosum* intersterility groups in Europe. In, *Heterobasidion annosum: biology, ecology, impact and control,* 93–104, eds S. Woodward, J. Stenlid, R. Karjalainen and A. Huttermann. CAB International, Wallingford.

Low, J.D. and Gladman, R.J. (1960). *Fomes annosus in Great Britain. An assessment of the situation in 1959.* Forestry Commission Forest Record 41. HMSO, London.

Meredith, D.S. (1959). The infection of pine stumps by *Fomes annosus* and other fungi. *Annals of Botany, New Series* **23,** 455–476.

Meredith, D.S. (1960). Further observations on fungi inhabiting pine stumps. *Annals of Botany, New Series* **24,** 63–78.

Morrison, D.J. and Redfern, D.B. (1994). Long-term development of *Heterobasidion annosum* in basidiospore-infected Sitka spruce stumps. *Plant Pathology* **43,** 897–906.

Niemela, T. and Korhonen, K. (1998). Taxonomy of the genus Heterobasidion. In, *Heterobasodion annosum: biology, ecology, impact and control,* 27–33, eds S. Woodward, J. Stenlid, R. Karjalainen and A. Huttermann. CAB International, Wallingford.

Peace, T.R. (1938). Butt rot of conifers in Great Britain. *Quarterly Journal of Forestry* **32,** 81–104.

Pratt, J.E. (1979). *Fomes annosus* butt-rot of Sitka spruce: I. Observations on the development of butt-rot in individual trees and in stands. *Forestry* **52,** 11–29.

Pratt, J.E. and Greig, B.J.W. (1988). *Heterobasidion annosum:* Development of butt rot following thinning in two young first rotation stands of Norway spruce. *Forestry* **61,** 339–347.

Pratt, J.E., Redfern, D.B. and Burnand, A.C. (1989). Modelling the spread of *Heterobasibion annosum* in Sitka spruce plantations in Britain. In, *Proceedings of the seventh international conference on root and butt rots,* 308–319, ed. D.J. Morrison. Canada, August 1998. Forestry Canada, Victoria, British Columbia, Canada.

Redfern, D.B. (1982). Infection of *Picea sitchensis* and *Pinus contorta* stumps by basidiospores of *Heterobasidion annosum. European Journal of Forest Pathology* **12,** 11–25.

Redfern, D.B. (1984). Factors affecting spread of *Heterobasidion annosum* in plantations. In, *Proceedings of the sixth international conference on root and butt rot of forest trees,* 104–114, ed. G.A. Kile. Australia, August 1983. CSIRO, Melbourne, Australia.

Redfern, D.B. (1993). The effect of wood moisture on infection of Sitka spruce stumps by basidiospores of Heterobasidion annosum. *European Journal of Forest Pathology* **23,** 218–235.

Redfern, D.B. (1998). The effect of soil on root infection and spread by *Heterobasidion annosum.* In, *Root and butt rots of forest trees: ninth international conference on root and butt rots,* 267–273, eds C. Delatour, J.J. Guillaumin, B. Lung-Escarment and B. Marcais. Carcans, France, September 1997. Les Colloques 89. INRA Editions, Paris, France.

Redfern, D.B. and Ward, D. (1998). The UK and Ireland. In, *Heterobasidion annosum: biology, ecology, impact and control,* 347–354, eds S. Woodward, J. Stenlid, R. Karjalainen and A. Huttermann. CAB International, Wallingford.

Redfern, D.B., Pratt, J.E. and Whiteman, A. (1994a). Stump treatment against *Heterobasidion annosum: a re-appraisal.* In, *Proceedings of the eighth international conference on root and butt rots,* 656–661, eds M. Johansson and J. Stenlid. Sweden and Finland, August, 1993. Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden.

Redfern, D.B., Pratt, J.E. and Whiteman, A. (1994b). *Stump treatment against Fomes: a comparison of costs and benefits.* Forestry Commission Research Information Note 248. Forestry Commission, Edinburgh.

Redfern, D.B., Gregory, S.C. and MacAskill, G.A. (1997). Inoculum concentration and the colonization of *Picea sitchensis* stumps by basidiospores of *Heterobasidion annosum. Scandinavian Journal of Forest Research* **12,** 41–49.

Redfern, D.B., Pratt, J.E., Gregory, S.C. and MacAskill, G.A. (in press). Natural infection of Sitka spruce thinning stumps in Britain by spores of *Heterobasidion annosum* and long-term survival of the fungus. *Forestry* **74.**

Rishbeth, J. (1949). *Fomes annosus* Fr. on pines in East Anglia. *Forestry* **22,** 174–183.

Rishbeth, J. (1950). Observations on the biology of *Fomes annosus,* with particular reference to East Anglian pine plantations. I. The outbreaks of disease and ecological status of the fungus. *Annals of Botany, New Series* **14,** 365–383.

Rishbeth, J. (1951). Observations on the biology of *Fomes annosus,* with particular reference to East Anglian pine plantations. II. Spore production, stump infection, and saprophytic activity in stumps. *Annals of Botany, New Series* **15,** 1–21.

Rishbeth, J. (1957). Some further observations on *Fomes annosus* Fr. *Forestry* **30,** 69–89.

Rodwell, J. S. and Patterson, G. S. (1994). *Creating new native woodlands.* Forestry Commission Bulletin 112. HMSO, London.

Stenlid, J. and Redfern, D.B. (1998). Spread within the tree and stand. In, *Heterobasidion annosum: biology, ecology, impact and control,* 125–141, eds S. Woodward, J. Stenlid, R. Karjalainen and A. Huttermann. CAB International, Wallingford.

Swedjemark, G. and Stenlid, J. (1993). Population dynamics of the root rot fungus *Heterobasidion annosum* following thinning of *Picea abies. Oikos* **66,** 247–254.

Woods, C.M., Woodward, S. and Redfern, D.B. (2000). Receptivity of *Picea sitchensis* stumps to infection by *Heterobasidion annosum basidiospores. Forestry* **73,** 457–465.

Squirrel Management

Squirrel Management

1. Development of a contraceptive vaccine for the grey squirrel

by Harry Pepper and Harry Moore*

An oral contraceptive vaccine for wild mammals offers the possibility of a humane method of controlling pest species (Moore, 1996). The development of such a vaccine is complex and detailed investigations must be performed at the molecular, cellular and systemic level to evaluate efficacy and safety. Likewise, ecological assessments are necessary to evaluate the potential of this approach for wildlife management.

Our previous studies (Pepper and Hodge, 1996) showed that a vaccine against a specific sperm antigen did induce antibodies that inhibited fertility and was targeted to the grey squirrel *(Sciurus carolinensis)*. Having shown that oral immunisation induces an immune response in the reproductive tract, a phase II fertility trial was carried out over spring/summer 1999. The squirrels used (17 females and 8 males) were captured in the wild in summer 1998 and kept separately to ensure they had not mated before treatment. Adult females readily take a dose of vaccine by mouth especially when sweetened.

Captive grey squirrels will not breed when confined in cages and so the fertility of captive animals cannot be assessed in the laboratory. Therefore, three large enclosures, one of 0.5 ha (Plate 1) and two of 0.25 ha, were established within a beech plantation to promote appropriate reproductive and mating behaviour and so ensure regular and reliable breeding under controlled conditions.

Plate 1 View of large squirrel enclosure showing squirrel-proof fence.

The female squirrels were released into the enclosures three weeks after receiving the vaccine treatment. They were subsequently recaptured at various times during the spring and summer and given a booster immunisation or monitored for their immune and reproductive status.

Although the trial was of a small number of squirrels, the results were encouraging. Only 15% of treated females (2/13) became pregnant while 50% (2/4) of the controls became pregnant and produced litters (Plate 2). We are repeating this phase II enclosure trial in 2000 together with a pilot forest trial to confirm this treatment effect. If the reduction in fertility is confirmed it will then be necessary to undertake even more comprehensive trials. Of course, giving a vaccine to individual animals is an impractical technique on which to base squirrel control through substantial forest areas. Therefore, it will be necessary to incorporate the vaccine into bait. We are currently investigating the stability of the formulation under various conditions and alternative strategies for feeding squirrels so that they obtain the required dose for effective immunisation.

Plate 2 Litter of grey squirrels born in nestbox in enclosure.

*Department of Molecular Biology and Biotechnology, University of Sheffield, PO Box 594, Firth Court, Western Bank, Sheffield S10 2UH

2. Co-existence of red squirrels and grey squirrels

by Harry Pepper, Jenny Bryce and Sarah Cartmel

The native red squirrel, *Sciurus vulgaris* (Plate 3), has been replaced by the introduced grey squirrel over much of its former range (Figures 1 and 2; Gurnell and Pepper, 1993). As the grey squirrel continues to spread there is concern that red squirrels may disappear completely from mainland England and Wales within the next 20 years. The long-term future of red squirrels in Scotland is also not secure.

Figure 1 Red squirrel distribution in 1999.

Figure 2 Grey squirrel distribution in 1999.

Plate 3 Red squirrel feeding on hazelnuts.

Two recent studies – Clocaenog and Craigvinean

Habitat composition appears to be the main factor determining the rate of red squirrel replacement. Two studies, one at Clocaenog Forest in north Wales and the other in Craigvinean Forest in east Scotland, were established to investigate the habitat requirements, population ecology and behaviour of co-existent red and grey squirrels. The studies should also provide an insight into the characteristics of the habitats that are likely to improve the current red squirrel conservation management guidelines (Pepper and Patterson, 1998).

The two forests have experienced different periods of red and grey squirrel co-existence. Grey squirrels have been present in north Wales for over 40 years, but have only been resident in Clocaenog since the 1980s, whilst the two species are thought to have been sympatric in Craigvinean for up to 30 years.

The majority of grey squirrels in Clocaenog appear to be non-resident opportunists moving into the predominantly coniferous forest in good mast (seed) years and moving out again to areas of broadleaved trees when the cone crops are depleted. The overall density of red squirrels does not appear to have been affected by this influx of grey squirrels. However, the presence of greys may have reduced the breeding potential of reds. For example, grey squirrels were present in their highest densities in 1997 following a large seed crop of Norway spruce in autumn 1996, and fewer immature red squirrels were caught in that summer.

In Craigvinean, there are small patches of mixed woodland where grey squirrels predominate, but red squirrels do not appear to have been excluded from any areas. Despite finding a relatively low proportion of female red squirrels lactating, the red squirrel population in Craigvinean is vigorous and appears to fluctuate in response to natural food availability. Hence there is no obvious impact of grey squirrels on the red squirrel population. However, we may be observing different processes (i.e. replacement or persistence) or merely different rates of the same process at the two sites.

Population estimates and dynamics

Different methods of density estimation were used at the two sites owing to the unique logistical problems encountered with trapping and sightings. The density estimates may not be directly comparable. However, comparing the most representative estimates for each site, it appears that the overall density of squirrels was higher in Craigvinean. In conifer woodland the mean collective density of red and grey squirrels was 1.71 ha^{-1} in Craigvinean and 0.55 to 0.8 ha^{-1} at Clocaenog. In Craigvinean the majority of this combined density was attributable to red squirrels, while in Clocaenog reds and greys occurred at varying ratios with generally more reds. However, during the influx of grey squirrels in 1996/97 the ratio of reds to greys was approximately 1:1. This ratio of reds to greys was also found in the mixed woodland habitats in Craigvinean with a mean combined density of 1.81 ha^{-1}.

Direct comparisons of home range sizes between sites are complicated by the differences in habitat composition and population densities. The sizes of core areas were very similar between sites but in Craigvinean the total home range areas used by red squirrels were marginally smaller than those in Clocaenog – possibly a consequence of the higher densities. In Clocaenog, total home ranges of greys were marginally smaller than reds, whilst in Craigvinean the ranges of greys (particularly males along the Tay river corridor) tended to be larger than those of reds. However, again, core areas of reds and greys were very similar between sites. The size of core home range of females is likely to be indicative of resource requirements. Results from the two sites suggest the 'perception' of habitat quality was not dissimilar between red and grey squirrels (core areas are 2.1 ha for reds and 1.7 ha for greys in Clocaenog and 1.7 ha for reds and 1.2 ha for greys in Craigvinean).

In neither study was there evidence that red and grey squirrels were either attracting or avoiding one another. However, there was a suggestion in both studies that fewer red squirrels were captured in areas or years where there were more grey squirrels.

The range and mean body weights encountered of both sex and species were almost identical between the two studies. The proportion of females trapped that were found to be lactating was highly variable between years at both sites. In Clocaenog the mean over the five years was 40.1% for red squirrels and 28.1% for grey squirrels, while in Craigvinean the mean proportions were 34.7% and 55.7% for red and grey squirrels respectively. It is difficult to make any general conclusions because of the differences in population density and food availability between the sites. No squirrels of either species were observed to have had two litters in the same year in Craigvinean, while one red squirrel did in Clocaenog.

The red squirrel population in Craigvinean appears to be stable and at present does not appear under threat from grey squirrels. However, the grey squirrel population could expand further into the red squirrel occupied areas following a succession of good mast years or an increase in planting of broadleaved trees. At Clocaenog, the grey squirrels already 'share' the forest with the red squirrels. Although many greys are transitory animals they have been found to occupy pure stands of Norway spruce during times of high seed availability.

Habitat use and implications for forest management

The patterns of habitat use found in these two studies can be combined to produce broad-based guidelines and recommendations for other conifer forests (Plate 4). There were some differences in the patterns of habitat use exhibited by red and grey squirrels between study sites, largely due to the differences in habitat composition. Craigvinean has a larger component of broadleaves which are also spatially separate from the conifer blocks.

Plate 4 View of large mature conifer forest (good red squirrel habitat).

Clocaenog has far fewer broadleaves, with no large blocks and the only pure stands are found as narrow strips along the road edges; the remainder are incorporated within conifer areas. Therefore, the spatial segregation of greys in broadleaves and reds in conifers found in Craigvinean was not observed in Clocaenog. However, at the stand scale, red and grey squirrels were found to make use of the same species in both studies.

In both locations, the preferred conifer food types for red squirrels in both cases were Norway spruce and Scots pine and, when coning, Japanese larch. In Clocaenog grey squirrels also made considerable use of Norway spruce stands although their numbers declined in years of Norway spruce cone failure. These areas are therefore unlikely to provide a refuge for red squirrels. However, they may provide areas where due to differences in foraging efficiency, red squirrels can persist and may act as source populations for neighbouring, less favoured habitats such as Sitka spruce. Therefore Norway spruce is likely to be an essential component of any conifer forest managed for red squirrels.

Scots pine was used intensively by both species at both sites (Plate 5). Scots pine has large seeds and may be less likely to provide red squirrels with a competitive advantage over greys. The fact that grey squirrels have largely replaced reds on pine dominated habitats including Thetford and Cannock may indicate that too high a proportion of pine may be detrimental to reds' persistence. However, as Scots pine cones more regularly than Norway spruce, it is likely to be important for ensuring the continuity of seed availability in years with poor spruce cone crops.

Japanese larch does not cone on a regular basis, but is utilised by both species when it produces a seed crop. The irregularity of coning may make it a less favoured species for grey squirrels and so it could be an important component of a mixed conifer forest.

Plate 5 Scots pine cone remains following squirrel feeding activity.

Sitka spruce was avoided for the majority of the time by both species at Craigvinean and Clocaenog. It was found to be a poor quality habitat, which was only utilised when there were no alternatives. Seed retention is poorer than for Norway spruce whose seed can remain in the cones for up to two years and provide a long term 'larder' for the squirrels. However, Sitka spruce could be used in a management plan to advantage red squirrels by offering the opportunities of a 'refuge' as well as a buffer to deter transient greys.

The Clocaenog study provided seven years data on the periodicity of coning and the Craigvinean study only three years. In Clocaenog, Norway spruce and Japanese larch produced a good cone crop in only one of the seven years, while Scots pine and Sitka spruce produced cone crops in most years except 1995. In Craigvinean all species produced at least some cones each year. Norway and Sitka spruce and Douglas fir produced good crops in two out of three years and Scots pine each year, hence food appeared to be more varied, abundant and more predictable in Craigvinean, which may account for the higher red squirrel densities encountered. Grey squirrels favoured large seeded broadleaved habitats in both areas. Red squirrels utilised areas of beech and hazel in Craigvinean and were seen to feed in beech in Clocaenog. The scarcity of broadleaves and good mast years may have obscured the potential importance of broadleaves to grey squirrels in Clocaenog. There was a high grey squirrel turnover in Clocaenog and grey squirrel numbers fell to very low levels in 1998 when the Norway spruce crop failed. The study does suggest that greys can persist at low densities in areas with very few broadleaves but it is not possible to conclude that grey squirrels were persisting in Clocaenog without continued immigration. In Craigvinean, the grey squirrels did not appear to be resident in the conifer stands, instead remaining largely within the corridors of mixed woodland. Patches of mature beech provided a foothold for greys in coniferous habitats and enabled greys to persist in habitats which would otherwise require continued immigration. The evidence supported the view that grey squirrels have a competitive advantage over reds in broadleaved woodlands, particularly those with a high proportion of oak. Hence, in areas identified as key red squirrel habitats it is recommended that the percentage of large seeded broadleaves should be kept to an absolute minimum (10% or less) and the removal of mature beech trees may be advisable. Isolated mature specimens or old trees of conservation value should be retained.

The effects of forest size and integrated control

The minimum size of woodland required to maintain a red squirrel population cannot be gauged as both forests studied were large (Craigvinean is approximately 2000 ha and Clocaenog 5000 ha). However, these studies support the contention that red squirrel populations are more likely to survive in larger conifer forests where they can be buffered from suitable grey squirrel habitats.

The time-scale of both projects was limited and it was not possible to predict the future viability of red squirrels in these forests indefinitely even with the suggested habitat recommendations. Neither of these studies addressed the issue of grey squirrel control. However, control of grey squirrels to limit immigration from source populations may complement habitat management as part of a strategic approach to maintaining red squirrel populations in large conifer dominated plantations.

Acknowledgements

The immuno-contraception work is being funded by the Forestry Commission, the Scottish Forestry Trust, the Joint Nature Conservation Committee and a consortium of timber growers.

Funding for the Clocaenog study came from the Forestry Commission and Countryside Council for Wales and for the Craigvinean study from the Forestry Commission, Scottish Natural Heritage and the People's Trust for Endangered Species.

References

Gurnell, J. and Pepper, H.W. (1993). A critical look at conserving the British red squirrel, *Sciurius vulgaris*. *Mammal Review* **23** (3/5), 127–137.

Moore, H.D.M. (1996). On developing an immunocontraceptive vaccine for the grey squirrel *Sciurius carolinensis*. In, Proceedings of a Symposium, *The conservation of red squirrels*. People's Trust for Endangered Species, London.

Pepper, H.W. and Hodge, S. (1996). Squirrel population and habitat management. In, *Report on Forest Research 1996*, 49–42. Forestry Commission, Edinburgh.

Pepper, H.W. and Patterson, G. (1998). *Red squirrel conservation*. Forestry Commission Practice Note 5. Forestry Commission, Edinburgh.

Woodland Restoration of Contaminated Land

Woodland Restoration of Contaminated Land

by Tony Hutchings, Andy Moffat and Ian Stubbs

The negative visual, socio-economic and environmental impacts of contaminated land are due in part to the paucity of vegetation. Grossly polluted sites can be almost totally biologically sterile. This may be due to a range of soil factors including poor physical structure, low nutrient capacity, absence of organic matter and heavy metal toxicity. A recent Forestry Commission publication, *The potential for woodland on urban and industrial wasteland* (Perry and Handley, 2000), suggests that 'forestry may offer an environmentally sound and effective end-use for contaminated land'. However, it also identified that research was needed to 'clarify the potential of contaminated land both as a medium for tree growth and to determine the role of woodland systems in stabilising (or mobilising) potentially toxic elements'.

Forestry Commission research into the restoration of disturbed land to woodland has been conducted since the early 1970s. The research has primarily addressed physical and nutritional problems on mineral workings, colliery spoils and former landfill sites. Comparatively few studies in the UK have considered the reclamation of land contaminated with heavy metals to woodland. Yet trees may have the potential to remove (phytoremediation) or stabilise (phytostabilisation) the contamination. Trees can break source–receptor pathways by immobilising contaminants in the soil, and so reduce the risk of contaminant pollution by off-site migration.

The use of trees for the safe and effective reclamation of contaminated land must be based on a good understanding of the factors that influence the success of tree establishment, and the long-term fate of contaminants within forest and woodland ecosystems.

The extent of contaminated land in the UK

Estimates of the total UK land area and the number of contaminated sites vary widely. The Royal Commission on Environmental Pollution (1996) estimated the UK contaminated land area to be between 50 000 and 200 000 ha, but the Environment Agency suggested that up to 300 000 ha may be contaminated in England and Wales (ENDS, 1999).

However, only a small number of sites are believed to constitute an actual danger to humans or the environment. Experience abroad shows that typically 1–4 % of sites defined as contaminated land will require priority treatment due to immediate hazard (Perry and Handley, 2000). The advent of clear definitions and guidance on the identification of contaminated land (Department of the Environment, Transport and the Regions (DETR), 2000) will enable a more realistic and definitive assessment of the extent of contaminated land in the UK.

In fact, the majority of land that contains elevated concentrations of heavy metals may not be defined as 'contaminated' because the pollutant linkage is deemed to be insignificant. This means that a contaminant, a relevant receptor and a pathway have not been identified, and so the contaminants do not pose any immediate threat to any defined receptor. Such land is open to conventional reclamation (including the establishment of trees) as long as the reclamation process itself does not pose a threat to a defined receptor. However, land defined as being 'contaminated' under the DETR definition can be restored to woodland if it can be shown that the establishment of woodland will aid the remediation of the site.

The government's intention is that remediation should result in land being suitable for beneficial use. Woodland provides a 'soft' end-use that requires less stringent remediation objectives than, for example, the building of residential properties. The aim of any remediation should be to ensure that in its current use it is no longer contaminated, and that the effects of any significant harm or pollution of controlled waters which have occurred are remedied. Remediation can be achieved by: removing or treating the pollutant; breaking or removing the pathway; protecting or removing the receptor. Woodland establishment has the potential of satisfying all the criteria.

The occurrence of trees on contaminated land in Britain

In 1998 we conducted a postal questionnaire to determine the frequency of trees or woodland on contaminated land. Survey forms were sent to local authorities, timber growers, industry and Government Agencies in the UK. The survey identified 250 sites covering an area of over 3200 ha from over 30 former contaminating land-uses (Table 1) and currently supporting a range of 20 tree species (Table 2). Although the results probably greatly underestimate woodland occurrence on this type of land, the survey demonstrates that a diverse number of tree species have been, or can become, established on a wide range of materials containing heavy metal and organic contaminants. The types of sites identified suggest that some tree species are relatively tolerant of some forms of contamination (notably from heavy metals), and that there are reasonable grounds to suppose that woodland can be re-established on such land. However, the survey does not show how tree performance is affected by contamination.

The effects of heavy metals on tree survival and growth

Trees show little evidence of genotypic selection for heavy metal tolerance. However, trees occur within many families, orders and classes, and therefore exhibit a broad genetic diversity. Consequently it is probable that at least one tree species will be suited to the combination of contaminants at any particular site.

Due to the lack of systematically collected data, it is difficult to determine from published research how tolerant trees are of heavy metal contamination. There is strong evidence that metal toxicity can have multiple direct and indirect effects on most plant physiological functions. Direct or primary toxic effects include the alteration and inhibition of enzyme activity, inhibition of root growth and membrane damage. The disturbance of these functions causes subsequent indirect or secondary toxic effects, including a reduction in nutrient uptake, inhibition of photosynthesis and carbon sequestration and alterations in plant–soil–water relations. These effects ultimately reduce plant growth and survival. Roots usually accumulate significantly larger amounts of heavy metals than the above-ground biomass. Metal toxicity not only affects the length of the primary roots, but can also change the architecture of the entire root system, and the ratio of root to shoot.

Table 1 Former contaminating land-uses identified in the survey as currently supporting trees.

Brickworks	Municipal facilities
Chemical works	Munitions factories and depots
Cokeworks	Papermills
Collieries	Pig bristle drying plants
Concrete works	Plating works
Drilling sites	Power stations
Firing ranges	Railways
Gasworks	Scrap yards
Iron and steel works	Sewage works
Jute/flax works	Smelting works
Landfill sites	Tanneries
Light industry	Tipping sites
Metal recycling plants	Wood processing plants
Metalliferous mines	

Table 2 Tree species identified in the survey.

Alder	*Alnus glutinosa*
Ash	*Fraxinus excelsior*
Beech	*Fagus sylvatica*
Birch	*Betula* spp.
Blackthorn	*Prunus spinosa*
Cherry	*Prunus* spp.
Elder	*Sambucus nigra*
Hawthorn	*Crataegus monogyna*
Horse chestnut	*Aesculus hippocastanum*
Lime	*Tilia* spp.
Maple	*Acer campestre*
Monterey pine	*Pinus radiata*
Norway spruce	*Picea abies*
Oak	*Quercus* spp.
Poplar	*Populus* spp.
Rowan	*Vibernum opulus*
Scots pine	*Pinus sylvestris*
Sitka spruce	*Picea sitchensis*
Sycamore	*Acer pseudoplatanus*
Willow	*Salix* spp.

To study the relationship between survival, growth and health of trees and the type and extent of contamination, a pot experiment was set up at Alice Holt nursery using contaminated material from the close vicinity of a zinc smelter. The pure material (C5) was mixed with silica sand (C0) to produce four intermediate metal treatments (C1–C4). Figure 1a shows where national limit concentrations, as defined by the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL), of cadmium, copper, lead, nickel, zinc, arsenic and mercury were exceeded in each treatment.

Ash, willow, sycamore, birch, oak, poplar, alder and Japanese larch have been grown in the contaminated material treatments under controlled nursery conditions. After one growing season the results suggest that certain tree species are more resistant to heavy metals than others. Heavy metal concentration significantly affected tree survival in ash, alder, birch, Japanese larch, oak and sycamore. Birch (Figure 1b) and poplar appear to have a higher tolerance to heavy metals than the other species tested. The highest mortality rate was exhibited by oak. The order of survival for the tested species was:

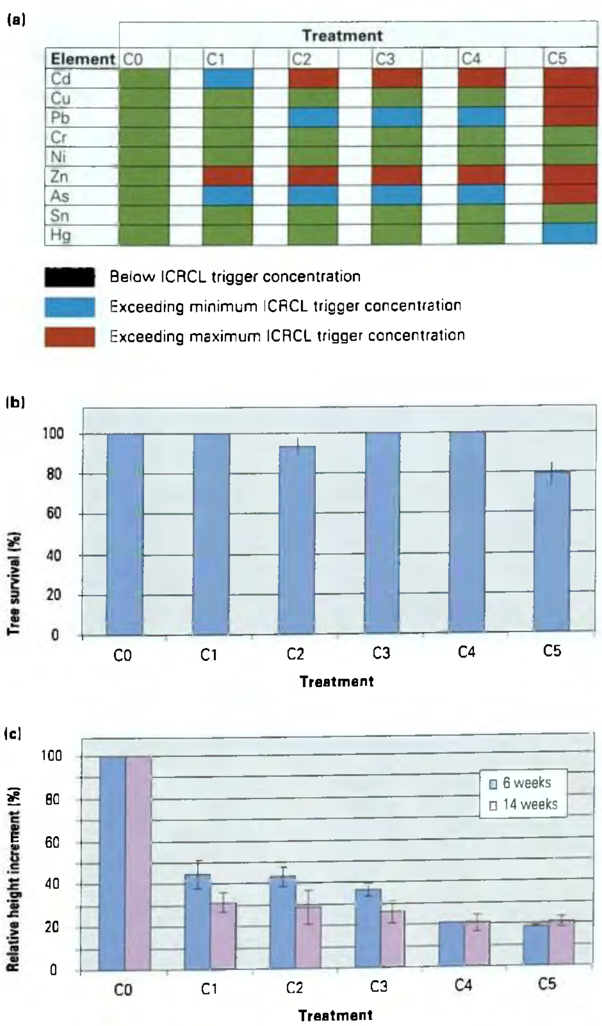
Birch > poplar > sycamore = ash > willow > alder > Japanese larch > oak.

The effect of heavy metal concentration on tree height increment is highly significant for all species, inferring that either a single metal, or more likely the interactive effects of multiple metals, significantly influence tree growth. For height growth, the relative resistance/tolerance of the tree species to the heavy metal treatments was:

Ash > willow = sycamore = birch > oak > poplar > alder > Japanese larch.

These results show that there is a significant variation in species tolerance to heavy metals. It must be recognised that the success of a species will be very dependent on the type and extent of contamination at a site-specific level. The order of survival and growth suggests that ash, birch (Figure 1c), poplar and sycamore would seem most suited for establishment in this particular contaminated material.

Figure 1 Relationship between survival and growth and the type and extent of contamination. **(a)** Soil treatment concentration where ICRCL-defined lower and upper trigger concentrations are exceeded. **(b)** Mean tree survival against treatment for birch (n=18). Bars show data range. **(c)** Relative height increment for birch in different treatments six and 14 weeks after planting (n=18). Bars show data range.



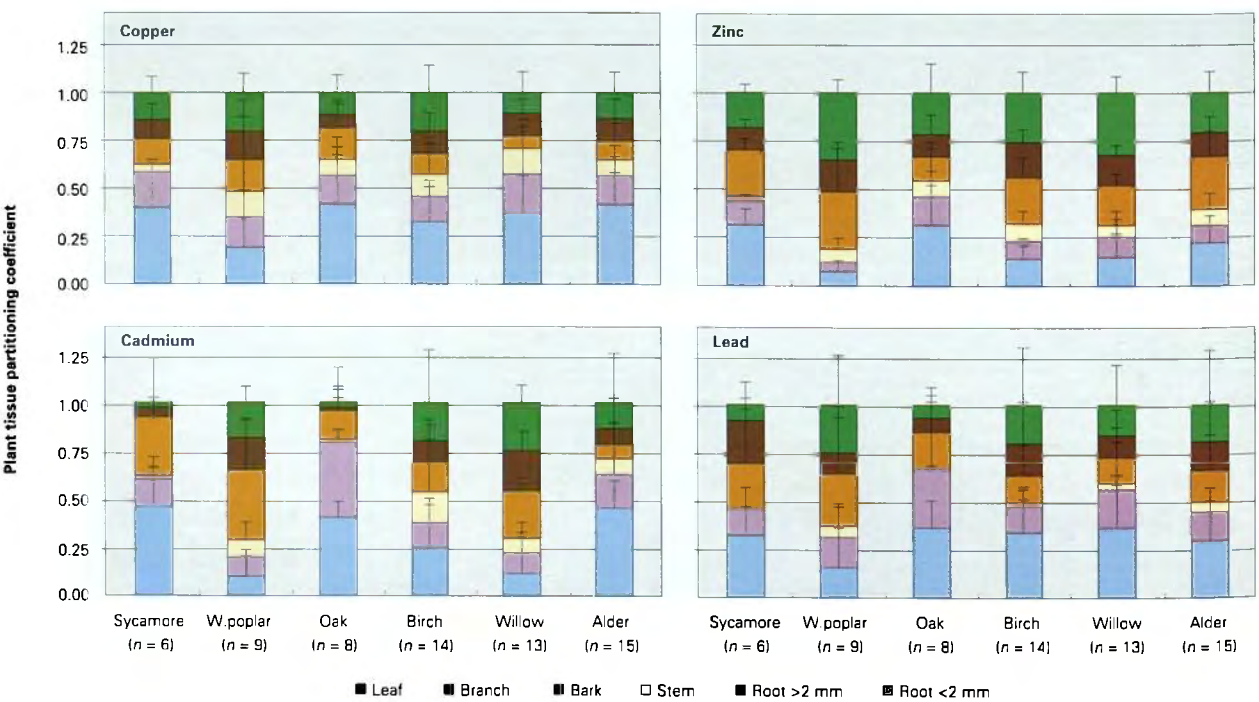
In order to quantify the effects of individual metals on tree survival and growth we are also growing trees in metal doped cultures. Although still in its preliminary stages, this work has already yielded some significant findings. Twelve species of tree were grown for 14 weeks in 1/4 strength Hoagland's nutrient solution (Hoagland and Arnon, 1941) with zinc amendments added as $ZnSO_4.7H_2O$ in the treatment solutions to provide concentrations of 0.02 (control), 5, 10, 50, 100 and 150 mg Zn l^{-1}. An example of a 'typical' growth response is shown for birch (Plate 1). Birch was zinc deficient in the control solution, optimal growth occurred between 5 and 10 mg Zn l^{-1}, and toxicity became severe in the 100 and 150 mg Zn l^{-1} treatments. All tree species exhibited similar overall responses but the concentration of zinc that caused deficient, optimal and toxic response was species specific. We intend to extend the use of this type of methodology to investigate the response of trees to a wider range of heavy metals and ultimately to produce an index of metal tolerance.

Plate 1 The response of birch to increasing zinc concentration in solution from 0.02 (far left) to 150 mg Zn l^{-1} (far right). Note deficiency at 0.02 mg Zn l^{-1}, optimal growth at between 5 and 10 mg Zn l^{-1} and severe toxicity at 100 and 150 mg Zn l^{-1}.

The uptake and compartmentation of heavy metals in trees

Many factors influence metal uptake, including root surface area, rate of transpiration and the nature and quantity of root exudates. Of the heavy metals, cadmium and zinc are considered to be most readily taken up and translocated within the tree and become concentrated in the above-ground biomass. Lead, arsenic, cobalt, chromium, mercury and tin show low phytoavailability, while copper, nickel and selenium have intermediate availability. The uptake, behaviour and fate of metals appears to vary considerably between tree species. For sites where woodland establishment and phytostabilisation are the primary objectives of planting, the best tree species should exhibit high metal tolerance and low metal uptake. In contrast, for sites where phytoremediation is the primary objective, optimum species should exhibit high metal tolerance, high above-ground yield of biomass and high metal uptake characteristics. We are working to establish species suitability for phytoremediation and phytostabilisation by assessing the inter-species variation in heavy metal compartmentation and tree survival and growth.

Figure 2 A species comparison of the plant tissue partitioning coefficient of copper, zinc, cadmium and lead.



Metal compartmentation is important when considering which tree species to plant. Both metal accumulators and excluders should show low metal distribution to the leaves and roots. This prevents the rapid return of the metals to the decomposition and elemental cycles that occur during leaf and root decomposition. 'Accumulating' species, used for the decontamination of land, should readily achieve high metal loadings in their trunk and branches so as to immobilise metals in the perennial tissues.

Measurements of the relative concentration of heavy metals between the basic components of a tree (fine roots, coarse roots, bark, stem, branches and leaves) may provide a method of predicting the potential of trees at stabilising, remediating and/or mobilising contaminants. We calculated the relative tissue concentration in each tree's components in order to provide a plant tissue-partitioning coefficient for six tree species which had been grown on a range of sites with varying types and degrees of contamination (Figure 2). The results suggest that plant tissue-partitioning coefficients vary significantly between species but show comparatively little intra-species variation. The compartmentation of metals may therefore be predictable at a species level and results show that certain species may be better suited to particular contamination scenarios. Although numerous soil and plant factors affect the accumulation and partitioning of metals in plants, the values are intended as guides to the order of magnitude of the partitioning coefficients and not precise values. Such information is invaluable when considering optimum species choice based upon predicted food-chain transfer, heavy metal stabilisation potential and metal cycling. We shall be using such information to develop a systematic approach for determining the potential of contaminated land for supporting woodland. Table 3 provides a preliminary overview of the approach.

Soil properties affecting heavy metal availability to trees

The mobility and phytoavailability of heavy metals can potentially be controlled, to levels that can be tolerated by trees, by the incorporation of soil amendments. We are currently investigating the potential of some soil amendments to reduce metal bioavailability and the associated risks of metal toxicity, whilst improving nutrient availability and thereby increasing tree growth and survival.

Table 3 Development of a systematic approach for assessing the potential of contaminated land for supporting woodland.

Stage	Action	Purpose	Research activity
1	Desktop survey, site evaluation and investigation	Identify contamination type, level and extent	Utilise historical land use records, preliminary site visit and soil survey
2	In-situ and ex-situ prediction of tree establishment viability	Assessment of heavy metal phytoavailability and other predicted effects on tree growth	Investigate the effects of heavy metals on tree survival and growth Establish physiological and chemical indicators of health for trees growing on contaminated land Investigate the use of soil amendments at improving tree survival and growth
3	Consideration of amendment use to improve tree performance	Identify optimum soil amendments and test for improved tolerance	Investigate the potential of trees as biological indicators of heavy metal phytoavailabilty Develop methodology for the ecotoxicological assessment of contaminated land
4	Determination of tree establishment type best suited to contaminated land	Determine optimum species choice and viability of tree establishment	Determine the compartmentation of heavy metals within trees
5	Evaluate the effects of tree establishment on the stabilisation and/or mobilisation of metals	Predict the effects of tree establishment on contaminant cycling	Model heavy metal cycling including: particulate capture, metal uptake and partitioning, litter decomposition and the effects of trees on soil properties
6	Predict woodland establishment viability, implications and rewards	Utilise Information from above actions to determine if woodland establishment has a net benefit	Determine the minimum acceptable standard of woodland establishment for trees on contaminated land Develop a decision support system for woodland establishment on contaminated land

Two examples of amendments which show large potential are composted materials and crushed limestone. The recycling of organic waste matter into compost is becoming increasingly popular (Department of the Environment, Transport and the Regions, 1999), and its use on contaminated sites may provide an attractive and viable alternative to more traditional disposal methods. The addition of organic matter both aids contaminant stabilisation and increases the nutrient status of a site, thereby potentially enhancing woodland establishment. An application of crushed limestone to contaminated sites can also be used to increase soil pH and so reduce metal mobility. Other possible waste materials include treated sewage sludge and animal slurries, straw, clay quarry waste, charcoal, seaweed, spent mushroom compost, papermill sludge and wood residues (Bending *et al.*, 1999). Preliminary amendment trials we have conducted demonstrate that the survival and growth of trees planted in contaminated soils amended with crushed limestone and thermally dried sewage sludge is improved considerably.

The use of trees to stabilise or remediate contaminated land

Pollutant linkages occur via transport mechanisms along pathways. These include: windblown erosion, leaching, surface water runoff and erosion, volatilisation, ingestion, inhalation, adsorption and food-chain migration. Trees have the potential for restricting, preventing or enhancing such pathways.

The establishment of trees and other vegetation has been shown to be effective at trapping and absorbing many airborne pollutant particles (e.g. Broadmeadow *et al.*, 1998) and so limiting the spread of contamination and potential exposure to humans and the environment. Woodland is also especially effective at retaining sediment material (including absorbed organic, heavy metal and nutrient contaminants).

The use of trees to restore heavy metal values to within acceptable limits has potential for low contamination scenarios, but is unlikely if contamination is moderate to high. However, total pollutant removal is not necessary as the bioavailable fraction is most important for transfer of pollutants to subsequent crops or to groundwater. The sustained removal of the phytoavailable metal fraction is termed Bioavailable Element Stripping (BES) (McGrath, 1998). We are currently examining the potential of trees to perform BES.

Conclusions

Our work continues towards the provision of detailed guidance on the establishment of woodland on contaminated land, but we have already demonstrated that trees can be successfully grown in soils contaminated with heavy metals. We are currently developing ecotoxicological assessment methods which should enable foresters to determine the suitability of contaminated land for woodland establishment. In addition, we are studying species choice, planting configurations and soil amendments that are likely to maximise the benefits of woodland planting for the stabilisation and remediation of contaminated land, whilst assessing the risk of contaminant mobilisation.

Acknowledgements

This article owes much to the contributions of colleagues in Environmental Research Branch (Mrs S. Cowdry, Mr E. Ward, Mr F. Bochereau and Dr M. Broadmeadow) and the Technical Support Unit (Mr S. Coventry, Miss L. Haydon, Mr J. Page, Mr R. Panton and Mr A. Dowell).

References

Bending, N.A.D., McRae, S.G. and Moffat, A.J. (1999). *Soil-forming materials: their use in land reclamation.* The Stationery Office, London.

Broadmeadow, M., Beckett, P., Jackson, S., Freer-Smith, P. and Taylor, G. (1998). Trees and pollution abatement. In, *Forest Research annual report and accounts 1997–1998,* 37–43. The Stationery Office, London.

Department of the Environment, Transport and the Regions (1999). *Limiting landfill: A consultation paper on limiting landfill to meet the EC Landfill Directive's targets for the landfill of biodegradable municipal waste.* The Stationery Office, London.

Department of the Environment, Transport and the Regions (2000). DETR Circular 2/2000 *Contaminated land: Implementation of Part IIA of the Environmental Protection Act 1990.* The Stationery Office, London.

ENDS (1999). April target for new contaminated land regime in England. *ENDS Report 297,* 45–48. Environmental Data Services, London.

Hoagland, D.R. and Arnon, D.I. (1941) *The water culture method for growing plants without soil.* Miscellaneous Publications No. 3514. Californian Agricultural Experiment Station, California.

McGrath, S.P. (1998). Phytoextraction for soil remediation. In, *Plants that hyperaccumulate heavy metals,* 261–288, ed. Brooks, R. R. CAB International, Wallingford.

Perry, D. and Handley, J. (2000). *The potential for woodland on urban and industrial wasteland in England and Wales.* Forestry Commission Technical Paper 29. Forestry Commission, Edinburgh.

Royal Commission on Environmental Pollution (1996). Nineteenth Report. *Sustainable use of soil.* HMSO, London.

Chloroplast DNA Variation in British Oak Populations

Chloroplast DNA Variation in British Oak Populations

by Joan Cottrell, Helen Tabbener, Robert Munro[1], Amanda Gillies[2], Ian Forrest, Douglas Deans[1] and Andrew Lowe[1]

Introduction

When planting native tree species such as oak there is increasing pressure to use locally sourced material. However, the use of seed from other parts of Britain or imported from the continent has been practised for centuries and locally sourced material is no guarantee of natural migration to the area. An understanding of the natural migration of oaks into Britain is a first step to identifying seed sources which are likely to have arrived by natural means. Until recently our knowledge of post-glacial colonisation routes has been based almost entirely on evidence derived from fossilised plant remains consisting largely of pollen. However, following the development of new DNA based techniques, variation in chloroplast DNA (cpDNA) has been found to be informative in determining historical routes of post-glacial colonisation in several plant species. The circular cpDNA molecule is a slow mutating, non-recombining, maternally inherited genome which can be used to trace routes of seed dispersal without the complicating factor of pollen mediated geneflow.

Methods

In the present study 1073 trees were sampled from 223 oak sites throughout Britain. Material was taken from five trees per wood and sampling was confined to the two native species, *Quercus robur* L. and *Q. petraea* (Matt.) Liebl. Sampling was largely restricted to old trees in ancient woodlands in order to minimise the possibility of testing planted trees (Plate 1).

Variation in cpDNA was examined using a PCR/RFLP (Polymerase Chain Reaction/Restriction Fragment Length Polymorphism) approach. This involved the use of sets of universal primers (short synthetic oligonucleotide sequences) to initiate the amplification of distinct regions of the cpDNA genome. The amplified region was then digested using restriction enzymes which cut the amplified cpDNA at regions consisting of specific base sequences.

Plate 1 Mature oak tree typical of the type sampled in this study.

The restricted cpDNA fragments were then run on a polyacrylamide gel and silver stained to visualise the fragments. Variation was scored according to the system devised by Dumolin-Lapègue *et al.* (1997).

The geographic location of each wood along with the species classification of its five sampled trees is shown in Figure 1. Samples from the south-east of England consisted largely of *Q. robur* whereas most of the samples from the west coast of England and north Wales were *Q. petraea*. Mixed species woodlands were relatively rare but occurred most frequently in Herefordshire, Kent and scattered throughout Scotland.

1 Centre for Ecology & Hydrology (Edinburgh), Bush Estate, Penicuik, Midlothian, EH26 0B
2 Current Address: Sir Harold Mitchell building, School of Environmental and Evolutionary Biology, University of St Andrews, St Andrews, Fife KY16 9TH

Figure 1 The distribution of *Q. robur, Q. petraea* and intermediate individuals in sampled ancient woods in Britain. White symbols indicate unclassified trees which were sampled during the winter time when no leaves were available to enable species determination. The size of each pie chart indicates the number of individuals sampled from each population (from 1 to 5).

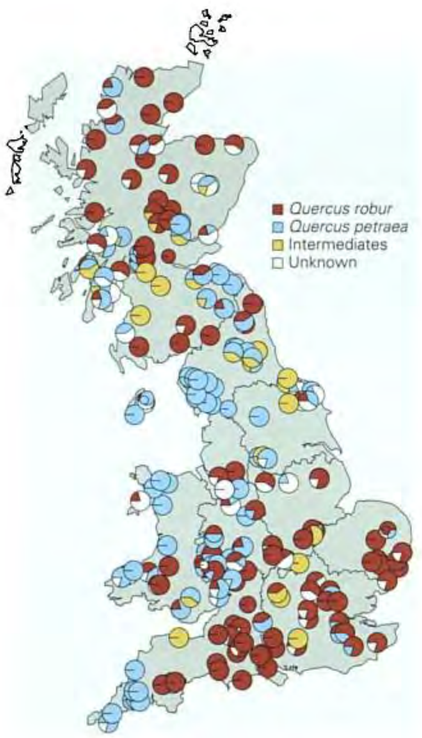
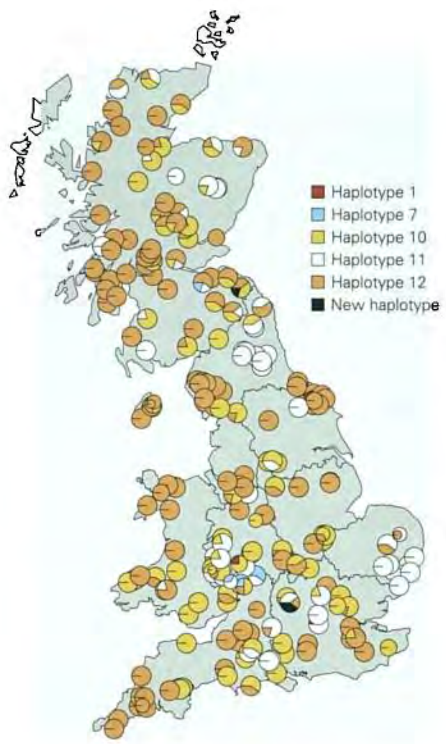


Figure 2 The distribution of haplotypes in sampled ancient woodlands in Britain. Orange, yellow and white haplotypes originate from Spain. Blue, red and black haplotypes are of non-Iberian origin. The size of the pie chart indicates the number of individuals sampled from each population (from 1 to 5).



Distribution of cpDNA haplotypes in Britain

The distribution of cpDNA haplotypes is shown in Figure 2. The different cpDNA haplotypes are coded by colour. The orange haplotype was present in 51% of the sample. It was most common in the west of Britain, and dominated populations in Cornwall, north Wales, the Isle of Man, the Lake District and west and central Scotland. Clusters of the orange haplotype also occurred in the east around Tyneside as well as in Kent. The yellow haplotype occurred in 27% of the sampled trees and was most frequently found in south Wales, southern England and central Scotland. The white haplotype, which constituted 20% of the sample, was most common in the east. It dominated populations in East Anglia and some areas of north-east England but also occurred more sporadically in the south of England, the Welsh Marches and Scotland. The distribution pattern of these three haplotypes provides an insight into the post-glacial routes of colonisation in Britain. Fossil data indicate that oak first re-entered Britain via Cornwall 9500 years ago and rapidly spread northwards along the west coast under the warming influence of the Gulf Stream. This is supported by the new cpDNA data.

The most likely scenario to explain the distribution of cpDNA variation in Britain is that a few individuals of *Q. petraea* of orange haplotype entered Cornwall from France and rapidly spread northwards to create *Q. petraea* woods of purely orange haplotype as far north as the west of Scotland. In the meantime, before more easterly sites could be invaded, a second colonisation event involving both species and all three haplotypes occurred in south-east England. It is possible that there were additional localised points of entry into Britain. For example, East Anglia is dominated by *Q. robur* white haplotype trees which may have entered from the east before the wave of colonisation from the west reached East Anglia.

Orange, yellow and white haplotypes are believed to originate from refugia in Spain (Dumolin-Lapègue *et al.*, 1997) and 98% of the oaks sampled in this study possessed one of these three haplotypes. This indicates that, with the possible exception of one area in the Welsh Marches, Britain was recolonised by oaks whose ancestors originated from glacial refugia in Spain, and descendants of trees from refugia in eastern Europe did not contribute to the colonisation process. The blue haplotype is thought to originate from a refugium in the Balkans and this haplotype occurred at four sites in the Welsh Marches.

Geographically, the closest oaks possessing this haplotype have previously been found in northern France (Dumolin-Lapègue *et al.*, 1997) and it is possible that their presence in the Welsh Marches is the result of a single long distance colonisation event. However, their absence from all other sites except for one tree growing on an estate in Scotland suggests that their presence in the Welsh Marches is more likely to be the result of man's activities. Two sites (Windsor Great Park and Collyweston Great Wood) possessed a red haplotype which is thought to originate from Italy. Once again, the rarity of this haplotype in Britain and the fact that the nearest trees possessing this haplotype occur in Belgium suggest that these have not arrived by natural means. Variation in cpDNA can therefore provide information on the degree of human interference which has occurred in our ancient oak woods.

The observed clumped distribution of a single haplotype in areas such as East Anglia is consistent with the leptokurtic model of colonisation where single, long distance dispersal events are mainly responsible for colonisation (Ibrahim *et al.*, 1996). The few individuals which became established ahead of the leading front formed large areas of single haplotype woods. The original pattern of distribution of haplotypes persists over many generations and can therefore still be detected in the woods of today.

The presence of more than one haplotype in a wood may have several explanations. A high proportion of mixed haplotype woods in an area may reflect the confluence of more than one migration route so that foundation stock for each wood was recruited from more than one source. Alternatively, mixed haplotype woods may be the product of human management where non-local haplotypes have been introduced by man. The observation that 42% of *Q. robur* woods were mixed haplotype compared with only 16% of *Q. petraea* may also be partly due to human management. It is well known that *Q. robur* was the species preferred for use as charcoal, timber and pigfeed so it is more likely to have been planted. This idea is supported by the fact that the areas such as the Welsh Marches and central Scotland which have a large proportion of mixed haplotype woods also have a long history of human management.

None of the haplotypes detected in the course of this study was specific to single regions of Britain so they could not be used as markers for local origin. The technique could however be used to detect the degree of importation of non-native planting stock from eastern Europe and this may be of practical value if concern regarding importation of non-native planting stock from abroad continues to increase. The technique could also be used in areas such as Cornwall, where single haplotypes dominate, to identify trees growing in the area which are not of local origin.

This work is part of a collaborative EU-funded project which aims to elucidate the post-glacial routes of migration of oaks from refugia in southern Europe to the sites where they are found today. This has involved the analysis of cpDNA from over 2500 populations throughout Europe as well as a thorough re-examination of available fossil pollen data from the region.

References

Dumolin-Lapègue, S., Demesure, B., Fineschi, S., Le Corre, V. and Petit, R.J. (1997). Phylogoegraphic structure of white oaks throughout the European continent. *Genetics* **146,** 1475–1487.

Ibrahim, K.M., Nichols, R.A. and Hewitt, G.M. (1996). Spatial patterns of genetic variation generated by different forms of dispersal during range expansion. *Heredity* **77,** 282–291.

UK Forest and Moorland Fire Suppression

UK Forest and Moorland Fire Suppression

by Ian Murgatroyd*

Introduction

Within the European Union, the UK is classified as a low fire risk area. It has a relatively uniform annual rain pattern with no regular dry season (the climatic factor conducive to catastrophic wildfires). Consequently, research into forest and moor/heath wildfire suppression is on a lesser scale than in countries such as Australia and America. However, heather and *Molinia* grass fires in the UK often develop sufficient intensities to be classed as 'High' or even 'Very high' in strong wind conditions (as defined by the Australian Fire Authorities Council rating system). Individuals and organisations dealing with fire suppression and with fire as a management tool need to be aware of the basic characteristics and the mechanics of efficient fire suppression.

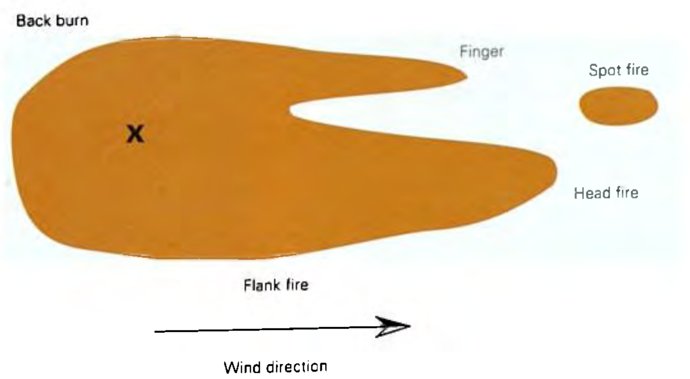
Technical Development Branch, in partnership with Michael Bruce of Glen Tanar Estate, Aboyne and Forest Enterprise, undertook an evaluation of fire fighting equipment and techniques. The trials improved our understanding of UK forest and moorland fire characteristics and identified how such knowledge could improve fire fighting practice in the UK. As a result some recommendations with regard to equipment and techniques required modification.

Fire characteristics

A simplified plan view of a fire can be seen in Figure 1. The origin of the fire is shown at 'X'. The fire front can move ahead faster in some areas rather than others due to fuel type or local wind speed, producing fingers which burn forward from the main body of fire. The head of the fire is the fastest moving part and has the greatest intensity. The flanks of the fire are not as intense or as fast moving as the head. The back fire or back burn is the slowest moving part with the least intensity. Spot fires can develop in front of the head by blown embers igniting fuel. Fire requires fuel, oxygen and heat. Fire suppression requires the removal or reduction of one of these elements.

Fuel in forest and moorland conditions generally comprises vegetation (dead or alive) and the organic layers of the soil. The characteristics of different fuels will affect combustion. Unpacked fine diameter fuels such as heather and grass can dry more readily and combust more quickly than larger diameter fuels such as stemwood in brash mats. More intense fires generally occur with greater quantities of fuel, greater wind speeds or on slopes. Preheating of vegetation in front of the fire also increases fire intensity in addition to the probable rate of spread. An important finding of the trials was that UK heather and grass head fires can achieve sufficient intensities in *unexceptional* weather conditions to be classed as 'High' or 'Very high' (Table 1).

Figure 1 Fire description.



***Present address:** Forestry Commission Scotland, South West Scotland Conservancy, 11 Church Crescent, Dumfries DG1 1DF

Table 1 Fire line intensities related to suppression techniques and fire danger rating. *Adapted from Australian Fire Authorities Council Wildfire Suppression 2 Learning Manual 2.29* (Anon., 1996).

Fire danger rating (Australian)	Flame height (m)	Intensity (kW/m)	Probable heather conditions	Suppression techniques
Low	<0.5	0–50	Young/sparse	Fires generally self-extinguish.
Moderate	0.5–1.5	50–500	Young/good cover Degenerate/limited cover	Direct attack with beaters, water-based systems
High	1.5–3.0	500–2000	Building Mature Degenerate/limited cover	Direct attack strenuous, especially with beaters. Use water systems such as fogging with beaters. Helicopter water bombing. Consider indirect attack (i.e. fire breaks) at upper limits (2000 kW)
Very high	3.0–10.0	2000–4000	Runaway heather fires especially in mature phase, driven by wind and slope	Direct attack by helicopter, water bombing. Indirect attack recommended
Extreme	>10	>4000 can exceed 60 000	Not found in UK	Control efforts probably ineffective. Defensive strategy recommended

Prediction of fire danger rating

To predict the fire danger rating of any potential fire site, the probable rate of spread, fire line intensity, access and extent of fire fronts have to be known in advance. To calculate the fire line intensity, the fuel load, which can be directly linked to vegetation height in heather, should be known. Further work is needed to establish a consistent method of forecasting fuel loads across vegetation types. With such information it would be possible to determine which suppression systems are most suitable. Previously known data could then be used to estimate the time required for fire suppression in given situations.

Trials

Trials of a range of fire suppression equipment and systems were carried out during winter 1998 and spring 1999. In all heather fires (apart from heather 'wildfire') the back burn, flanks and head fires were suppressed. In the *Molinia* test fires only the back burn and flanks were suppressed because the head fires moved very quickly and were then confined by firebreaks. In some test conditions, greater fire intensities were experienced with smaller fuel loads with a fast rate of spread than with fires with large fuel loads and a slow rate of spread.

Plate 1 Belt and wire mesh beaters.

Operator protection

The trials confirmed that heat stress and protection against burning debris were important factors when preparing for fire fighting. It is strongly recommended that full length face shields and gloves are used. They provide excellent protection against radiant heat to the face, neck and hands. It is also recommended that Proban-treated welding cotton overalls are worn for UK forest and moorland fire fighting.

Waterless fire suppression

Fire beaters

The trials identified some principles which, while simple, are significant with regard to the choice of beater design:

- Long handles (2.8 metres) should be fitted to beaters (currently 2.2 metre handles are commonly used). Maximum operator protection is essential and the extra distance from the fire source will reduce heat stress.
- For heather fires mesh heads (Plate 1) are more suitable because they are more durable than conveyor belt heads, and they are more effective when raking and scrubbing muirburn vegetation.
- Conveyor belt heads (Plate 1) are best for *Molinia* fires, as flaming grass can become entangled in mesh heads, helping the fire to spread.

Trials found that the Cawdor Estate design (Plate 2), with its combined advantages of a long handle, a mesh head for raking and a partial insert, had an effective smothering action when used in heather.

Plate 2 Cawdor Estate beater.

Air blowers

Air blowers have been used in America and China to blow flames away from fuel sources but trials indicated that they were not cost-effective. Also, use of petrol-powered equipment close to the fire source was considered to be a potential fire hazard. Use of air blowers is therefore not recommended at present.

Fire suppression with water

The following types of water stream systems were evaluated during field trials:

- *Jet:* this has a long reach and good penetration.
- *Spray:* this has a greater surface area than a jet and is therefore better for heat absorption
- *Fog:* the very fine spray of water droplets is best for heat absorption, requiring less water, but has a short reach and is affected by wind.

Fog pattern

This pattern (Plate 3) is commonly produced by high pressure low volume pumps. The efficient water usage rates of fogging units and their relatively light weight enables these systems to be carried on light ATVs or ATC trailers.

Plate 3 Fog pattern.

Plate 4 Combined fogging and beater fire suppression.

Heather and *Molinia* fire suppression

The fogging jet was aimed at the base of the fire to wet burning fuels and knock the fire down. The three beaters, at a spacing of about 10 metres, extinguished any remaining fires and subsequent flare ups. The use of the fogging system with three beaters in support (Plate 4) required a water volume as low as 0.63 litres per metre for heather fire fronts compared with over 4 litres per metre for conventional pump systems (spray pattern). For *Molinia* fires the fogging system water usage could be as low as 0.35 litres per metre. Fogging systems with beater support are therefore strongly recommended for both heather and *Molinia* fire fighting.

Brash fire suppression tests

Four types of water-based systems were evaluated on the two brash sites:

- Plain water
- Low expansion foam
- Focstop (fire suppression additive)
- Fogging

The fogging unit had the lowest water usage rates of any system by a very significant factor. However, two main concerns were identified with fogging in brash fire suppression: the operator was subjected to the highest levels of heat exposure working close to the fire and with smaller quantities of water; and with high wind speeds re-ignition was about three times as common as with other systems.

Low expansion foam (Plate 5) and Focstop water usage rates were similar and consistent, both being significantly less than with plain water. Both were judged to have superior damping down abilities than with use of plain water.

Plate 5 Damping down with low expansion foam.

Foam was found to have the advantage of being less susceptible to incorrect mixing; it was also highly visible when applied. It is recommended that low expansion foam systems are used to suppress intense fires in brash (Plate 6) and similar fuels.

Plate 6 Direct attack of brash fire with low expansion foam.

Indirect fire fighting – fire breaks

Medium expansion foam trace widths of 1 m have been recommended previously as adequate breaks for wildfire control in heather and *Molinia*. This investigation concluded that foam fire break width should be at least 6–10 m (depending on conditions) with little or no fuel available in the break for these fuel types. Alternatively, cut vegetation traces can be used as a fire break. They should be at least 15 m wide and cut immediately before lighting a fire.

Further information

The above are extracts from the full project report which includes fire suppression techniques, personal protective equipment, waterless suppression, suppression with water, fire breaks and use of helicopters. The report is available on the Internet at www.forestry.gov.uk/forest_research.

References and further reading

Anon. (1996). *Australian Fire Authorities Council Wildfire Suppression 2 Learning Manual 2.29.* Addison-Wesley Longman Australia, South Melbourne, Australia.

Anon. (1991). *Forest fires.* Information Note 9. Queensland Forest Service, Australia.

Donarski, R. *et al.* (1995). *Evaluation of firefighters' protective clothing.* New South Wales Department of Bush Fire Services, Australia.

Ingoldby, M.J.R. and Smith, R.O. (1982). *Forest fire fighting with foam.* Forestry Commission Leaflet 80. HMSO, London.

Murgatroyd, I.R. (1998). *Foam concentrates for forest fire fighting.* Technical Development Branch Technical Note 7/97. Forestry Commission, Edinburgh.

Murgatroyd, I.R. (1998). *High pressure/low volume fire pump foam trace (development work).* Technical Development Branch Technical Note 12/98. Forestry Commission, Edinburgh.

Phillips, J. (1993). *A muirburn code.* Scottish Natural Heritage, Battleby, Redgorton, Perth.

Appendices

Appendix 1

Forestry Commission Technical Publications

The following titles were published during the year ending 31 March 2000

Report

Forest Research annual report and accounts 1998–1999. (£18.50)

Bulletins

119 Cultivation of soils for forestry, by D.B. Paterson* and W.L. Mason. (£14.00)

120 The potential for the natural regeneration of conifers in Britain, by C.J. Nixon† and R. Worrell*. (£14.00)

121 Forest tree seedlings - best practice in supply, treatment and planting, by J. Morgan†. (£12.50)

Field Book

18 How many deer? A field guide to estimating deer population size, by B.A. Mayle, A.J. Peace and R.M.A. Gill. (£14.00)

Information Notes (free)

18 PG suspension for the control of Fomes root rot of pine, by J. Pratt.

19 Forest condition 1998, by D. Redfern, R. Boswell and J. Proudfoot.

20 Overwinter physiology and the practical implications for handling of bare-rooted silver birch seedlings, by H. McKay.

21 Approved poplar varieties, by P. Tabbush and D. Lonsdale.

22 Dieback of pedunculate oak, by J. Gibbs.

23 Using natural colonisation to create or expand new woodlands, by R. Harmer.

24 Low technology kilns and drying schedules for hardwood in small-scale operations, by S. Riddiough*.

25 Comparison of sawlog quantity and quality between Sitka spruce seedlots originating from Washington and Queen Charlotte Islands, by S. Lee, J. Webber, C. Jones and J. Methley.

26 Predicted genetic gains from Sitka spruce production populations, by S. Lee.

27 Genetic gain from Scots pine: potential for new commercial seed orchards, by S. Lee.

28 Domestic stock grazing to enhance woodland biodiversity, by B. Mayle.

29 What is continuous cover forestry? by W. Mason, G. Kerr and J. Simpson*.

30 Phytophthora pathogens of trees: their rising profile in Europe, by C. Brasier.

Inventory Reports

National Inventory of Woodland and Trees. Scotland - Strathclyde Region. Part 1 - Woodlands of 2 hectares and over. (£5)

National Inventory of Woodland and Trees. Scotland - Lothian Region. Part 1 - Woodlands of 2 hectares and over. (£5)

National Inventory of Woodland and Trees. Scotland - Borders Region. Part 1 - Woodlands of 2 hectares and over. (£5)

National Inventory of Woodland and Trees. Scotland - Dumfries and Galloway Region. Part 1 - Woodlands of 2 hectares and over. (£5)

National Inventory of Woodland and Trees. Scotland - Fife Region. Part 1 - Woodlands of 2 hectares and over. (£5)

National Inventory of Woodland and Trees. Scotland - Tayside Region. Part 1 - Woodlands of 2 hectares and over. (£5)

National Inventory of Woodland and Trees. Scotland - Central Region. Part 1 - Woodlands of 2 hectares and over. (£5)

Practice Notes (free)

6 Managing deer in the countryside, by B. Mayle.

7 Establishment of short rotation coppice, by A. Armstrong.

8 Using local stock for planting native trees and shrubs, by R. Herbert*, C. Samuel and G. Patterson†.

9 Recommendations for fallow, roe and muntjac deer fencing: new proposals for temporary and reusable fencing, by H. Pepper.

10 Nant-yr-Hwch long-term forest design plan: an example of good practice from the private sector, by S. Bell* and G. Heath*.

Technical Papers

27 Woodland creation: experience from the National Forest, by G. Kerr and H.V. Williams*. (£5)

28 Herbicide update, by I. Willoughby and D. Clay*. (£5)

30 The native woodland resource of Scotland. A review 1993–1998, by N.A. MacKenzie*. (£5)

Miscellaneous

Forest Research business plan 1999–2000. (Free)

Short rotation coppice and wood fuel symposium. From research to renewable energy, edited by A. Armstrong and J. Claridge. (Free)

*Authors outwith Forest Research
†FC staff formerly with Forest Research

Appendix 2

Publications by Forest Research Staff

[Appleby, B.M., Anwar, M.A. and] Petty, S.J. (1999)
Short-term and long-term effects of food supply on parasite burdens in tawny owls, *Strix aluco*. *Functional Ecology* **13**(5), 315–321.

Armstrong, A.T., Johns, C. and Tubby, I.W. (1999)
Effects of spacing and cutting cycle on the yield of poplar grown as an energy crop. *Biomass and Bioenergy* **17**(4), 305–314.

[Bardos, P., French, C.J.,] Moffat, A.J. [and Nortcliffe, S.] (1999)
Can biomass kill three birds with one stone? *Land Contamination and Reclamation* **7**(3), 174–176.

[Bardos, P., French, C.J.,] Moffat, A.J. [and Nortcliffe, S.] (1999)
Renewable energy, decontamination and recycling. Can biomass kill three birds with one stone? *Waste Management* August 1999, 38–39.

[Beckett, K.P.,] Freer-Smith, P.H. [and Taylor, G.] (2000)
Effective tree species for local air quality management. *Journal of Arboriculture* **26**(1), 12–18.

[Bending, N.A.D. and] Moffat, A.J. (1999)
Tree performance on minespoils in the South Wales coalfield. *Journal of Applied Ecology* **36**(5), 784–797.

[Bending, N.A.D., McRae, S.G. and] Moffat, A.J. (1999)
Soil-forming materials: their use in land reclamation. 237pp. The Stationery Office, London. Department of the Environment, Transport and the Regions (DETR).

[Bending, N.A.D.,] Moffat, A.J. [and McRae, S.G.] (2000)
The use of waste materials in land reclamation. *Waste Planning* **34,** 11–13.

[Bending, N.A.D.,] Moffat, A.J. [and McRae, S.G.] (2000)
The use of soil-forming materials in land reclamation. *Mineral Planning* **82,** 3–8.

Brasier, C.M. (2000)
Intercontinental spread and continuing evolution of the Dutch elm disease pathogen. In, *The elms: breeding, conservation, and disease management*, ed. C.P. Dunn, 61–72. Kluwer Academic Publishers, Boston, Massachusetts.

Brasier, C.M. (2000)
Viruses as biological control agents of the Dutch elm disease fungus *Ophiostoma novo-ulmi*. In, *The elms: breeding, conservation, and disease management*, ed. C.P. Dunn, 201–212. Kluwer Academic Publishers, Boston, Massachusetts.

Broadmeadow, M.S.J., Freer-Smith, P.H. and Jackson, S.B. (1999)
Climate change: the evidence so far and predictions for tree growth. *Irish Forestry* **55**(2), 122–132.

Broadmeadow, M.S.J., Heath, J. and Randle, T.J. (1999)
Environmental limitations to O_3 uptake: some key results from young trees growing at elevated CO_2 concentrations. In, *Special issue: Forest growth responses to the pollution climate of the 21st century. Contributions from the 18th IUFRO workshop on air pollution stress. Edinburgh, 21–23 September 1998*, eds L.J. Sheppard and J.N. Cape. *Water, Air and Soil Pollution* **116**(1–2), 299–310.

[Bullock, D.J. and] Armstrong, H.M. (2000)
Grazing for environmental benefit. In, *Grazing management: the principles and practice of grazing for profit and environmental gain, within temperate grassland systems*, eds A.J. Rook and P.D. Penning, 191–200. *British Grassland Society Occasional Symposium 34*. British Grassland Society, Reading, Berks.

[Cameron, A.D. and] Dunham, R.A. (1999)
Strength properties of wind- and snow-damaged stems of *Picea sitchensis* and *Pinus sylvestris* in comparison with undamaged trees. *Canadian Journal of Forest Research* **29**(5), 595–599.

[Campbell, P.I., Vials, C.] and Matthews, R.W. (2000)
ERGO: an integrated, user-friendly model for computing energy and greenhouse gas budgets of bioenergy systems. In, *IEA Bioenergy Task 25, Greenhouse gas balances of bioenergy systems. Proceedings of the Workshop. Bioenergy for mitigation of CO_2 emissions: the power, transportation, and industrial sectors*, Gatlinburg, Tennessee, USA, 27–30 September 1999, eds K.A. Robertson and B. Schlamadinger, 45–58. IEA Bioenergy Task 25, Graz, Austria.

[Clarke, N.D. and] Nicoll, B.C. (1999)
Influence of nutrient availability on development of tree root architecture. *Journal of Experimental Botany* **50** (Supplement), 46.

[Cole, T.E, Hong, Y.,] Brasier, C.M. [and Buck, K.W.] (2000)
Detection of an RNA-dependent RNA polymerase in mitochondria from a mitovirus-infected isolate of the Dutch elm disease fungus, *Ophiostoma novo-ulmi. Virology* **268**(2), 239–243.

Coutts, M.P., [Nielsen, C.C.N. and] Nicoll, B.C. (1999)
The development of symmetry, rigidity and anchorage in the structural root system of conifers. *Plant and Soil* **217**(1-2), 1–15.

Cundall, E.P. (1999)
Sycamore: choosing a seed source. Reversing the trend of declining quality of hardwoods is the aim of broadleaved tree improvement says Dr Ned Cundall. *Forestry and British Timber* **28**(4), 20–22, 24.

Cundall, E.P. (2000)
Management and conservation of oak *(Quercus petraea, Quercus robur)* and beech *(Fagus sylvatica)* genetic resources in the United Kingdom. In, *Second EUFORGEN meeting on social broadleaves,* compiled by J. Turok, A. Kremer, L. Paule, P. Bonfils and E. Lipman, 82–87. Plant Genetic Resources Institute, Rome, Italy.

[Dagnall, J., Gurnell, J. and] Pepper, H.W. (1998)
Bark-stripping by grey squirrels in state forests of the United Kingdom: a review. In, *Ecology and evolutionary biology of tree squirrels. Proceedings of the International Colloquium on the ecology of tree squirrels, Powdermill Biological Station, Carnegie Museum of Natural History (Pittsburgh, Pennsylvania), 22–28 April 1994,* eds M.A. Steel, J.F. Merritt and D.A. Zegers, 249–261. Virginia Museum of Natural History, Martinsville, Virginia, USA. (Special Publication 6).

[Day, K.R.,] Armour, H.L. and Henry, C.J. (1999)
The performance of the green spruce aphid (*Elatobium abietinum* Walker) on provenances of Sitka spruce (*Picea sitchensis* (Bong.) Carr.). In, *Physiology and genetics of tree-phytophage interactions. International symposium, Gujan, France, 31 August–5 September 1997,* eds F. Lieutier, W.J. Mattson and M.R. Wagner, 199–210. INRA Editions, Versailles, France. (INRA Les Colloques 90).

[Del Re, A.A.M., Brown, C., Capri, E., Errera, G.,] Evans, S.P. [and Trevisan, M.] (eds) (1999)
Human and environmental exposure to xenobiotics. *Proceedings of the XI Symposium Pesticide Chemistry, Cremona, Italy, 11–15 September 1999.* 911pp. La Goliardica Pavese, Pavia, Italy.

Dewar, J. (1999)
Alternative genetic improvement strategies (Letter). *Forestry* **72**(3), 285–286.

[Dixon, F.L., Clay, D.V. and] Willoughby, I. (2000)
Herbicide programmes for the control of creeping thistle *Cirsium arvense* in farm woodland. In, *Vegetation management in changing landscapes. Aspects of Applied Biology* **58,** 47–53. Association of Applied Biologists, Wellesbourne, Warwick.

[Dobson, M.C. and] Moffat, A.J. (1999)
Examination of tree and root performance on closed landfills in Merseyside. *Arboricultural Journal* **23**(3), 261–272.

[Dolwin, J.A.,] Lonsdale, D. [and Barnett, J.] (1999)
Detection of decay in trees. *Arboricultural Journal* **23**(2), 139–149.

Dunham, R., [Miller, D.R. and Broadgate, M.L.] (1999)
A Decision Support Demonstrator for abiotic damage to trees using a WWW interface. In, *Integrating information infrastructures with GIS technology. Innovations in GIS 6,* ed. B. Gittings, 79–91. Taylor and Francis, London.

[Et-Touil, A.,] Brasier, C.M. [and Bernier, L.] (1999)
Localization of a pathogenicity gene in *Ophiostoma novo-ulmi* and evidence that it may be introgressed from *O. ulmi. Molecular Plant-Microbe Interactions* **12**(1), 6–15.

Evans, H.F. (1999)
Factors in the success and failure of microbial insecticides in forestry. *Integrated Pest Management Reviews* **4,** 295–299.

Evans, H.F. (1999)
Asian longhorn beetle threatens Britain's trees. *Tree Warden News* Issue 19, Autumn 1999, 2–3.

Evans, S.P., [Mayr, T.R., Hollis, J.M. and Brown, C.D.] (1999)
SWBCM: A soil water balance capacity model for environmental applications in the UK. *Ecological Modelling* **121**(1), 17–49.

Ferris, R. and Humphrey, J.W. (1999)
A review of potential biodiversity indicators for application in British forests. *Forestry* **72**(4), 313–328.

[Gartland, K.M.A., Gartland, J.S., Fenning, T.M., McHugh, A.T., Irvine, R.J. Main, G.D. and] Brasier, C.M. (2000)
Genetic manipulations with elms. In, *The elms: breeding, conservation, and disease management,* ed. C.P. Dunn, 259–269. Kluwer Academic Publishers, Boston, Massachusetts.

[Gelernter, W.D. and] Evans, H.F. (Guest Editors) (1999)
Factors in the success and failure of microbial insecticides. *Integrated Pest Management Reviews Special Edition* **4,** 279–316.

Gibbs, J.N. (2000)
Foreword to *'The elms: breeding, conservation, and disease management',* ed. C.P. Dunn, xii–xiv. Kluwer Academic Publishers, Boston, Massachusetts.

[Good, J.E.G., Thomas, T.H., Clough D. and] Humphrey, J.W. (1999)
The potential for expansion of upland woodlands and the environmental and agri-economic constraints: a Welsh case study. *Scottish Forestry* **53**(1), 47–52.

Gosling, P.C. (1999)
Why isn't tree seed 'ready to sow'? *Forestry and British Timber* **28**(12), 30, 32–33.

Gosling, P.C. (1998)
ISTA Forest tree and shrub committee. *Prophyta* April 1998, 11.

Gosling, P.G., Parratt, M. and Peace, A.J. (1999)
Identifying the optimum pretreatment duration and germination temperature for *Abies nordmanniana* ([Steven] Spach) seed, and assessing the effect of moisture content and storage temperature on longevity. *Seed Science and Technology* **27,** 951–961.

Gosling, P.G., Samuel, Y.K. [and Jones, S.K.] (1999)
Short-term storage of untreated and pretreated seeds of *Leucaena leucocephala. Canadian Tree Improvement Association Tree Seed News Bulletin* **30,** 15–18.

Gregory, S.C. and Heritage, S.G. (1999)
Transplant dipping out. *Forestry and British Timber* **28**(12), 33.

Harmer, R. (1999)
Survival and new shoot production by artificially browsed seedlings of ash, beech, oak and sycamore grown under different levels of shade. *Forest Ecology and Management* **116**(1), 39–50.

Harmer, R. (1999)
Establishment of broadleaved woodlands using natural colonisation: current research in the south of England. *Native Woodlands Discussion Group Newsletter* **24**(1), Spring 1999, 41–43.

Harmer, R., Willoughby, I. and Robertson, M. (2000)
Use of herbicides to control weeds and promote the natural regeneration of *Fagus sylvatica.* In, *Vegetation management in changing landscapes. Aspects of Applied Biology* **58,** 9–14. Association of Applied Biologists, Wellesbourne, Warwick.

Hislop, A.M. [and Palmer, H.] (1999)
Assessing woodland shelter on farms. When evaluating the role of trees in meeting the farmer's need for shelter, follow the Bauhaus design maxim: 'Form follows function' writes Max Hislop, Forest Research, Northern Research Station, Roslin and Harriet Palmer, SAC, Craibstone Estate, Aberdeen. *Forestry and British Timber* **28**(5), 19, 21–25.

[Hong, Y., Cole, T.E.,] Brasier, C.M. [and Buck, K.W.] (1998)
Evolutionary relationships among putative RNA-dependent RNA polymerases encoded by a mitochondrial virus-like RNS in the Dutch elm disease fungus. *Ophiostoma novo-ulmi,* by other viruses and virus-like RNAs and by the Arabidopsis mitochondrial genome. *Virology* **246**(1), 158–169.

[Hong, Y., Cole, T.E.,] Brasier, C.M. [and Buck, K.W.] (1998)
Novel structures of two virus-like RNA elements from a diseased isolate of the Dutch elm disease fungus, *Ophiostoma novo-ulmi. Virology* **242**(1), 80–89.

[Hong, Y., Dover, S.L., Cole, T.E.,] Brasier, C.M. and [Buck, K.W.] (1999)
Multiple mitochondrial viruses in an isolate of the Dutch elm disease fungus, *Ophiostoma novo-ulmi. Virology* **258**(1), 118–127.

[Hudson, J.B., Hudson, R.J. and] Saunders, C.J. (1999)
Reliability and harvesting productivity when using excavators as backhoe loaders. In, *Excavators and backhoe loaders as base machines for forest operations, Dublin,* ed. J. Johansson, 91–107. Swedish University of Agricultural Sciences, Uppsala, Sweden. Research Note 1/1999.

Humphrey, J.W. and Nixon, C.J. (1999)
The restoration of upland native oakwoods following removal of conifers: general principles. *Scottish Forestry* **53**(2), 68–76.

Humphrey, J.W. and Nixon, C.J. (1999)
Summary paper. Restoration of upland native oakwoods after removal of conifers: general principles. *Native Woodlands Discussion Group Newsletter* **24**(1), 37–38.

Jinks, R.J. and Kerr, G. (1999)
Establishment and early growth of different plant types of Corsican pine (*Pinus nigra* var. *maritima*) on four sites in Thetford Forest. *Forestry* **72**(4), 294–304.

[Johansson, M., Asiegbu, F.O. and] Pratt, J.E. (1998)
Stump treatment against *Heterobasidion annosum* with urea: possible modes of action. In, *Root and butt rots of forest trees. 9th international conference on root and butt rots, Carcans-Maubuisson (France),* 1–7 September 1997, eds C. Delatour, J.J. Guillaumin, B. Lung-Escarmant and B. Marçais, 409–420. INRA, Paris, France. Institut National de la Recherche Agronomique (INRA) and International Union of Forestry Research Organizations (INRA Les Colloques 89).

Jones, D.H. (1999)
Small scale chip fired woodfuel heating systems. In, *Information Leaflet of the OPET Cymru/Dyfi Eco Valley Partnership,* 2–14. Janet Sanders, Machynlleth, Powys.

Jones, W.M., Saunders, C.J. [and Ramsay, E.B.] (1999)
The health and safety implications of increased mechanisation in forestry. In, *Forestry engineering for tomorrow. Forestry Engineering Group's 1st international conference, Edinburgh University, Edinburgh, 28–30 June 1999.* Machinery technical papers (Paper 2). 11pp. Institution of Agricultural Engineers, Silsoe, Beds.

Kennedy, F. and Moffat, A. (1999)
Tree species selection for restored landfills. Fiona Kennedy and Andy Moffat of the Forest Research Station, summarise recent trials and make recommendations for tree planting on landfill sites. *Waste Planning* **33**, 7–8.

Kennedy, F.M., Moffat, A.J. and Armstrong, A.T. (1999)
The effect of *Frankia* infection on the growth of *Ceanothus thyrsiflorus* in the nursery and after outplanting. *Arboricultural Journal* **23**(2), 113–123.

Kerr, G. (1997)
Epicormics on oak (*Quercus petraea* and *Q. robur*): effects of intensity and timing of pruning. Abstract only. In, *Proceedings: Advances in research in intermediate oak stands, conference, Freiburg, Germany, 27–30 July 1997,* eds H. Spiecker, R. Rogers, Z. Somogyi, 126. Albert-Ludwigs-University of Freiburg, Freiburg, Germany.

Kerr, G. (1999)
European silver fir *(Abies alba)* in Britain: time for a reassessment? *Quarterly Journal of Forestry* **93**(4), 294–298.

Kerr, G. (1999)
Is blackheart a black mark for ash? *Quarterly Journal of Forestry* **93**(2), 110–112.

Kerr, G. (1999)
The use of silvicultural systems to enhance the biological diversity of plantation forests in Britain. *Forestry* **72**(3), 191–205.

Kerr, G. (2000)
European silver fir (*Abies alba* Mill.) in Britain: time for a reassessment? (Shortened version). *Continuous Cover Forestry Group Newsletter,* Issue 16, January 2000, 35–40.

[Kull, O.,] Broadmeadow, M., [Kruijt, B. and Meir, P.] (1999)
Light distribution and foliage structure in an oak canopy. *Trees* **14**(2), 55–64.

[Lambin, S.,] Petty, S.J. [and MacKinnon, J.L.] (2000)
Cyclic dynamics in field vole populations and generalist predation. *Journal of Animal Ecology* **69**(1), 106–118.

Lee, S.J. (1999)
Improving the timber quality of Sitka spruce through selection and breeding. *Forestry* **72**(2), 123–133.

Lee, S.J. (1999)
Predicted genetic gains for Scots pine and Sitka spruce. *Forestry and British Timber* **28**(5), 28–29, 32–34.

Lee, S.J. (2000)
Improved Sitka spruce: the proof is in the planting. *Forestry and British Timber* **29**(2), 17–21.

Lee, S.J., Samuel, C.J.A. and John, A. (1999)
'It was 50 years ago today ...' The Tree Improvement Branch of the FC's Forest Research Agency celebrated 50 years of British tree breeding in September 1998. Just what has been achieved in the intervening period by one of the world's oldest tree breeding organisations? *Forestry and British Timber* **28**(7), 36–37, 40–41.

[Loizou, P.J., Blackburn, G.A. and] Broadmeadow, M.S.J. (1999)
The effects of ozone fumigation on the seasonal variation in spectral reflectance for three species of deciduous oak (*Quercus robur, Quercus petraea* and *Quercus rubra*) at the leaf scale. In, *Proceedings of the 24th annual conference of the Remote Sensing Society: from data to information, Cardiff*, 8–10 September 1999, 151–158.

Lonsdale, D. (1999)
Principles of tree hazard assessment and management. 388 pp. The Stationery Office, London. Department of the Environment, Transport and the Regions and Forestry Commission. (Research for Amenity Trees 7)

MacDonald, E.C. (1999)
Timber quality in Great Britain: key issues and implications for forestry engineering. In, *Forestry engineering for tomorrow. Forestry Engineering Group's 1st international conference, Edinburgh University, Edinburgh, 28–30 June 1999.* Timber technical papers (Paper 2). 9 pp. Institution of Agricultural Engineers, Silsoe, Beds.

McKay, H.M., Jinks, R.L. and McEvoy, C. (1999)
The effect of desiccation and rough-handling on the survival and early growth of ash, beech, birch and oak seedlings. *Annals of Forest Science* **56**(5), 391–402.

[McKillop, I.G., Butt, P., Lill, J.,] Pepper, H.W. [and Wilson, C.J.] (1998)
Long-term cost effectiveness of fences to manage European wild rabbits. *Crop Protection* **17**(5), 393–400.

[Malcolm, D.C. and] Mason, W.L. (1999)
Experimental mixtures of Scots pine and birch: 30 year effects on production, vegetation and soils. In, *Management of mixed-species forest: silviculture and economics*, eds A.F.M. Olsthoorn, H.H. Bartelink, J.J. Gardiner, H. Pretzsch, H.J. Hekhuis and A. Franc, 79–87. DLO Institute for Forestry and Nature Research (IBN-DLO), Wageningen, Netherlands. (IBN Scientific Contributions 15)

[Masawe, P.A.L.,] Cundall, E.P. [and Caligari, P.D.S.] (1998)
Performance in south-eastern Tanzania of local cashew germplasm and selected clones. In, *Proceedings of the international cashew and coconut conference: trees for life - the key to development, Dar es Salaam, Tanzania, 17–21 February 1997*, eds C.P. Topper, P.D.S. Caligari, A.K. Kullaya, S.H. Shomari, L.J. Kasuga, P.A.L. Masawe, A.A. Mpunami, 146–150. BioHybrids International Ltd, Reading, UK.

Mason, W.L. (1999)
Silviculture in a recession. *Timber Grower* No.151, Summer 1999, 26–27.

Mason, W.L., Cairns, P. and Tracy, D.R. (1999)
Kilmun Forest Garden: a review. *Scottish Forestry* **53**(4), 247–258.

Mason, W.L., [Hardie, D., Quelch, P., Ratcliffe, P.R., Ross, I., Stevenson, A.W. and Soutar, R.] (1999)
'Beyond the two solitudes'; the use of native species in plantation forests. *Scottish Forestry* **53**(3), 135–144.

Matthews, R.W. and [Mortimer, N.D.] (2000)
Estimation of carbon dioxide and energy budgets of wood-fired electricity generation systems in Britain. In, *IEA Bioenergy Task 25, Greenhouse gas balances of bioenergy systems. Proceedings of the Workshop. Bioenergy for mitigation of CO_2 emissions: the power, transportation, and industrial sectors,* Gatlinburg, Tennessee, USA, 27–30 September 1999, eds K.A. Robertson and B. Schlamadinger, 59–78. IEA Bioenergy Task 25, Graz, Austria.

Mayle, B.A. and Peace, A.J. (1999)
Recent progress in determining deer population size: factors influencing faecal pellet decay. In, *Advances in deer biology: proceedings of the 4th international deer biology congress, Kaposvar, Hungary, June 1998,* ed. Z. Zomborszky, 57–62.

[Mboyi, W.M. and] Lee, S.J. (1999)
Incidence of autumn frost damage and lammas growth in a 4-year-old clonal trial of Sitka spruce *(Picea sitchensis)* in Britain. *Forestry* **72**(2), 135–146.

[Medlyn, B.E., Badeck, F.W., Pury, D.G.G. de, Barton, C.V.M.,] Broadmeadow, M., [Ceulemans, R., Angelis, P. de, Forstreuter, M., Jach, M.E., Kellomäki, S., Laitat, E., Marek, M., Philippot, S., Rey, A., Strassenmeyer, J., Laitinen, K., Liozon, R., Portier, B., Roberntz, P., Wang, K. and Jarvis, P.G.] (2000)
Effects of elevated CO_2 on photosynthesis in European forest species: a meta-analysis of model parameters. *Plant, Cell and Environment* **22**(12), 1475–1495.

Moffat, A.J. (1999)
Trees, people and profits - into the next millennium: environmental changes. *Quarterly Journal of Forestry* **93**(3), 211–220.

Moffat, A.J. (1999)
Soil formation in soil-forming materials for land reclamation: a pedological viewpoint. *SEESOIL* **14**, 54–63.

Murgatroyd, I.R. (1999)
Shortwood coniferous harvesting techniques on difficult ground and brash mat trafficking trials. In, *Forestry engineering for tomorrow. Forestry Engineering Group's 1st international conference, Edinburgh University, Edinburgh, 28–30 June 1999.* Machinery technical papers (Paper 3). 8 pp. Institution of Agricultural Engineers, Silsoe, Beds.

Nixon, C.J. (1999)
Composition, structure and regeneration of tree species within Scotland's native pinewoods. In, *Management of mixed-species forest: silviculture and economics,* eds A.F.M. Olsthoorn, H.H. Bartelink, J.J. Gardiner, H. Pretzsch, H.J. Hekhuis and A. Franc, 191–198. DLO Institute for Forestry and Nature Research (IBN-DLO), Wageningen, Netherlands. (IBN Scientific Contributions 15)

[O'Neill, M. and] Evans, H.F. (1999)
Cost–effectiveness analysis of options within an Integrated Crop Management regime against great spruce bark beetle, *Dentroctonus micans* (Kug.) (Coleoptera: Scolytidae). *Agricultural and Forest Entomology* **1**, 151–156.

Petty, S.J. (1999)
Diet of the tawny owl *Strix aluco* in relation to the field vole *Microtus agrestis* abundance in a conifer forest in northern England. *Journal of Zoology* **248**(4), 451–465.

[Powell, M.A.,] Webber, J.F. and [Eaton, R.A.] (2000)
Changes in moisture, soluble carbohydrate, and bacterial numbers during water storage of pine. *Forest Products Journal* **50**(3), 74–80.

Pratt, J.E., Brooks, D.J., MacAskill, G.A. [and Rickwood, D.] (2000)
A modified sprayer for use in stump treatment trials to control *Heterobasidion annosum. Forest Pathology* **30**(1), 61–64.

Pratt, J.E. [and Thor, M.] (1999)
Improving mechanised stump treatment against root rot in Europe. In, *Forestry engineering for tomorrow. Forestry Engineering Group's 1st international conference, Edinburgh University, Edinburgh, 28–30 June 1999.* Machinery technical papers (Paper 8). 13 pp. Institution of Agricultural Engineers, Silsoe, Beds.

Pratt, J.E., Gibbs, J.N. and Webber, J.F. (1999)
Registration of *Phlebiopsis gigantea* as a forest biocontrol agent in the UK: recent experience. *Biocontrol Science and Technology* **9**(1), 113–118.

Preskett, D. (2000)
Bio- or cooking oils? *Arboricultural Association Newsletter* Issue 108, March 2000, 21–25.

[Proe, M.F., Craig, J.,] Dutch, J.C. [and Griffiths, J.] (1999)
Use of vector analysis to determine the effects of harvest residues on early growth of second-rotation Sitka spruce. In, *Indicators of sustainable forest management: Papers presented at the IEA Bioenergy Task XII Workshop, Eddleston, Scotland, 20–25 September 1997*, eds M.F. Proe, C.T. Smith and A.T. Lowe, *Forest Ecology and Management* **122**(1–2), 87–105.

Purdy, K.M. and Ferris, R. (1999)
A pilot study to examine the potential linkage between and applications of multiple woodland datasets: a GIS based analysis. A commissioned Research Contract on behalf of JNCC (Contract No. F76-01-256). 45 pp. JNCC, Peterborough. Joint Nature Conservation Commission (JNCC Report 298).

Quine, C.P., Humphrey, J.W. and Ferris, R. (1999)
Should wind disturbance patterns observed in natural forests be mimicked in planted forests in the British uplands? *Forestry* **72**(4), 337–358.

Rose, D.R. (1999)
Decline of the oak. David Rose outlines the latest developments in research into oak decline and dieback. *Tree News,* Autumn 1999, 13.

Rose, D.R. (1999)
Disease Diagnostic and Advisory Service in the U.K. In, *Methodology of Forest Insect and Disease Survey in central Europe: Proceedings of the Second Workshop of the IUFRO Working Party 7.03.10 Sion-Chateauneuf Switzerland, 20–23 April 1999,* eds B. Forster, M. Knizek and W. Grodzki, 168–174. Swiss Federal Institute of Forest, Snow and Landscape Research, Birmensdorf, Switzerland.

Rose, D.R. (1999)
Oak mildew. This is one of the commonest diseases of oak leaves, attacking trees of all ages. *Woodland Heritage* **5,** 26.

[Rounsevell, M.D.A.,] Evans, S.P. [and Bullock, P.] (1999)
Climate change and agricultural soils: impacts and adaptation. *Climate Change* **43**(4), 683–709.

Saunders, C.J. (1999)
Health and safety in mechanised harvesting. In, *Excavators and backhoe loaders as base machines in forest operations, Dublin,* ed. J. Johansson, 123–131. Swedish University of Agricultural Sciences, Uppsala, Sweden. Research Note 5/2000.

[Schoeman, M.W.,] Webber, J.F. [and Dickinson, D.J.] (1999)
The development of ideas in biological control applied to forest products. *International Biodeterioration and Biodegradation* **43**(3), 109–123.

Smith, S.M. (1999)
National woodland survey aims to be finished next year. *Timber Grower* No. 153, Winter 1999, 34.

Smith S.M. (1999)
The National Inventory of Woodland and Trees: Scotland. *Scottish Forestry* **53**(3), 163–168.

Smith, S.M. and Gilbert, J.R. (1999)
Scotland: new forecast of softwood availability. *Forestry and British Timber* **28**(7), 47, 49–52.

[Uzunovic, A.,] Webber, J.F., Peace, A.J. [and Dickinson, D.J.] (1999)
The role of mechanized harvesting in the development of bluestain in pine. *Canadian Journal of Forest Research* **29**(2), 242–251.

Vickers, G.J. (1999)
Small scale equipment for the harvesting of small broadleaved woodland. In, *Forestry engineering for tomorrow. Forestry Engineering Group's 1st international conference, Edinburgh University, Edinburgh, 28–30 June 1999.* Machinery technical papers (Paper 14). 10 pp. Institution of Agricultural Engineers, Silsoe, Beds.

Vickers, G.J. (1999)
All terrain cycles. In, *Forestry and Forest Products International 1999,* p.37. Sterling Publications in association with LIGNA, Hanover, Germany.

[Wang, H., Malcolm, D.C. and] Fletcher, A.M. (1999)
Pinus caribaea in China: introduction, genetic resources and future prospects. *Forest Ecology and Management* **117**(1–3), 1–15.

Webber, J.F. (2000)
Insect vector behaviour and the evolution of Dutch elm disease. In, *The elms: breeding, conservation, and disease management*, ed. C.P. Dunn, 47–60. Kluwer Academic Publishers, Boston, Massachusetts.

Webber, J.F., [Jacobs, K. and Wingfield, M.J.] (1999)
A re-examination of the vascular wilt pathogen of takamaka *(Calophyllum inophyllum). Mycological Research* **103**(12), 1588–1592.

[Welch, R.C. and] Jukes, M.R. (1999)
Clitostethus arcuatus (Rossi) (Col.: Coccinellidae) from malaise traps in Northamptonshire, Norfolk and Hampshire. *Entomologist's Record and Journal of Variation* **111**(3), 133–134.

[White, J. and] Gibbs, J.N. (1999)
The value of alders to Britain. *Quarterly Journal of Forestry* **93**(4), 23–28.

Willoughby, I. (1999)
Control of coppice regrowth in roadside woodlands. *Forestry* **72**(4), 305–312.

Willoughby, I. (1999)
Further alternatives to the use of herbicides in British forestry. In, *Proceedings of the third international conference on forest vegetation management, Sault Ste Marie, Ontario, Canada, 24–28 August 1998. Canadian Journal of Forest Research* **29**(7), 866–874.

Willoughby, I. [and Claridge, J.] (2000)
Trees and weeds: an update on herbicides. *Forestry and British Timber* **29**(2), 30–31.

Willoughby, I. [and McDonald, H.G.] (1999)
Vegetation management in farm forestry: a comparison of alternative methods of inter-row management. *Forestry* **72**(2), 109–121.

Wyatt, G. (1999)
Supply of wood fuel from small-scale woodlands for small-scale heating. 99 pp. ETSU/Forestry Commission Technical Development Branch, Harwell, Oxon/Machynlleth, Powys.

Appendix 3

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. The use of Pest Risk Analysis techniques to determine contingency options for potential pests.

Restocking pests
Stuart Heritage and Roger Moore
Research into effective use of chemicals for direct control of restocking pests, notably *Hylobius abietis*, and develop Integrated Pest Management (IPM) strategies for plant protection within the IFM framework. IPM relies on effective monitoring linked to knowledge of population dynamics of *H. abietis*, and the use of insect parasitic nematodes for direct control of larval stages in stumps. The aim is to develop decision support systems for forest managers to avoid or reduce reliance on chemicals.

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
Develop the concepts and science of Integrated Forest Management (IFM) to underpin sustainable forestry with particular emphasis on reductions in chemical pesticides.

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 an Integrated Pest Management (IPM) 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 and site studies
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 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.

The 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.

***Note:** Further details can be found in the 'Catalogue of Forestry Commission Research' on the Commission's website at www.forestry.gov.uk/research/research.html

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
Andy Moffat and Peter Crow
Evaluate the impact of tree growth and forest operations on features of archaeological interest. Examine how forest practices can be manipulated to minimise the risk to archaeological 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
Derek Redfern, David Rose and David Lonsdale
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
Derek Redfern and John Gibbs
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.

Non-chemical protection
Joan Webber
Investigate various approaches to biological control of tree diseases, with special emphasis on root rot pathogens, stain and decay organisms, and Dutch elm disease.

Fomes root and butt rot of conifers
Derek Redfern and Jim Pratt
Conduct research on Fomes root and butt rot of conifers and investigate approaches to management and control.

Phytophthora diseases of trees
Clive Brasier, John Gibbs 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
Helen McKay
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
Helen McKay, Steve Smith 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, Franka Brüchert 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.

Conifer natural regeneration and silvicultural systems
Bill Mason, Colin Edwards and Sophie Hale
Investigate natural regeneration processes in major conifer species to predict and manipulate the timing and density of natural seedling establishment. Evaluate canopy structure manipulation to promote regeneration as an alternative silvicultural system to patch clearfelling.

Stability of stands
Barry Gardiner, Roger Dunham, 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.

Social forestry
Max Hislop
Research into the social values of forestry and the development of methodologies for the integration of these values into forest planning.

Silviculture and Seed Research Branch

Social forestry
Gary Kerr
Silviculture as applied to areas with high levels of access; urban and community forests, the National Forest, arboreta.

Poplars
Paul Tabbush
Evaluate poplar clones with potential for timber production.

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
Alan Armstrong
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.

Silviculture systems
Gary Kerr
Examine the potential for diversifying the range of silvicultural systems used in lowland woodlands.

Seed biology
Peter Gosling
Improve the quality and performance of tree seeds to develop more reliable and economic methods of plant production, establishment and regeneration.

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 and planting
Steve Morgan 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
Greg Vickers and David Jones
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
Gordon Wyatt
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
Dave Preskett
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. 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.

Biochemical and molecular study of genetic variation
Ian Forrest and Joan Cottrell
Study of genetic variation in natural and breeding populations. Characterisation of populations, families and clones.

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

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

Woodland Ecology Branch

Assessing biodiversity in managed forests
Richard Ferris
Determine the biodiversity status of plantation forests, develop practical assessment methodologies and identify potential biodiversity indicators.

Forest habitat management
Jonathan Humphrey and Russell Anderson
Understand natural ecosystem processes, and how they are modified by management, to promote characteristics of forest structure and composition that confer ecological and conservation benefits as well as meeting other management objectives.

Landscape ecology and forest design

Richard Ferris and Chris Quine

Provide recommendations on the landscape scale design of forests for the conservation and enhancement of biodiversity.

Ecological site classification and decision support systems

Duncan Ray

Devise and promote an ecologically based site classification as a tool for sustainable forestry in Britain.

Squirrel management

Brenda Mayle

Develop cost-effective means of managing the impact of grey squirrels on timber production. Work to secure the future of the red squirrel as a component of the British woodland fauna.

Deer population ecology and management

Brenda Mayle and Robin Gill

Provide a sustainable basis for deer management in UK woodlands by investigating and developing new techniques and technologies to provide information on deer population dynamics, behaviour and impacts.

Tree protection

Harry Pepper

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.

Appendix 4

Research Contracts Awarded by Forest Research

Abertay University
Genetic engineering of English elm.

Avon Vegetation Research
Forestry herbicide evaluation.

J. Bryce
Habitat use by squirrels, Dunkeld.

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

Fountain Forestry
Water monitoring, Halladale.

S. Davey
Lichen survey in semi-natural and plantation oak woodland.

Imperial College, London
Biocontrol of sap-staining fungi.

Control of decay in utility poles.

Development of a biological control agent for Dutch elm disease.

King's College London
Detection and monitoring of the effects of ozone pollution on deciduous forest physiology: remote sensing as a predictive tool.

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 Birmingham
Woody debris in forest aquatic habitats.

University College London
Effects of forestry on surface water acidification.

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

University of Leeds
Atmospheric boundary layer over forests.

Chemical transport in forests.

University of Newcastle
Squirrel population modelling.

University of Oxford
Flow structures over forests of irregular height.

University of Southampton
Remote sensing of forest canopy gaps.

Water and fine sediment transport in rivers with wooded floodplains.

University of Sussex
Biochemical mechanisms for plants to act as sinks for atmospheric pollutants.

Biodiversity of pine forests.

Drought tolerance in poplars.

University of Ulster
Feeding ecology of the large pine weevil.

Impact of defoliating insects on forests.

University of Wales
Endophytic establishment of wood-degrading fungi.

Appendix 5

Contract Work Undertaken by Forest Research for External Customers

(some projects may also be part-funded by FC customers)

British Biogen
Gauging the effect of twig breakers and grading plates on chip quality.

Testing the main variables that affect chip quality.

Woodfuel chipping.

Christie Elite Nurseries
Grafting of basic material for an improved Sitka spruce seed orchard.

Deer Commission for Scotland
Assessment of deer damage.

Department for International Development
Virus control of teak defoliator in India.

Department of the Environment, Transport and the Regions
Health monitoring in non-woodland trees.

Potential for woodland establishment on landfill sites.

Research and demonstration in the National Forest.

Department of the Environment, Transport and the Regions/Aspinwall & Company
Effectiveness of provisions for the aftercare of mineral workings.

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 the Environment, Transport and the Regions/Wye College
The use of soil-forming materials in the reclamation of older mineral workings and other reclamation schemes.

Department of Trade and Industry
Carbon budget factsheet.

Evaluation of equipment and methods relating to wood fuel supply.

Wood fuel supply for small scale heating from small woodlands.

Yield models for energy coppice of poplar and willow.

English Nature
Development of a self-extracting trailer.

Reversal of woodland fragmentation.

Environment Agency
Best practice guidance for forest operations.

Phytophthora disease of alder.

European Union
Alternatives to methyl bromide for quarantine treatment.

Control of decay.

Effects of forestry on extreme river flows.

Forest condition surveys.

Larch wood chain.

Intensive monitoring of forest ecosystems.

Native black poplar genetic resources in Europe.

Oak resources in Europe.

Phytophthora in European oak decline.

Plant vitality and dormancy.

Silviculture and biodiversity of Scots pine forests in Europe.

Tree seed dormancy.

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

EU/AFOCEL
Douglas fir resources in Europe.

EU/Highland Birchwoods
Conservation of native oakwoods.

EU/INRA, Nancy
Young oak high forest.

EU/Potsdam Institute for Climate, Germany
Quantifying forest ecosystem dynamics in northern Europe.

EU/Scottish Natural Heritage
Restoration of wet woods.

EU/SSFRC, Sweden
Natural regeneration of oak.

EU/Swedish University of Agricultural Sciences
The use of excavators and backhoe loaders in forestry.

EU/University of Edinburgh
The likely impact of rising CO_2 and temperature on European forests.

EU/University of Kent
Restoration of environmental diversity by effective ecosymbiont monitoring.

EU/University of Ulster
Improving protection and resistance of forests to the spruce aphid.

EU/University of Wales, Bangor
Poplar for farmers.

FAO
Research design in afforestation, forestry research, planning and development in the three northern regions of the Republic of China.

Friends of the Ochils
Native woodland potential for the Ochils.

Greater Exmoor Woodland Initiative
Harvesting operations in small woodlands workshop.

Griffin (Europe) SA
Root control in container seedlings.

Health and Safety Executive
Evaluation of and recommendations for take-down procedures and equipment for hung-up trees.

Highways Agency
Stump treatments with herbicides.

Isle of Man
Assessment of DNA variation in oak.

Joint Nature Conservation Committee
GIS mapping of constraints.

Red squirrel conservation.

Kemira Fertilisers
Slow release fertilisers for cell-grown seedlings.

Leverhulme Trust/University of Ulster
Novel methods for quantifying the impact of defoliating insects in forests.

Macaulay Land Use Research Institute
Bog management.

Macfarlane Smith
Vertebrate repellents.

Marches Woodland Initiative
Development of a solar kiln.

Evaluation of small-scale forwarders.

Ministry of Agriculture, Fisheries & Food
Provenance testing of broadleaved species in farm forestry.

Development of a site-specific yield model for ash in lowland England and Wales.

Vertebrate repellents (with CSL, ADAS).

Yield models for energy coppice of poplar and willow.

A. Y. Morton
Evaluation of the Galmore tree planter.

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

Niko Chemical Co Ltd
Animal repellent studies.

Scottish Forestry Trust/Joint Nature Conservation Committee and others
Development of an immuno-contraceptive vaccine for the grey squirrel.

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

Scottish Natural Heritage
Bog restoration.

Seed vitality in the Mar Lodge pinewoods.

Scottish Office/Scottish Crops Research Institute
Genetic variability in native pinewoods.

University of Viterbo, Italy
Modelling long-term growth of beech.

Appendix 6

Forest Research Staff as at 31 March 2000

Chief Executive

J. Dewar, B.Sc., M.I.C.For.

Personal Secretary

Mrs M.W. Holmes

Chief Research Officer

P.H. Freer-Smith, B.Sc., Ph.D.

Personal Secretary

Mrs C.A. Holmes

Branches based at Alice Holt

Administration Branch

K.N. Charles, F.M.S., *Personnel and Administration Officer, Head of Branch*

Central Services Section

Mrs S.J. Hutchings*, *Head of Section*
D.M. Payne
Mrs A. Smith*
M.L. Young

Personnel Section

M.G. Wheeler, *Head of Section*
Mrs M. Craven*
Mrs P.C. Fawcett
Mrs W.B. Groves
Miss J.R. Lacey

Typing Section

Mrs M.C. Peacock*, *Head of Section*
Mrs J.M. Bell*
Mrs S.C. Stiles*

Finance Branch

A.J. Cornwell, F.C.M.A., *Head of Branch*
Miss L.J. Caless
Mrs J. Cook
P.A. Filewood
Mrs J.M. Turner

Communications Branch

E.J. Parker, Ph.D., C.Biol., M.I.Biol., *Head of Branch*

Library and Information Section

Miss C.A. Oldham, B.A., M.A., Dip.Lib., A.L.A., *Head of Section and Librarian*
Mrs E.M. Harland, M.A., Dip.Lib., *Assistant Librarian*
Mrs K.A. Hutchison, M.A. *(at Northern Research Station)*
Mrs T.D. Smalley

Photography Section

G.L. Gate, *Head of Section*
G.R. Brearley *(at Northern Research Station)*
Miss M. Trusler *(also with Central Services Section)*
J. Williams

Entomology Branch (with section at Northern Research Station)

H.F. Evans, B.Sc., D.Phil., F.R.E.S., *Head of Branch*
Mrs G. Green, B.Sc.*
M.R. Jukes, C.Biol., M.I.Biol.
Miss J.T. Staley, B.Sc., M.Sc.
Mrs S.A. Stephens*
N. A. Straw, B.Sc., Ph.D., F.R.E.S.
Mrs C.A. Tilbury, B.Sc.
D. Wainhouse, M.Sc., Ph.D., F.R.E.S.

Environmental Research Branch

A.J. Moffat, B.Sc., Ph.D., *Head of Branch*
Miss L.C. Adams, B.Sc.
Mrs S.E. Benham, B.Sc.
F.J.M. Bochereau, B.Sc., M.Sc.
Mrs S.B. Broadmeadow, B.Sc., M.Sc.
M.S.J. Broadmeadow, B.Sc., Ph.D.
Mrs S.R. Cowdry*
P.G. Crow, B.Sc.
D.W.H. Durrant, B.A.
Miss J.N. Edgerton, B.Sc.
T.R. Hutchings, M.Sc.
Miss F.M. Kennedy, B.Sc., Ph.D.
T.R. Nisbet, B.Sc., Ph.D.
Mrs R.M. Pitman, B.Sc., Ph.D.
E. Ward, B.Sc., M.Sc., C.Chem., M.R.S.C.
Mrs C.E. Whitfield*
Miss C.A. Woods *(also with Woodland Ecology Branch)*

Mensuration Branch

Mrs J.M. Methley, B.Sc., *Head of Branch*
T.D. Cooper
I.R. Craig
Professor S.P. Evans, B.A., M.A., Ph.D.
R.W. Matthews, B.Sc., M.Sc.
J.C. Proudfoot
Mrs M. Sennett*
J.M. Taylor, B.Sc.

Pathology Branch (with section at Northern Research Station)

J.N. Gibbs, M.A., Ph.D., Sc.D., OBE, *Head of Branch*
Professor C.M. Brasier, B.Sc., Ph.D., D.Sc.
A. Jeeves
Mrs S.A. Kirk
Mrs C.A. Lishman*
D. Lonsdale, B.Sc., Ph.D.
D.R. Rose, B.A.
Mrs J. Rose
Miss K.V. Thorpe, B.A., M.Sc., D. Phil.
Ms J.F. Webber, B.Sc., Ph.D.

Silviculture and Seed Research Branch

P.M. Tabbush, B.Sc., M.I.C.For., *Head of Branch*
A. Armstrong, M.I.C.For.
Mrs C.A. Baker, B.Sc.
P.G. Gosling, B.Sc., Ph.D.
R. Harmer, B.Sc., Ph.D.
P.A. Henshall, B.Sc.
R.L. Jinks, B.Sc., Ph.D.
G. Kerr, B.Sc., M.I.C.For.

*denotes part-time staff

M.J.R. Parratt
I. Tubby, B.Sc.
M. Robertson, B.Sc.
I. Willoughby, B.Sc., M.B.A., M.I.C.For.
Mrs A. Yeomans

Statistics and Computing Branch (with section at Northern Research Station)

Miss B.J. Smyth, B.Sc., *Head of Branch*
R.C. Boswell, B.Sc., M.I.S.
Mrs C.A.V. Foden*
Miss L.M. Halsall, B.Sc.
Miss T.J. Houston, B.Sc., M.I.S.
D. Jeffries, B.Sc.
Mrs P.E. Newell*
A.J. Peace, B.Sc.
Mrs L.P. Pearce*
T. Porter, B.Sc.

Woodland Ecology Section (of branch at Northern Research Station)

R. Ferris, B.Sc., Ph.D., *Head of Section*
A.J. Brunt
M. Ferryman
R.M.A. Gill, B.Sc., Ph.D.
Mrs B.A. Mayle, M.Sc.
Miss K.M. Purdy, B.Sc., M.Sc.
Miss C.A. Woods *(also with Environmental Research Branch)*

Branches based at Northern Research Station

Administration

M. Abrahams
G.T. Cockerell
Miss E. Hall
Mrs E.E. Ker
Mrs S.F. Lamb*
Mrs L.G. Legge*
Mrs G.E. Mackintosh*
Mrs R.G.L. Shields*

Entomology Section (of branch at Alice Holt)

S.G. Heritage, M.B.A., C.Biol., M.I.Biol., *Head of Section*
R. Moore, B.Sc., Ph.D.
Miss V.E. Wykes, B.Sc.

Pathology Section (of branch at Alice Holt)

D.B. Redfern, B.Sc., Ph.D., M.I.C.For., *Head of Section*
S.J. Hendry, B.Sc., Ph.D.
Miss G.A. MacAskill
J.E. Pratt
Mrs H. Steele*, B.Sc.

Silviculture North Branch

W.L. Mason, B.A., B.Sc., M.I.C.For., *Head of Branch*
Ms F. Brüchert, B.Sc., Ph.D.
R.A. Dunham, B.Sc., Ph.D.
C. Edwards
B.A. Gardiner, B.Sc., Ph.D., F.R.Met.S.
Ms S.E. Hale, B.Sc., Ph.D.
A.M. Hislop, M.I.C.For.
C. McEvoy, B.A.
Ms H.M. McKay, B.Sc., Ph.D.
S.J. Mochan
B.C. Nicoll, B.Sc.
S.A. Smith, B.Sc., M.I.C.For
J.C. Suárez-Minguez, B.Sc., M.Sc.
R.N. Thompson

Statistics and Computing Section (of branch at Alice Holt)

R. W. Blackburn, B.Sc., *Head of Section*
Mrs L. Connolly*
T. Connolly, B.Sc., Ph.D.
A. Gaw, B.Sc.
A.D. Milner, B.Sc., Ph.D.
Mrs L. Rooney*

Tree Improvement Branch

C.J.A. Samuel, B.Sc., Ph.D., *Head of Branch*
Miss C.M.M. Baldwin
Ms J.E. Cottrell, B.Sc., Ph.D.
E.P. Cundall, B.Sc., Ph.D.
G.I. Forrest, B.Sc., Ph.D.
A. John, B.Sc., Ph.D.
S.J. Lee, B.Sc., Ph.D., M.I.C.For
Mrs M.A. O'Donnell*
R.J. Sykes
Miss H.E. Tabbener, B.Sc.

Woodland Ecology Branch (with section at Alice Holt)

C.P. Quine, M.A., M.Sc., M.I.C.For., *Head of Branch*
A.R. Anderson
Ms H.M. Armstrong, B.Sc., Ph.D.
Miss A.C. Broome, B.Sc.
J.D. Clare, B.Sc., MSc.
J.W. Humphrey, B.Sc., Ph.D.
Mrs M. Plews *(also with Technical Support Unit North)*
D. Ray, B.Sc.

Branch based at Ae Village

Technical Development Branch

W.M. Jones, *Head of Branch*
Mrs Y. Butler
W.J. Jones
S.R. Morgan
J.D. Neil
Mrs N. Nicholson*
Mrs B.J. Rammell*
C.J. Saunders
Mrs A. Wallace*

Midlands

M.A. Lipscombe
D. Preskett, B.Sc.
G.J. Vickers
G. Wyatt

Wales

Mrs V. Edwards*
D.H. Jones, Eng.Tech., A.M.I.Agr.E.

Branch based at Edinburgh HQ

Woodland Surveys Branch

S. Smith, B.Sc., B.A., M.B.A., *Head of Branch*
R.H. Beck
G.D. Bull
Mrs C. Brown
J.R. Gilbert, B.Sc.
Miss S. Macintosh
Mrs E.S. Whitton

Field Station Staff

Technical Support Unit (North)

Ms K.A. Fielding, *Head of Branch*

Bush

A.J. Harrison, B.Sc., *Head of Station*
D.R. Anderson
J.H. Armstrong
D.C. Clark
G.M. Crozier
C.D. Gordon
J.T. Howell
M. Hunter
N.R. Innes
P.J. Love
G.W. Mackie
G. Mercer
S.P. Osborne, B.Sc.
A. Purves
S. Sloan

Cairnbaan

D.R. Tracy, B.Sc., *Head of Station*
Mrs J.M. McDonald*
R.L. Preston
Mrs P.M. Simson, B.Sc.
Mrs E.M. Wilson, B.Sc.

Kielder

P.W. Gough, *Head of Station*
T.C.O. Gray
M. Ryan
L. Thornton
I. J. Yoxall

Mabie

D.M. Watterson, *Head of Station*
L.R. Carson
J.M. Duff
Miss H. Russell
Miss J. Sneddon*
H. Watson
J. White

Newton, Lairg and Inverness

A.W. MacLeod, *Head of Station*

Newton

Miss G. Bowen
Miss L.A. Bradbury, B.Sc.
Miss A.R. Cowie
Mrs J. Gittins
H. MacKay
F. McBirnie
S.T. Murphy, B.Sc., M.Sc.
C. Smart

Inverness

P.J. Walling

Lairg

A.J. Bowran
C.M. Murray
D. Williams

Engineering Services

D.J. Brooks
J.A. Nicholl
J.E. Strachan

Perth

A. Herd, *Head of Station*
N.C. Evans
W.F. Rayner

Technical Support Unit (South)

N.C. Day, *Head of Branch*

Alice Holt

N.J. Tucker, *Head of Station*
M.J.S. Awdry
R.I. Bellis
Mrs S.N. Bellis
J.L. Budd
A. Bright
S.M. Coventry
I.L. Green
Miss L.M. Haydon
A. Martin
R.A. Nickerson
J.E. Page
W. Page
R.M. Panton
R. Brooker

Alice Holt Workshop

J. Davey
M.F. Johnston

Exeter

D.G. Rogers, *Head of Station*
S.A. Minton
D.J. Parker
A.M. Reeves
P. Wooton

Fineshade

D.A. West, *Head of Station*

J. Laing, B.Sc., M.I.C.For.

J. Lakey

Mrs E.M. Richardson

P. Turner

D.S. Watts

Shobdon

N.J. Fielding, *Head of Station*

B.J. Hanwell, B.Sc.

Mrs S.A. Hardiman

D.M. Jones

J.P. Jones

Miss E. Maddocks

J.J. Price

Talybont

C.D. Jones, B.Sc., *Head of Station*

Mrs L. Ackroyd*

M.J. Chappell

D. M. Evans

A. Hoppit

B. Jones

Ms R.J. Keeble

R.J. Keddle

T.A. Price

Ms R. Sparks

D.J. Thomas

G.K. Williams

Wykeham

D. Kerr, *Head of Station*

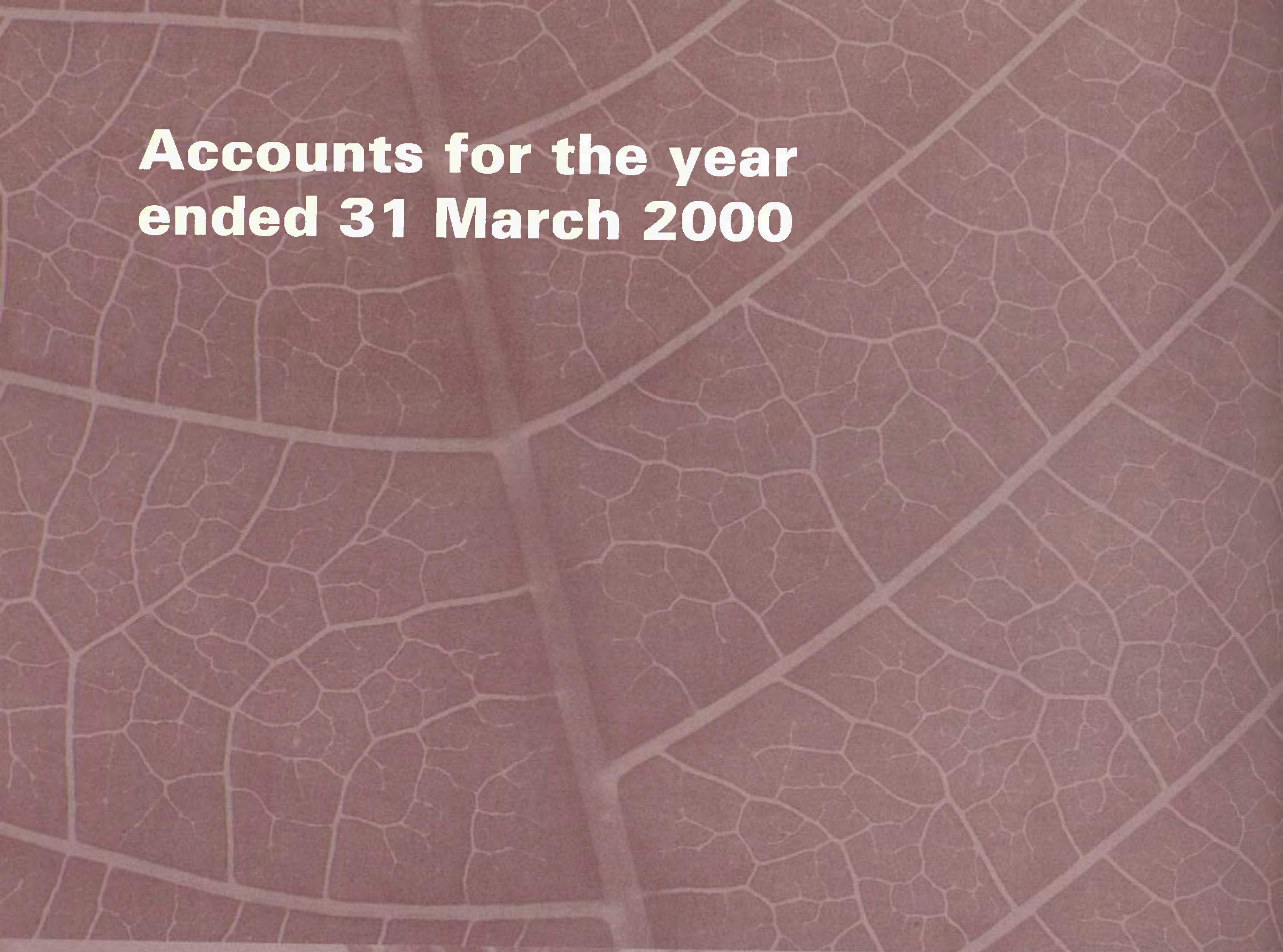
I.F. Blair

L.S. Cooper

A.J. Hill

Mrs P.A. Jackson*

Accounts for the year ended 31 March 2000



Contents

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 forest research programmes as well as technical development, scientific services and survey work.

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.

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 Grant-in-Aid drawn down from Class X Vote 3 .

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 3 of the Report.

3. Review of Activities

This is Forest Research's third year of operation as an agency. Forest Research produced a net operating surplus of £646,000 on its Income and Expenditure Account, excluding the notional cost of capital. A comparison of income and expenditure with the previous year shows that:

- staff costs increased by £362,000 (5%);
- other management costs increased by £240,000 (14%);
- materials and service costs were reduced by £10,000;
- income from external customers increased by £122,000 (9%);

The net surplus for the year after cost of capital of £521,000 was £126,000.

After adjusting the total surplus for items not involving the movement of cash and for capital expenditure and income, the net cash surplus paid to the Forestry Commission was £1,120,000.

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. Supplier Payment Policy

Forest Research observes the principles of the CBI prompt Payers Code. 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. A sample analysis for 1999–2000 indicates that 97.9% of invoices were paid within the due date. Arrangements for handling complaints on payment performance are notified to suppliers on orders.

6. 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.

7. Year 2000

The agency reviewed all its IT systems to ensure that each was capable of operating after 1 January 2000 and has experienced no significant problems.

8. Pension Liabilities

Forest Research staff are part of the Forestry Commission 'by analogy scheme' which is a reserved GB matter. A separate pension scheme statement has been produced.

9. Management

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

Nick Brown	*Secretary of State*
Elliot Morley	*Parliamentary Under-Secretary*

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

Jim Dewar	*Chief Executive*
Peter Freer-Smith	*Chief Research Officer*
Ken Charles	*Personnel and Administration Officer*
Tony Cornwell	*Head of Finance*

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

10. 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.

J. Dewar
Chief Executive and Agency Accounting Officer
29 November 2000

Statement of Forestry Commission's and Chief Executive's Responsibilities

Under Section 5 of the Exchequer and Audit Departments Act 1921 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 the System of Internal Financial Control

As Accounting Officer, I acknowledge my responsibility for ensuring that an effective system of internal financial control is maintained and operated by Forest Research.

The system can provide only reasonable and not absolute assurance that assets are safeguarded, transactions authorised and properly recorded, and that material errors or irregularities are either prevented or would be detected within a timely period.

The system of internal financial control is based on a framework of regular management information, administrative procedures including the segregation of duties, and a system of delegation and accountability. In particular, it includes:

- Comprehensive budgeting systems with an annual budget which is reviewed and agreed by the Management Board of Forest Research;
- Regular reviews by the Management Board of periodic and annual financial reports which indicate financial performance against the forecasts;
- Setting targets to measure financial and other performance;
- Clearly defined capital investment control guidelines;
- As appropriate, formal project management disciplines;
- A programme of accounting inspections.

The Forestry Commission has an internal audit unit, which operates to standards defined in the Government Internal Audit Manual. The work of the internal audit unit is informed by an analysis of the risk to which the body is exposed, and annual internal audit plans are based on this analysis. The analysis of risk and the internal audit plans are endorsed by the Forest Research Audit Committee and approved by me. At least annually, the Head of Internal Audit (HIA) provides me with a report on internal audit activity in Forest Research. The report includes the HIA's independent opinion on the adequacy and effectiveness of the body's system of internal financial control.

My review of the effectiveness of the system of internal financial control is informed by the work of the internal auditors, the Audit Committee which oversees the work of the internal auditor, the executive managers within the body who have responsibility for the development and maintenance of the financial control framework, and comments made by the external auditors in their management letter and other reports.

Implementation of the Turnbull Report

In September 1999, the Institute of Chartered Accountants of England and Wales published the Report of the Turnbull Committee: *Internal control: guidance for directors on the Combined Code.* The effect of the Turnbull Report was to extend the existing requirement to provide a statement in respect of financial controls to cover all controls including financial, operational, compliance and management of risk.

As Accounting Officer, I am aware of the recommendations of the Turnbull Committee and am taking reasonable steps to comply with the Treasury's requirement for a statement of internal control to be prepared for the year ended 31 March 2002.

J. Dewar
Chief Executive and Agency Accounting Officer
29 November 2000

The Certificate and Report of the Comptroller and Auditor General to the House of Commons

I certify that I have audited the financial statements on pages 79 to 81 under the Exchequer and Audit Departments Act 1921. 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 page 82.

Respective Responsibilities of the Commission, Accounting Officer and Auditor

As described above, the Commission and Accounting Officer are responsible for the preparation of the financial statements and for ensuring the regularity of financial transactions. The Commission and Accounting Officer 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 Exchequer and Audit Departments Act 1921 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 76 reflects Forest Research's compliance with Treasury's guidance 'Corporate governance: statement on the system of internal financial 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 Opinion

I conducted my audit in accordance with 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 Commission and Accounting Officer in the preparation of the financial statements, and of whether the accounting policies are appropriate to Forest Research'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 2000 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 Exchequer and Audit Departments Act 1921 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
26 January 2001
Comptroller and Auditor General
National Audit Office
22 Melville Street
Edinburgh EH3 7NS

Income and Expenditure Account

for the year ended 31 March 2000

		2000	1999
Income	Notes	**£000**	£000
Income from research, development and survey services			
Forestry Commission customers	2	**11,253**	11,015
Non-Forestry Commission customers		**1,469**	1,347
Total income		**12,722**	12,362
Expenditure			
Staff costs	3	**7,219**	6,857
Other management costs	4	**1,915**	1,675
Materials and services	5	**2,942**	2,952
Total expenditure		**12,076**	11,484
Net operating surplus/(deficit)		**646**	878
Notional cost of capital	7	**(520)**	(496)
Net surplus/(deficit) for the year		**126**	382
Transferred to General Fund		**126**	382

Statement of Total Recognised Gains and Losses

for the year ended 31 March 2000

	2000	1999
	£000	£000
Net surplus/(deficit) for the year	**126**	382
Revaluation surplus for the year	**148**	1,959
Total recognised gains/(losses)	**274**	2,341

There have been no discontinued operations during the year.

The notes on pages 82 to 87 form part of these accounts.

Balance Sheet

for the year ended 31 March 2000

	Notes	**31 March 2000 £000**	31 March 1999 £000
Fixed assets			
Tangible fixed assets	6	**8,161**	8,175
Current assets			
Stocks and Work in progress	8	**110**	56
Debtors	9	**489**	850
Cash at banks and in hand		**1**	
		600	907
Current liabilities			
Creditors - amounts falling due within one year	10	**252**	248
Net current assets		**348**	659
Total assets less current liabilities		**8,509**	8,834
Taxpayers Equity			
General Fund	11	**5,920**	6,393
Revaluation Reserve	12	**2,589**	2,441
Total Taxpayers Equity		**8,509**	8,834

J Dewar
Chief Executive and Agency Accounting Officer
November 2000

The notes on pages 82 to 87 form part of these accounts.

Cash Flow Statement

for the year ended 31 March 2000

	Notes	**2000** £000	1999 £000
Reconciliation of net surplus to net cash flow from operating activities			
Net surplus for the year		**126**	382
Notional cost of capital	7	**520**	496
Depreciation	4 & 6	**421**	344
Surplus(-)/loss on sale of assets		**–**	24
Decrease/(-)Increase in stocks and work in progress		**(54)**	56
Decrease in debtors		**361**	72
Increase/(-)Decrease in creditors		**4**	49
Net cash inflow from operating activities		**1,378**	1,423
Capital expenditure			
Payments to acquire tangible fixed assets		**(258)**	(161)
Total net cash inflow		**1,120**	1,262
Financing			
Cash surplus transferred to Forestry Commission		**1,120**	1,262
Increase in cash		**–**	–
Reconciliation of net cash flow to movement in net funds			
Increase in cash			–
Net funds at 1 April 1999		**1**	1
Net funds at 31 March 2000		**1**	1

The notes on pages 82 to 87 form part of these accounts.

Notes to the Accounts

Note 1. Accounting Policies

1.1 Form of Accounts

In accordance with Section 5(1) of the Exchequer and Audit Departments Act 1921, 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.

1.3 Valuation of Assets

Land and buildings are revalued every three years 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.

Buildings - over 20 to 80 years
Research and office equipment - over 2 to 20 years

1.5 Stocks and Works in progress

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 Corporation Tax

Forest Research is not subject to corporation tax.

1.7 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.

1.8. 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 £10 million as originally assessed. 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 on a full cost recovery basis.

Total income from Forestry Commission customers consisted of:

	2000	1999
	£000	£000
Research development and survey services to:		
Forestry Commission	**10,011**	9,969
Forest Enterprise	**1,242**	1,046
	11,253	11,015

Note 3. Staff Costs and Numbers

3.1 Employee costs during the year amounted to:

	2000	1999
	£000	£000
Wages and Salaries	**5,860**	5,555
Social Security Costs	**427**	410
Employer's Superannuation Costs	**932**	892
	7,219	6,857

The agency's staff are covered by the Forestry Commission Pension Scheme which is a defined benefit pension scheme. Employer's superannuation contributions, calculated as percentages of pensionable pay, are paid to the Forestry Commission Pension Scheme and are included in the Income and Expenditure Account. The rates of employer's contributions were from 15 to 22 per cent according to grade. Actual pension payments are met by the Forestry Commission. The receipts and payments of the pension scheme, its status and how it operates, and the valuation of unfunded past service liabilities, are shown in the accounts of the Forestry Commission published in its Annual Reports and Accounts.

3.2 The total remuneration, excluding pension contributions, of the Chief Executive, the highest paid member of the Management Board, was £58,849 (1998–99: £55,194). The Chief Executive is an ordinary member of the Forestry Commission 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 Forestry Commission Pension Scheme.

	2000	1999
Management Board Members	**Number**	Number
£30,000–£34,999	**2**	2
£40,000–£44,999		1
£45,000–£49,999	**1**	

Pension benefits are provided through the Forestry Commission Pension Scheme, which is run by analogy with 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. 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 during the year was as follows:

	2000	1999
	Number	Number
Permanent Staff	**256**	257
Casual Staff and Staff on Fixed-term Appointments	**34**	33
	290	290

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 13 loans with an outstanding balance of £2,500 or more to individual members of staff at 31 March 2000. The total value of these loans was £104,800.05.

Note 4. Other Management Costs

Other management costs are stated after charging:

	2000	1999
	£000	£000
Exchange Rate Losses on EC Contracts	**8**	28
Auditors' Remuneration	**12**	12
Depreciation of Fixed Assets	**421**	344
Loss on disposal of fixed assets		24
Travel and Subsistence	**401**	397
Staff Transfer Expenses	**90**	77
Training	**102**	83
Building Maintenance	**322**	254
Utilities	**213**	207
Computer Supplies	**175**	117

Note 5. Materials and Services

The cost of materials and services includes service charges from the Forestry Commission and Forest Enterprise amounting to £1,171,078.

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 Headquarters.

Note 6. Fixed Assets

	Land and Buildings	Machinery and Equipment	Total
Valuation:	£000	£000	£000
At 1 April 1999	7,131	3,879	11,010
Additions	26	232	258
Disposals and transfers		6	6
Revaluation adjustment	170	(43)	127
At 31 March 2000	**7,327**	**4,074**	**11,401**
Depreciation:			
At 1 April 1999		2,835	2,835
Provided in year	150	271	421
Disposals and transfers		5	5
Revaluation adjustment		(21)	(21)
At 31 March 2000	**150**	**3,090**	**3,240**
Net book value:			
At 31 March 2000	**7,177**	**984**	**8,161**
At 31 March 1999	7,131	1,044	8,175

Fixed assets were revalued as at 31 March 1999 in accordance with accounting policies. The valuation includes the principal research stations at Alice Holt Lodge near Farnham, Surrey, and the Northern Research Station, Roslin near Edinburgh, with net book values of £5.1 million and £1.9 million respectively at 31 March 2000.

Note 7. Cost of Capital

Notional cost of capital based on 6% of average total assets less current liabilities employed in 1999–2000 amounted to £520,000.

Note 8. Stocks and Work in Progress

	2000	1999
	£000	£000
Stocks	**52**	56
Research Work in Progress	**58**	
	110	56

Note 9. Debtors

	2000	1999
	£000	£000
Trade debtors	**331**	796
Other debtors	**158**	54
	489	850

Note 10. Creditors: amounts falling due within one year

	2000	1999
	£000	£000
Payments received on account	**45**	49
Trade creditors	**169**	151
Other creditors including taxation and social security costs	**38**	48
	252	248

Note 11. General Fund

	2000	1999
	£000	£000
Balance brought forward	**6,393**	7,252
Movement in year		
Net surplus for year	**126**	382
Transfer of fixed assets from/(–) to other Forestry Bodies	**1**	(475)
Cash surplus transferred to Forestry Fund	**(1,120)**	(1,262)
Notional cost of capital	**520**	496
Balance carried forward	**5,920**	6,393

Note 12. Revaluation Reserve

	2000	1999
	£000	£000
Balance brought forward	**2,441**	482
Revaluation surplus for the year ended 31 March 2000		
Land and Buildings	**170**	1,915
Machinery and Equipment	**(22)**	44
Balance carried forward	**2,589**	2,441

Note 13. Contingent Liabilities

There were no contingent liabilities at 31 March 2000 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 the Environment, Transport and the Regions, the Department of Trade and Industry and the Ministry of Agriculture, Fisheries and Food.

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 £646,663 which, after allowing for the cost of capital (£520,000), represented a cost recovery of 101%.

Accounts Direction given by the Treasury in accordance with Section 5(1) of the Exchequer and Audit Departments Act 1921

The Forestry Commission Research Agency shall prepare resource accounts for the year ended 31 March 2000 in compliance with the accounting principles and disclosure requirements of the H.M.Treasury *Resource accounting manual* (The Stationery Office) which is in force for that financial year.

The accounts shall be prepared so as to give a true and fair view of the state of affairs of the agency at 31 March 2000, and of the income and expenditure, recognised gains and losses and cash flows for the financial year then ended.

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.

This direction supersedes that dated 3 July 1998.

B. Glicksman
Treasury Officer of Accounts
25 October 2000

Contact addresses

Forest Research
Alice Holt Lodge
Wrecclesham, Farnham
Surrey, GU10 4LH
Tel: 01420 22255
Fax: 01420 23653
E-mail: ahl@forestry.gsi.gov.uk

Forest Research
Northern Research Station
Roslin, Midlothian, EH25 9SY
Tel: 0131 445 2176
Fax: 0131 445 5124
E-mail: nrs@forestry.gsi.gov.uk

Technical Development Branch
Forest Research
Ae Village, Dumfries,
DG11QB
Tel: 01387 860264
Fax: 01387 860386
E-mail: tdb.ae@forestry.gsi.gov.uk

Woodland Surveys
Forest Research
Forestry Commission
231 Corstorphine Road,
Edinburgh, EH12 7AT
Tel: 0131 314 6122
Fax: 0131 314 6173
E-mail: woodland.surveys@forestry.gsi.gov.uk

Website
http://www.forestry.gov.uk/forest_research

General enquiries, E-mail: forest.research@forestry.gsi.gov.uk

Printed in the UK for The Stationery Office Limited on behalf of the Controller of Her Majesty's Stationery Office
01/01

Designed and produced by **Navy Blue Design Consultants** Edinburgh and London
Photographs supplied by **Forest Research Photo Library, Forest Life Picture Library** and individual authors

Forest Research

Northern Research Station
Roslin, Midlothian EH25 9SY
Tel 0131 445 2176
Fax 0131 445 5124
http://www.forestry.gov.uk/forest_research

Alice Holt Lodge
Wrecclesham, Farnham
Surrey GU10 4LH
Tel 01420 22255
Fax 01420 23653

Published by The Stationery Office and available from:

The Stationery Office Bookshops
71 Lothian Road, Edinburgh EH3 9AZ
0870 606 5566 Fax 0870 606 5588
123 Kingsway, London WC2B 6PQ
020 7242 6393 Fax 020 7242 6394
68-69 Bull Street, Birmingham B4 6AD
0121 236 9696 Fax 0121 236 9699
33 Wine Street, Bristol BS1 2BQ
0117 926 4306 Fax 0117 929 4515
9-21 Princess Street, Manchester M60 8AS
0161 834 7201 Fax 0161 833 0634
16 Arthur Street, Belfast BT1 4GD
028 9023 8451 Fax 028 9023 5401
The Stationery Office Oriel Bookshop
18-19 High Street, Cardiff CF1 2BZ
029 2039 5548 Fax 029 2038 4347

The Stationery Office
(Mail, telephone and fax orders only)
PO Box 29, Norwich NR3 1GN
General enquiries 0870 600 5522
Order through the Parliamentary Hotline Lo-call 0845 7 023474
Fax Orders 0870 600 5533
Email book.orders@theso.co.uk
Internet http://www.ukstate.com

The Parliamentary Bookshop
12 Bridge Street, Parliament Square,
London SW1A 2JX
Telephone orders 0171 219 3890
General enquiries 0171 219 3890
Fax orders 0171 219 3866

Accredited Agents
(see Yellow Pages)

and through good booksellers

£16.30

ISBN 010-298-500-6

9 780102 985009