Forest Research

Annual Report and Accounts | 2004–2005

Forest Research
The research agency of the Forestry Commission

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Annual Report and Accounts | 2004–2005

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

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Forest Research
The research agency of the Forestry Commission

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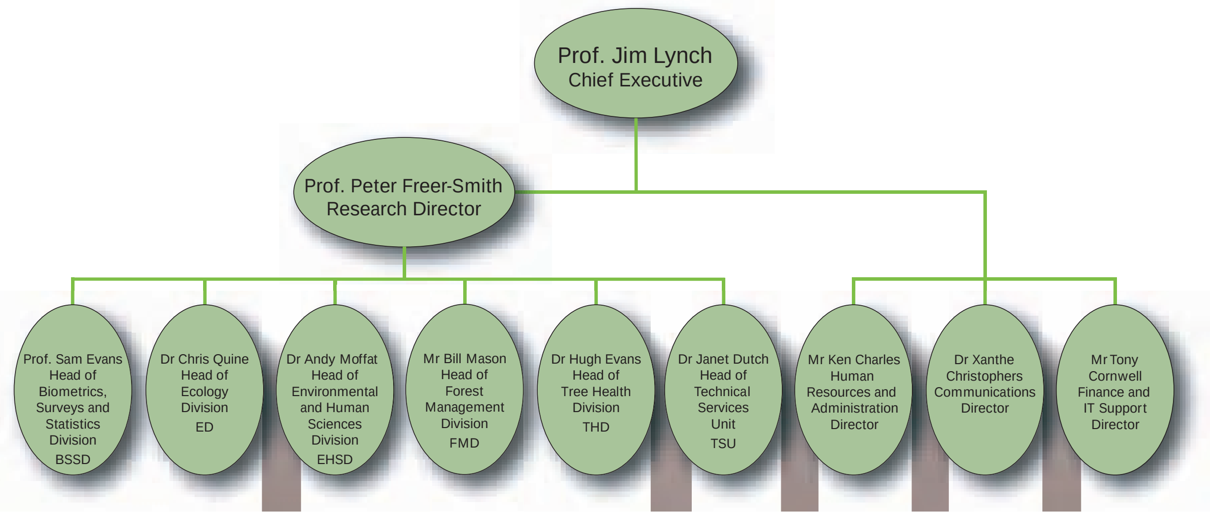

Cover photo: Glistening ink cap (*Coprinus micaceus*) amongst beech and ivy leaves in woodland, Selborne, Hants.

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About Forest Research

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

Aims and objectives

The aims and objectives of Forest Research (FR) are to assist the Forestry Commission (FC) in achieving its high-level objective.

On behalf of all three administrations, to take the lead in development and promotion of sustainable forest management and to support its achievement internationally.

FR's Aims

To support and enhance forestry and its role in sustainable development, by providing high-quality research and development in a well-run organisation.

FR's Objectives

- To inform and support forestry's contribution to the development and delivery of the policies of the UK government and the devolved administrations.
- To provide research, development and monitoring services relevant to UK forestry interests.
- To transfer knowledge actively and appropriately.

Research funding

Much of FR's work is funded by the FC with Corporate and Forestry Support 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 was responsible for managing the FC estate during 2004–05, and purchased research, development and surveys specifically related to this estate. In recent years FR has successfully applied for external (non-FC) funding from government departments, the European Union, UK research councils, commercial organisations, private individuals and charities. Collaborative bids with other research providers and consortium funding have become increasingly important, placing emphasis on effective partnerships.

Activities

Research and development are essential components in delivery of the benefits of sustainable forestry in a multifunctional landscape. FR's research, surveys and related scientific services address the social, economic and environmental components of sustainability. There is a focus on providing new knowledge and practical solutions based on high quality science. Our projects provide understanding, policy advice and guidelines on implementation of best practice (e.g. on forest hydrology, continuous cover forestry, timber quality, land reclamation to woodland, and restoration of native woodlands). Much of the research is directed at increasing the biodiversity, landscape and recreational benefits of woodlands. Protection of GB woodlands from pests and diseases, and predicting the impacts of environmental change are also overarching themes. FR works closely with the FC, the Commission of the European Communities and other international organisations to ensure compliance with international agreements on the sustainable management of forests and related subjects. The Agency also carries out work on genetic conservation, tree improvement, seed testing, method studies, product evaluation, crop inventory, surveys (e.g. *The national inventory of woodland and trees*), 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 (now part of Forest Management Division) is located at Ae in Dumfriesshire with subsidiary offices in the English Midlands and Wales. The Agency also has 10 field stations (the Technical Support Units) from which an extensive network of field trials, sample plots and monitoring sites is assessed. Contact information is given on page 116. The Agency employs 260 staff, not including visiting scientists and sandwich students. FR has published a Corporate Plan for the period 2005–2008 and copies are available to download from www.forestresearch.gov.uk/corporateplans

Chief Executive's Introduction

Challenges and goals

A further year has seen the Agency responding successfully to challenges and realising our target goals. In particular I would like to highlight that:

- We have demonstrated during the year a highly responsive work force to major challenge. This has been particularly illustrated with the onset of the threat of the disease Sudden Oak Death (SOD) caused by *Phytophthora ramorum* and associated diseases generated by other species of this pathogenic fungus. Working closely with our partners in the Forestry Commission and Defra, we have not only been able to provide the scientific background and tools to analyse the aetiology of this pathogen, but we have also been able to mobilise our Technical Support Unit across the UK to analyse the extent of the problem.
- As I start to look for a return on the investment from research I am delighted that we have begun to analyse opportunities for the exploitation of our Intellectual Property. A wide range of patenting opportunities have been identified and the advantage to the Agency would be that any funding generated from the exploitation could be utilised to further our research activity.
- Staff have become increasingly involved in the internationalisation of our research by participation in co-operative research, symposia and research discussions both in Europe through EU and COST activities and on a wider global scale. Our new divisional structure has settled in well over the course of the year. Organisation into fewer, larger units has brought about better internal communication with associated benefits to our science programmes. As for the external partnerships referred to above, there have been a number of inter-divisional initiatives to create new programmes. The outputs from some of these new areas of work are described in the Research Highlights on pages 14–25. Together with the five main articles of this report, these highlights provide a selective account of FR's research and scientific services as completed during 2004–05. (A full list of our research programmes and contracts is presented on pages 74–79.) In addition to *Phytophthora ramorum*, other current threats to tree health are summarised by Joan Webber and Hugh Evans (Highlights, pages 24 and 25), and Sarah Green's article on birch dieback illustrates the universal extent of such threats. Our social science research has continued to expand, helped by major successes in winning co-funding from the European Union. With the success of our recent EU bid in this area (EFORWOOD), our research on sustainable forest management will also benefit from being part of a European consortium in the future.

One of the best illustrations of global environmental problems to which forestry research can contribute is the issue of climate change. Trees have the capacity to sequester carbon and mitigate some of the damage generated by carbon emissions, the factor which is largely responsible for climate change. Forest Research has a tremendous capacity to monitor, analyse and quantify the magnitude of the forestry contribution to global carbon balances. I believe that we have an exceptional skill base at the investigator level, as well as having unique monitoring sites and analytical capability at those sites that can be utilised as part of international co-operation. Of course we have to be concerned about what is happening in Great Britain, but the problems are on a truly international scale. Therefore I will be looking at ways in which Forest Research can take the lead in stimulating international debate on the importance of forest ecosystems to the sustainability of the planet.

As the UK Government develops its strategy for science, I am delighted that forestry has a seat at the table of those debates; for example I personally have been pleased to attend the Chief Scientific Advisers Committee (CSAC). Increasingly, national activities in research are being tuned to international needs. For many years I have represented the UK on the Organisation for Economic Co-operation and Development (OECD) Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems. In that programme, which is renewed on a quinquennial basis, we have recently identified the important role that forestry plays in integrated land use and the sustainability of the environment. Similarly, Tim Rollinson as Director General of the Forestry Commission has been heavily involved as co-chair of the UN Committee on Sustainability of Forests. Between us we feel that Britain has much to contribute to the global agenda on sustainability.

One positive step forward in international co-operation was the first meeting of the European State Heads of Forestry Research Institutes in Vienna in August 2004. Good progress was made towards co-operation; I was pleased to have been invited to address the Heads of all International Forestry Research Institutes at the IUFRO Quinquennial Conference in Brisbane in August 2005.

Implicit in the international dimension is the change in place for forestry in integrated land use. In this respect we do not just have to consider the rural agenda, but also the urban and peri-urban opportunities that are created by forestry. In Great Britain, for example, there are major areas of brownfield land which lend themselves to forestry and other forms of greening. This is not just to provide an appealing landscape but also to make available the opportunity for exercise in many forms, for example walking and cycling. One of the notable events of the year was the launch of the European COST Action on Forests and Health. Working closely in association with the Scottish Executive, I deputised for the Minister (Rhona Brankin) in opening the conference and outlining the opportunities that such forestry presents, particularly in areas of social deprivation. There is a clear correlation between poor health and social deprivation. Subsequent discussions with the Chief Medical Officer in Scotland have led to co-operative agreements to encourage people to exercise on our land, as the major land owner in Great Britain. We are also working towards identifying locations where new forests might be generated in these areas of social deprivation. This is an area where our intended objective of increasing the profile of social science research alongside our natural science approaches is likely to pay strong dividends. There are huge opportunities in generating interfaces between social and natural science approaches to research.

One of the pleasing features of our development has been the networks that we are generating with partners in universities and in research institutes. Maps of our national and international links on pages 72 and 73 show the range of these networks. Such co-operation was further enhanced when the Biotechnology and Biological Sciences Research Council (BBSRC) credited us with partial academic analogue status. I am unequivocal in my view that the way forward to benefit forestry research overall is for networks to develop and share the responsibilities and kudos that are derived from analysing the critical environmental problems where forestry has a role to play.

I am pleased that we are achieving our key targets but I intend to look increasingly carefully at the way in which we communicate our results through publications and other methods. Clearly there is a need for the scientific community to be able to access through the peer review system the quality of the research that we undertake, but we need to recognise that the views of the community also need to be appraised of our outputs. These are issues of balance and I hope that our status can be enhanced by analysing more critically the communication and commercialisation of our research findings.

Targets and achievements over the past five years

Performance measure		2000/01	2001/02	2002/03	2003/04	2004/05
Customer satisfaction	Target	96%	96%	97%	90%	90%
	Achieved	97%	97%	98%	97%	97%
Peer-reviewed papers	Target	43	48	48	45	45
	Achieved	48	48	48	45	47
Unit cost/research day (unweighted) 98/99 =100	Target	94	94	92	90	88
	Achieved	82	81	79	78	78
Unit cost of support services	Target	96	94	92	89	87
	Achieved	92	86	84	82	82
Cost recovery	Target	100%	99%	100%	100%	100%
	Achieved	100%	100%	100%	100%	99.8%
Reports, FC publications and articles[a]	Target	–	–	–	25	25
	Achieved	–	–	–	25+	25+
Income from customers[a] other than FC	Target	–	–	–	£1.5m	£1.5m
	Achieved	–	–	–	£1.65m	£2.11m
External review of research programmes[a]	Target	–	–	–	Silviculture	Social Research
	Achieved	–	–	–	Completed	Completed

[a] New targets set following the Agency's first Quinquennial Review.

Advisory Committee on Forest Research

The Advisory Committee met in April and November 2004 at Alice Holt Lodge and Northern Research Station respectively. These meetings allowed members to get to know the staff and facilities at FR's two main research stations. The Committee also appointed and received a report from an external Visiting Group to FR's Social Research Group (chaired by Dr Victoria Edwards OBE with Professor Bill Slee and Professor Thomas Randrup as members). This Visiting Group reported that the Social Research Group has successfully established itself as an active and effective group particularly with Forestry Commission customers and within Europe. A significant amount of research has been established with EU co-funding. The Visiting Group also recommended expansion of the Social Research Group, particularly in the socio-economic area. There is a need for social research input to UK forestry and to the wider environmental and natural sciences research programme. The Group will require strategic direction, and will need to develop its intellectual direction over the next few years. The Advisory Committee also received reports on the implementation of the Visiting Group recommendations on the Entomology and Silviculture programmes (2003) and was kept informed of the preparation of the FC's new Science and Innovation Strategy by the FC Research Strategy Management Board.

Finance

Income in the year increased by 6.0% compared to the previous year. Within this, non-FC income exceeded £2.0 m for the first time. There was a 5% increase in payroll costs with an overall increase in operating expenditure of 6% over 2003–04 levels.

Unexpected and unplanned premature retirement costs of £135,000 arose in the latter half of the year and it proved too late to secure the full recovery of this sum from other sources. As a result the net operating surplus fell short of the target of £409,000 by £27,000, delivering a full cost recovery performance of 99.8% against the target of 100%.

Capital investment of £398,000 covered a wide range of scientific and technical purchases including, notably, dedicated electrical supplies, chemical analysis equipment, updated data capture systems as well as IT equipment and laboratory, office and infrastructure refurbishments.

People

Over the past year, Forest Research welcomed almost 30 new members of staff who have joined existing staff across FRs sites. Amongst these are:

David Beattie who joined FR (THD) to work on species boundaries in *Phytophthora* pathogens in trees, on a newly established Defra student fellowship. David has previously worked on the genetics of potato blight at UCW Bangor. Finlay McAllister who transferred from Technical Services at Shobden to FMD’s Technical Development team, as a Technical Development forester based at Talybont. David Edwards who joined FR as social sciences project leader in the EHSD. David’s work has included participatory approaches to issues of land use and rural development. His responsibilities will include work on the new EC contracts RECOAL and SENSOR. Heike De Silva who joined THD at NRS, to study the distribution and biology of the fungal pathogen responsible for birch dieback in Scotland. Heike, originally from Germany, completed an MSc in Horticultural Science in 2003 in New Zealand.

Janet Dutch took over as head of Technical Services Unit (TSU) in August 2004, and is based at NRS. Janet transferred to FR from the FC, having worked previously as Special Advisor for the physical environment and, from 1999 to 2004, as part the Forest Enterprise GIS development team. Nadia Barsoum joined EHSD to lead the ‘Environmental monitoring and evaluation of forest ecosystems’ programme. Previously Nadia worked on Riparian Ecology at the Centre d’Ecologie de Systèmes

Aquatiques Continentaux, Toulouse and the Universities of Umeå and Mid-Sweden. Jeff Sharp joined FMD at NRS as an IAESTE (International Association for the Exchange of Students for Technical Experience) trainee working on the stability, timber quality and silvicultural systems programmes. Joy Cornwell joined BSSD as Divisional Administrative Support Officer. Joy previously worked for Historic Royal Palaces at the Tower of London. Maureen Wilkes joined Alice Holt Typing Services, moving from working at Farnham Hospital. Xanthe Christophers joined FR as Director of Communications, coming from a background in international development and natural resources, most recently working for Barnardo's.

Many FR staff are recognised internationally as experts in their research fields. I would like to congratulate all the staff who have been honoured by awards or who have achieved qualifications over the past year including:

Alexis Achim (FMD) who was awarded a PhD from the Université Laval, Quebec; Andy Moffat (Head of EHSD) who was awarded a DSc from Reading University and Bill Mason (Head of FMD) who was awarded Honorary Fellowship of the College of Science and Engineering, University of Edinburgh. Sam Evans (Head of BSSD) was honoured with a Visiting Professorship at the University of Sheffield, linked to the NERC Centre for Terrestrial Carbon Dynamics in the Department of Applied Mathematics.

Jason Hubert (ED) was invited to join FC Scotland Broadleaves Working Group, to explore opportunities to grow quality broadleaves in Scotland. Kath Thorpe (THD) joined the Executive Board of the International Society of Arboriculture (UK and Eire Chapter). Martin Jukes (THD) gained the Diploma in Health and Safety Management and became a member of the Institute of Occupational Safety and Health. And Ralph Harmer (ED) was awarded the James Cup 2004 for *'Bramble for beginners'* – the best article of the year in the *Quarterly Journal of Forestry* 98(4), 273–279.

But sometimes we say goodbye to old friends. This year, almost 20 members of staff have left, some of whom had been with FR for many years. We will particularly miss the professionalism and familiar faces of:

Dave Durrant (EHSD) who retired after 23 years supporting and leading research projects examining the effects of air pollution on trees. His field studies have included the establishment and management of the Level II network of intensively monitored sites, and promoting the work across Europe. Derry Neil (FMD) retired after almost 40 years with FC, FE and latterly with FR. During his time in Technical Development, Derry saw the group move from Research to Forestry Authority and back to Research. Ralph Nickerson (TSU), whose career spanned 40 years and three continents, and Tim Cooper (BSSD) who took early retirement after 29 years with FR.

Visitors and events

Forest Research operates in the increasingly high profile area of the environment and natural resources alongside universities and other research organisations. Over the past year, visits from overseas scientists and interested policy-makers, and participation at a range of events, has ensured that FR is increasingly known for providing excellent research coupled with practice-based outputs both within and beyond the UK.

The Forestry Minister for England, Ben Bradshaw, visited Alice Holt in July 2004, to get an insight into Forest Research's work. During the visit, Mr Bradshaw discussed with scientists a number of topical issues including climate change, woodfuel, *Phytophthora ramorum* and squirrel management. The FC Commissioner Anthony Bosanquet also visited Alice Holt to catch up on latest research developments. Topics discussed included the work of the Social Research Group, hydrology projects, continuous cover forestry, squirrel management and the joint landscape project 'BEETLE', currently being undertaken by FR with the Countryside Commission of Wales. The FC's Expert Group on Research and

Development met at Alice Holt in May 2004. As well as discussing environmental research, FR's modelling work, forest protection, continuous cover forestry and the Social Research Group, they toured the Chemical Analysis Service, the Soils Laboratory, and Seed Testing.

Thirteen foresters from the province of Himachal Pradesh in Northern India spent two days with FR at Alice Holt, as part of a two week training programme organised by Tropical Forestry Resource Group. The main focus of the course was the formulation and implementation of forestry policy, but delegates also participated very enthusiastically in a tug-of-war at the Alice Holt 'Olympics'!

FR's exhibit at the Royal Society Summer Science Exhibition: *Biological cruise missile: beetle vs beetle in forest protection* attracted considerable attention from both visitors and the media. The evening soirée was attended by the FC Chairman Lord Clark and Director General Tim Rollinson. Hugh Evans (Head of THD) was subsequently interviewed by BBC Radio 4 for the programme: *Leading Edge.* Hugh visited Beijing in May 2004 to attend the XV International Plant Protection Congress. In addition to organising and chairing a forestry section session, he presented two papers on FR's biological control programme against *Dendroctonus micans* using the predator *Rhizophagus grandis.*

Tug-of-war at the Alice Holt 'Olympics'.

Discussions with visitors to FR's exhibit at the Royal Society Summer Science Exhibition 2004.

Jim Lynch attended the first international meeting of the Heads of European State Forest Research Institutes hosted by the Austrian Federal Office and Research Centre for Forests in Vienna. Delegates were enthusiastic about the new opportunities for the closer integration of forestry and environmental programmes across the expanded European arena. Tim Rollinson was among the visitors to Forest Research's stand at APF 2004, the largest UK arboriculture, forestry and woodland show. The focus of FR's stand was the new guidance on best practice for winching and the importance of ground preparation techniques for root development and stability. FR's new award-winning excavator bucket design attracted considerable attention.

FR's successful seminar, 'Accessibility of woodlands and natural spaces', attracted a wide-ranging audience including planners, police, academics and environmental professionals. It addressed five themes: access and perception of risk; how to manage exclusionary behaviour; access and liability; crime reduction and rehabilitation of offenders; and the location and design of accessible woodland. The workshop was organised by Liz O'Brien and Paul Tabbush (EHSD), with backing from English Nature, CABE Space and Lancashire Constabulary. The 'Ecology and management of large native pinewoods' conference, held in Inverness-shire by

FR and BES, brought together a wide range of groups interested in pinewood ecology and biodiversity. The issue of climate change and its influence on the pinewood ecosystem was a major area of debate. The very successful Annual FTA/ICF Research Update (at NRS) sponsored by FC Scotland covered a range of topics including forest habitat networks, climate change and dieback of birch in new native woodlands.

The new *Woodfuel information pack,* written by Duncan Ireland, Andy Hall and David Jones, was launched by Geoff Hatfield (Director FE England) at 'Woodfuel – getting it right', a workshop which combined talks from industry experts and site visits to installations and woodland production sites. The workshop aimed at improving awareness of the opportunities that wood and forest residues present as a source of renewable energy and to increase understanding of the harvesting, processing and combustion of wood as a fuel. In September, at Heriot-Watt University, Edinburgh, 125 delegates from around the globe attended the 'Forestry woodchain' conference organised jointly by FR and BRE.

Hugh Evans (Head of THD) visited New Zealand to deliver a seminar on Forest Research's UK plant health work to the Forest Research institute at Rotorua and to speak about invasive organisms to the New Zealand bio-security group based in Wellington. Hugh also attended the IUFRO Conference in Hanmer Springs to deliver two joint papers developed with Nigel Straw and Christine Tilbury, on pinewood nematodes and horse chestnut leaf miner, and the International Entomology Conference in Brisbane, Australia to deliver two further papers on pest risk analysis and plant resistance.

Jim Lynch gave the keynote opening address at the Rhizosphere 'Perspectives and challenges' conference in Munich in September and co-chaired the closing session. The meeting was co-sponsored by EU and OECD and attracted 450 participants. Jim Lynch and Bill Mason also gave keynote lectures at the EFI Conference in Bangor on 'Continuous cover forestry', which was well attended by FR staff. Joan Webber contributed to the 'Plant health and seed inspectorate' annual conference, discussing the quarantine of *Phytophthora.* Andy Moffat presented at SUBR:IM's annual conference on 'Joined up regeneration of brownfields'.

Quality Assurance

FR is dedicated to achieving and maintaining appropriate standards of quality in order to meet the needs of its work programmes and the requirements of its internal and external customers. Over the past year, FR has introduced its Quality Assurance (QA) system to meet the requirements of the Joint Code of Practice for Research (2003) and all staff have attended comprehensive QA seminars. The Joint Code was developed in partnership between the Department for Environment, Food and Rural Affairs (Defra), the Biotechnology and Biological Sciences Research Council (BBSRC), the Food Standards Agency (FSA) and the Natural Environment Research Council (NERC). The Joint Code has subsequently been endorsed by The Scottish Executive and Rural Affairs Department (SEERAD), the Welsh Assembly Government Agriculture and Rural Affairs Department (WAGARAD), and the Department of Agriculture and Rural Development for Northern Ireland (DARDNI).

The Joint Code provides a framework for auditing research processes and applies, where possible, to all research funded by Defra, the FSA, SEERAD, DARDNI and WAGARAD and to research funded by BBSRC and NERC in their own institutes.

FR has also retained Pesticide Safety Directorate (PSD) accreditation as a recognised testing station for chemical and other plant protection products and continues to work towards full integration of both the PSD and QA systems.

Freedom of Information

The Forestry Commission's Open Information Group was charged with ensuring that all parts of the FC were ready when the Freedom of Information (FOI) Act came into force on the 1 January 2005 to deliver a competent 'Open Information' service to the public. Open Information encompasses the Freedom of Information Act, the Data Protection Act, Environmental Information Regulations and records management. Over the past year, training courses and briefing sessions at Alice Holt and NRS have enabled FR staff to understand their role and develop processes to provide this service to the public.

Professor Jim Lynch
Chief Executive

Research Highlights by Division

Biometrics, Surveys and Statistics

Towards an integrated woodchain model

Ash growth and yield model

Ecology

Habitats and Rare Priority and Protected Species (HaRPPS)

Coning studies establish synchrony between trees species and across regions

Environmental and Human Sciences

Influences of stand age and soil properties on forest biodiversity

Iterative learning from social research

Forest Management

Seed dormancy and climate change

Rhododendron ponticum: planning and implementing a control operation

Rack management in continuous cover forestry

Tree Health

Risks from introduced pathogens

Risks posed by wood packaging materials in international trade

Towards an integrated woodchain model

Tim Randle

Understanding and modelling tree growth and timber output allows researchers to make predictions of timber quality from existing and future forests. Modelling can predict the influence of new sites, climate and management regimes and so indicate the most suitable management techniques to enhance the economic value of forests. Models of forest growth, whether empirical or process-based, tend to finish at 'roadside'. But better descriptions of form and quality are needed to predict the correct market value for trees. The form and quality of wood is associated with several inter-related factors including genetics, forest management and environmental conditions (including site factors such as soil type).

In order to understand the linkages between growth, the physical characteristics of the tree and wood, and the effect on timber and its end-use, FR is developing an integrated model in collaboration with the Building Research Establishment at Watford. To achieve this, researchers have constructed a model or series of linked models to take account of the processes along the woodchain (Figure 1).

The integrated model takes tree-level mensurational descriptions and cuts the bole into log-lengths, accounting for straightness and desired log-length. The logs are cut into battens using a saw-optimising model, which prioritises cuts of batten size. The cut battens are then classified using strength characteristics such as knots and wood density to produce different grades suitable for different purposes. These processes are analagous to some methods used in modern automated sawmills (Figure 2), which are able to use laser and x-ray technologies.

Figure 2

Automatic processing of logs entering a mill.

FR's model demonstrates how environmental conditions and management practices affect both growth rates and the quality of wood produced by a stand, which in turn influences all stages of the woodchain model. The quality and final use of the timber determines its market value but also affects the carbon budget in terms of the length of time the carbon is 'locked up', and energy costs for transportation and production of various products.

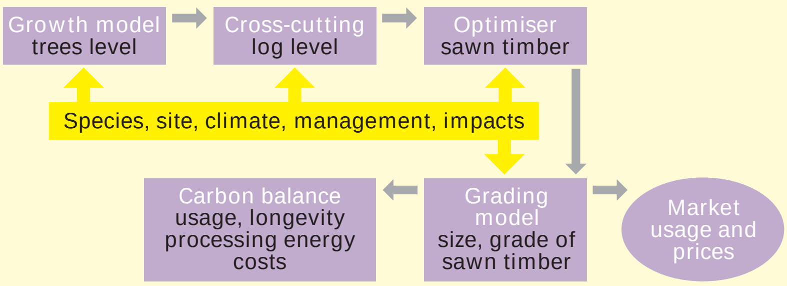


Figure 1

Flow chart of a series of models, linked to create an initial woodchain model.

Ash growth and yield model

Miriam Baldwin

A new stand-level model has been created from data collected from England, Scotland and Wales to predict stand volume of ash (*Fraxinus excelsior* L.). The sampling method allows sufficient data to be collected in a much shorter time frame than previously expected and is already being implemented under the restructuring of the permanent sample plot network.

Approximately 200 plots consisting of a mixture of permanent and temporary sample plots and increment plots were used to build the model. The increment plots were established in the same way as permanent plots, but maintained for a shorter period with more intense monitoring. From a potential 400 sites, 98 were established as increment plots. For this study a 5-year retention was used although 10-20 years is more appropriate. Increment plots were successfully employed for the first time to achieve pseudo-time series data. Annual measurements for diameter were taken, with height and crown measurement recorded every 5 years. A range of environmental data were also collected.

A database was compiled combining selected data taken from FRED (Forest Research Ecological Database), and new measurements taken as part of this work package. The database was built using Microsoft® Access and is suitable for amalgamation with FRED. Software was produced as a tool to aid in stand management decisions. The software is MS-Windows compatible, written in C++ with a 'point and click' front end (Figure 1).

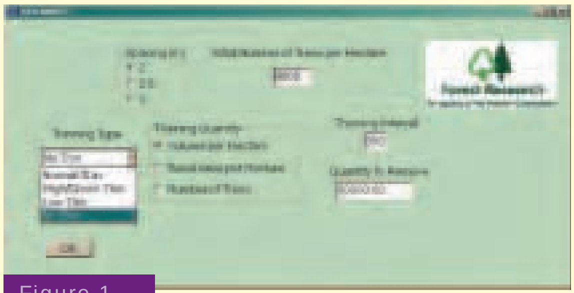


Figure 1

Software input screen.

In general the new model is predicting more dense stand populations with thinner and taller trees. The individual growth variable increment is better correlated with observed growth patterns. Direct comparison between old and new models demonstrated an increased flexibility of initial stand and management descriptions for the new model (Figure 2). Describing the full range of thinning scenarios is currently being investigated through the revision of the permanent sample plot network. The model is structured to allow future amendment and refinement. This work demonstrates that incorporation of increment, permanent and temporary plots, within the current sample plot network, sources enough data for much needed refinement of growth and yield models for all species within the *Yield models for forest management* suite of models (Booklet 48 by Edwards and Christie published in 1981).

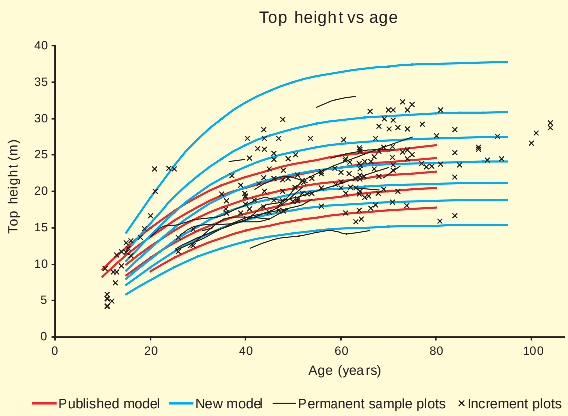


Figure 2

New model predictions.

Habitats and Rare Priority and Protected Species (HaRPPS)

Duncan Ray and Chris Quine

Sustainable forest management places considerable pressures on forest managers (and their stakeholders) to access appropriate information that has a bearing on their decisions. With respect to biodiversity and wildlife conservation, forest managers need up-to-date and concise recommendations for managing a broad range of woodland and open habitats, with a significant number of associated priority, protected and rare species. Last year (*Forest Research annual report and accounts 2003–04*) an article by Broome *et al.* explained the various strands of research being conducted within the Species Action Plan Research Programme to plug some of the key knowledge gaps. However, there is already much existing knowledge and literature describing the autecology of species, impacts of management on species and habitats, guidance on best management practice, and the occurrence of species in particular habitat types and locations. Discussions with conservation managers in each of the countries identified the need for an improved way of accessing these resources.

As a consequence we have been working on a new decision support tool (HaRPPS – Habitats and Rare Priority and Protected Species) that provides managers with quick and easy access to the legal requirements, species-habitat links, forest management impacts and recommended practice for managing species and habitats. The aim is to deliver this tool over the internet – thereby enabling the database to be updated and rapidly made available to all users. Figure 1 illustrates the structure of HaRPPS and its linkages to other databases and sources. Information in the background database comes from a systematic review process, in which individual records have a citation and data quality tag enabling users to assess the authority and impact of information. HaRPPS will provide access to the websites of NBN (National Biodiversity Network) and UKBAP (UK Biodiversity Action Plan) and, importantly, will be accessed directly from GLADE (Grants and Licences Applications Delivered Electronically) and Forester GIS applications. This will enable HaRPPS to deliver spatially explicit species and habitat guidance to private woodland owners, managers and agents, and to FC woodland officers and managers.

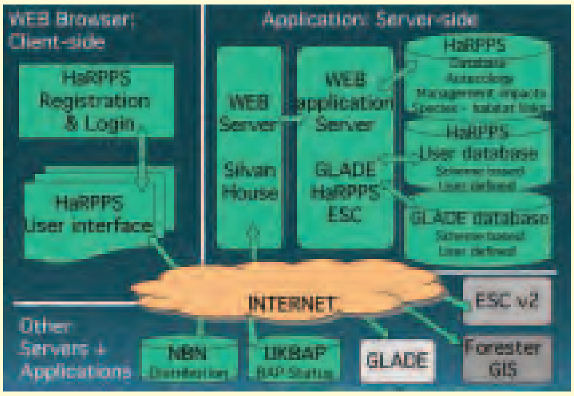


Figure 1

Schematic illustrating the main structure and linkages of HaRPPS.

Considerable progress has been made in developing the structure of the decision support tool – with a user interface structured to reflect the type of likely queries and a supporting database developed for a number of key species. The relative priorities of different options in the development has been guided by a steering group of key practitioners, and the prototype is now being tested by representative users. Results from this beta-testing will focus the subsequent development and roll-out of this system.

Coning studies establish synchrony between tree species and across regions

Alice Broome, Andrew Peace, Chris Quine and Steven Hendry

Conifer seed is a valuable forest resource which provides reproductive material for forest regeneration, and an important foodstuff for many woodland species. Some of Britain's rarest species depend upon this food resource, for example, the red squirrel (*Sciurus vulgaris* L.) and Scottish crossbill (*Loxia scotica* L.), as described in 'Research in support of the UK Biodiversity Action Plan' (*FR Annual report and accounts 2003–04*). Information on cone and seed production of the main forest species is necessary to implement new forest management systems and to understand the population dynamics within forest ecosystems, but has rarely been the focus of studies. Now a new source of data has been explored and has yielded some fascinating results. Since 1989 coning has been recorded in Norway spruce, Sitka spruce and Scots pine from sites across Britain as part of the Forestry Commission's Forest Condition monitoring programme. Fieldwork has confirmed the relationship between the scoring system and cone counts in the crowns of the sample trees, and an 11-year period of the records has been analysed to establish annual cone production by species and coning synchrony (publication of further details is in preparation). Figure 1 illustrates the geographic and temporal coverage of the analysis.

The results indicate that Norway spruce and Sitka spruce tend to cone sporadically, with a 4-year period between mast crops when cone density (cones per m^2) can be very low or cone production absent. Scots pine produces a good cone crop in most years throughout Britain. In mast years coning in both spruces is in synchrony across Britain; the synchrony occurs over distances of up to 200 km. There is no synchrony between coning in Scots pine and that in the spruces.

These findings have implications in the design of forests for wildlife conservation, and particularly how to mix tree species to ensure a supply of seed in most years. The findings are also of value in considering how to monitor seed production, and contribute to the development of appropriate silvicultural systems for the species involved. The results also raise some intriguing questions about the factors governing the masting and the synchrony and what are the equivalent patterns in other key forest tree species. It is hoped that further work will explore these aspects.

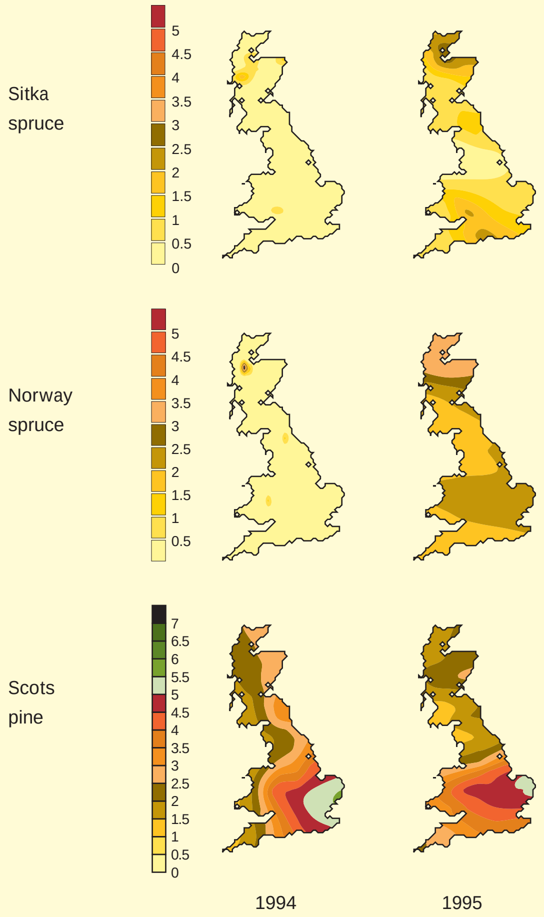


Figure 1

Extract from the coning analysis for three conifer species across Britain in 1994 and 1995. Scale gives average cone density interpolated from point samples (cones per m^2 of canopy: note different scale used for the spruces and Scots pine).

Influences of stand age and soil properties on forest biodiversity

Rona Pitman and Elena Vanguelova

Soil properties and ground flora in a chronosequence of 40 plots in Alice Holt Forest, Hampshire, selected from those in the Environmental Change Network (ECN) surveyed in 2002, were analysed using modified Ellenberg values as an investigative tool. Data were grouped into stand age class (thicket, mid-rotation and mature) to explore the effects of maturing stands on soil and plant properties. A succession of increasing plant diversity under oak was indicated, with Ellenberg values showing significant adaptation to higher levels of nitrogen (N) with age, rising pH and declining water availability. Under Corsican pine stands, similar trends were found from a more limited flora, but with increasing water availability in older stands. The ecological synopsis shown by the Ellenberg values was confirmed by the mineral soil analysis (0–15 cm depth), where nitrogen and pH levels rose with age under both species, and mid-summer moistures declined under old oaks. Significant differences were found in the nature of the plant available N in the soil under each species, with higher levels of nitrate (NO_3–N) under pine stands but higher ammonium (NH_4–N) under the oak (Figure 1a). A comparison of the soil pH under the two forest communities indicates that soil under the pine is significantly more acidic than that under the oak (Figure 1b).

A further collaborative study between FR and Exeter University aims to develop a greater understanding of the relationship between soil nitrogen processes and soil microbial diversity and function. For this study, a representative number of both conifer and broadleaved mature forest plots from the ECN network were selected. Soil microbial diversity associated with nitrification, denitrification and nitrogen fixation were analysed by functional genes (such as those coding from ammonia mono-oxygenase [amoA] for nitrification; NO_2–reductase [*nir*K and *nir*S], N_2O reductase [*nos*Z] for denitrification and [nifH] for nitrogen fixation). The molecular microbiological data corroborated the soil chemical analyses, suggesting that oak forest associated with heavier textured clay soil has higher nitrification and denitrification potentials and thus higher buffering capacity towards N compounds entering the system, compared to the more acidic and sandier textured soils under Corsican pine (Table 1).

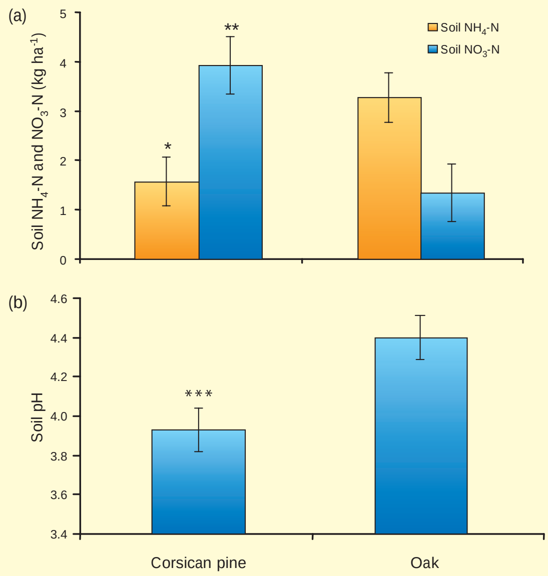


Figure 1

(a) Soil nitrogen species and (b) soil pH under Corsican pine and oak forests. Mean values are from 10 plots with their standard errors.

Forest type	Presence of gene types in the plots						
	Denitrifiers					Nitrifiers	N-fixers
	narG	*napA*	*nirK*	*nirS*	*nosZ*	*nifH*	*amoA*
Pine	0	6	4	0	0	0	0
Oak	0	10	6	2	0	5	0

Table 1

Presence of the functional gene PCR amplifications from soils in 10 plots under each forest type.

Taken together, the ecological and microbiological studies clearly demonstrate the importance of soil properties and processes, along with nitrogen capital, in determining the complexity of both above-ground and below-ground biodiversity in forests.

Iterative learning from social research

Paul Tabbush and Liz O'Brien

FR's Social Research Group is using the breadth of its work in the UK and Europe to inform its research in the field. A study of consultation and community involvement in forest planning was based on areas in the New Forest, Cranborne Chase and North Dorset (Figure 1). The main recommendations included the need to make a clear distinction between strategic and site-specific issues and then to choose engagement methods suitable for each. It is also important to record and feed back participant views, to stress that they are being listened to, incorporated into the plans and acted upon. Focus group work in Blandford Forum, North Dorset, revealed a clear potential to enhance the public benefit from Forest Enterprise managed woodlands.

Figure 1

Cranborne Chase and North Dorset Forest Design Plan Forum meeting on 24 October 2003.

Inner London woodland study

In 2004 the Group undertook a project looking at trees and their impacts on the emotional well-being of local residents on two inner London social housing estates. The project was a partnership between the Forestry Commission, Peabody Trust (London's largest housing association), Trees for Cities (an environmental charity), with Forest Research carrying out work to explore residents' use of and attitudes towards their local wood called Peabody Hill Wood, situated in Lambeth. Questionnaires, focus groups, a workshop with young people and a walk through the wood were the methods used to gain an understanding of how residents from the two housing estates viewed the woodland. The project also involved residents in a community woodland clearance and a tree planting day (Figure 2). There was a complex mix of perceptions: many valued the wood as an element of nature in their urban environment and as a piece of wild space which provided the opportunity to view wildlife, but residents were also concerned about some of the abuses that took place in the wood and for some this outweighed the potential for using the wood for their everyday enjoyment.

Figure 2

Residents plant oak trees at Peabody Hill Wood, London, 2005.

The findings suggest that outreach work is needed to encourage those who never use the wood to consider how it might be improved and become usable; this would need to involve all sections of the community. The report of the work is available at: www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-6C8GNH

The Group also started work on two shared-cost European projects during the year. In both projects, social research methods are being used to help to define the problems and to ensure that solutions take the local social contexts into account.

- SENSOR aims to produce Sustainability Impact Assessment Tools to assess the potential impacts of European policy instruments. Case studies are based on multifunctional landscapes, mainly located in the Accession States.
- RECOAL aims to find solutions to problems caused by pollution with coal ash in Bosnia, based on sites near Tuzla.

Seed dormancy and climate change

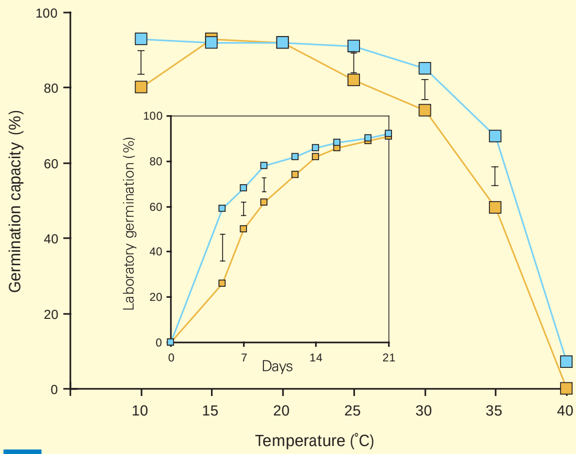
Peter Gosling and Mark Broadmeadow [a]

The ‘Seed and seedling biology’ and ‘Climate change impacts’ programmes have collaborated to explore the potential effects of winters that are either warmer, shorter or both on the dormancy breakage process and hence natural regeneration of native trees and shrubs from seeds.

The majority of tree seeds in the UK exhibit one of two sorts of dormancy. A few (alders, birches and Scots pine) have seeds that exhibit ‘shallow dormancy’. In this type of dormancy a varying proportion of seeds germinate at different temperatures – and usually only slowly. However, all seeds respond to a relatively short prechill which stimulates faster germination at all temperatures and improves the maximum germination percentage at most temperatures. These characteristics are illustrated for Scots pine in Figure 1a. If climate change brings longer, warmer autumn temperatures, then the seeds of these species may germinate too soon in autumn. Their highly vulnerable seedlings will be much more likely to be killed by any subsequent freezing temperatures of a later winter (■ - ■). The figure also shows that if the seeds don’t germinate too soon, they require relatively little moist chilling for an even higher percentage to germinate more quickly the following spring (■ - ■).

The native trees that are most likely to be affected by climate change are those with ‘deeply dormant’ seeds – especially if winters are either warmer, shorter or both, and early spring temperatures are higher. Unfortunately, this is the majority of native trees (including the conifers – juniper and yew, and nearly all broadleaves – ash, beech, cherry, dogwood, etc.). Figure 1b shows that freshly shed seeds of these species have a complete metabolic block to germination at any temperature (■ - ■); also that there is an absolute requirement for a relatively lengthy and unbroken period of cold moist conditions to bring about any germination at all. The figure shows that although 15 weeks of prechilling (■ - ■) enables 60% of seeds to germinate at lower spring temperatures (10–15 °C), it requires another month of prechilling to stimulate a similar germination percentage at 20–25 °C (▲-▲). If climate change brings about winters that are warmer or shorter or both, and these are succeeded by faster rising spring and summer temperatures, then many of these species may not be as well suited to natural regeneration in the projected climate of the future.

(a)



(b)

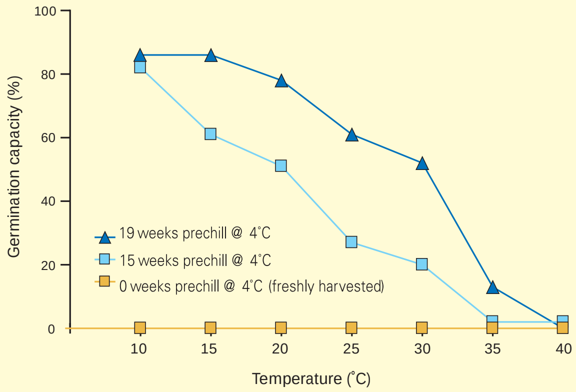


Figure 1

(a) Maximum germination percentage of Scots pine seeds at constant temperatures following 0 and 3 weeks moist prechill at 4°C (inset shows course of germination at 20°C, with and without a 3 week moist prechill).
(b) Maximum germination percentage of beech seeds at constant temperatures following 0, 15 and 19 weeks moist prechill at 4°C. Bars signify statistically significant confidence limits at 95% level.

There are currently a number of groups encouraging the collection and propagation of ‘native-trees’ from ‘local seed sources’ – the laudable aim being to preserve locally adapted genotypes. However, if the UK climate is likely to significantly change in the next 50–100 years then perhaps seed sources adapted to local environmental conditions may not be so appropriate after all.

[a] EHS Division.

Rhododendron ponticum: planning and implementing a control operation

Colin Edwards

Despite its attractive flowers, *Rhododendron ponticum* (Figure 1) only has a negative impact on areas it colonises, reducing the numbers of earthworms, birds and plants and the regenerative capacity of such sites, and impairing physical access which pushes up management costs. A long-term challenge, researchers have recently developed techniques and guidance for the sustainable control of *R. ponticum*. A forthcoming Forestry Commission Practice Guide: *The management and control of invasive R. ponticum* takes the forest manager through a series of steps partly formulated as a decision chart.

Figure 1

R. ponticum – an introduced, woody, ornamental species that is now a major invasive weed of forests and heathland habitats.

The first step is a detailed site survey describing *R. ponticum* in the target woodland area. The safest and most efficient method of control then depends on the size, life stage and accessibility of the bush. Although stem treatment is generally the most effective and efficient method of killing bushes, where there is no access to stems, a foliar spray can be used. Small bushes can be easily treated, but foliar sprays cannot be applied safely to larger bushes so they must be reduced in size with a mechanical flail or manual cutting before application of the herbicide.

The Guide gives details of how to plan a control operation, including information on approved methods of application and herbicides for effective control of *R. ponticum*. Sections on prioritising areas for control and monitoring the success of operations aid managers in making the most effective use of the resources available to them. The Guide is due for publication early in 2006 and should be used in conjunction with FC Practice Guide *Reducing pesticide use in forestry* and the FC pesticides resource website.

Research is still under way – stem treatment is a relatively new technique for controlling bushes where each stem is > 3 cm diameter and can be individually accessed (Table 1). While the basic technique has been found to be effective in Scotland and North Wales, some aspects of the technique, such as the best time of year for application, are still being investigated. The techniques described in the Guide are effective: treatments early in the growing season prevent flowering, reduce seed dispersal and potential colonisation of other sites while mature bushes should be dead within 6 months of application.

Table 1

Kintyre 21: health score of treated stems 6 and 12 months after application. Health scored 1–6, where 1 = healthy, 6 = dead.

Treatment	Health score	
	6 months	12 months
Control	1.40	1.20
Stem girdling	1.80	3.60
Water	2.60	1.60
Undiluted Glyphosate	6.0	6.0
50% solution Glyphosate	6.0	6.0
25% solution Glyphosate	6.0	6.0

Rack management in continuous cover forestry

Duncan Ireland

Racks are simple corridors through the standing tree crop that allow access for harvesting and management operations. When forwarding, racks should be spaced as far apart as machine reach will allow. This reduces the area subject to compaction, the loss of potentially productive land, and potential wind blow risk when opening up the canopy. The long-term sustainability of timber harvesting and extraction in continuous cover forestry (CCF) is closely connected with rack management.

Methods of reinforcing racks against disturbance include redistributing brash, adding biodegradable materials and adding stone to selected sections. The cost of reinforcement should be considered against the loss in productive time during timber extraction due to reduced/restricted access as a result of degraded racks. The useable life of the rack network can also be increased through operational controls including alternate racks in later thinnings (Figure 1) and reducing loading by forwarding partial loads.

Rack layout should be designed to minimise the number of watercourse crossings. Where required, efficient crossings can be provided using a range of techniques; the simplest comprises a polypropylene pipe, transported by harvester, placed into the drainage channel and covered by brash. The pipe can be transported by harvester and removed for reuse when felling is complete.

Movement of machinery over dry ditches can be facilitated by temporarily inserting logs into the channel and laying brash over the top, followed by regular checks during felling to ensure the channel remains dry and that produce is removed after use. To allow machinery to cross wider channels, bundles of pipes, secured with chains can be used to form a 'fascine'. Different numbers and gauges of pipes can be used to span a range of watercourse widths.

Low value, small dimension roundwood can be used to construct sections of 'corduroy' rack (lengths of timber placed side by side along the extraction route covered with brash) to prevent ground damage where the soil is locally wet.

The ongoing mechanised harvesting access required for successful CCF transformation and management will only be achieved through the use of appropriate rack construction and maintenance techniques throughout the development of the stand. Some of these aspects are being investigated at demonstration sites, including Coed Trawlim in Wales in collaboration with the School of Agricultural and Forest Sciences of the University of Wales, Bangor.

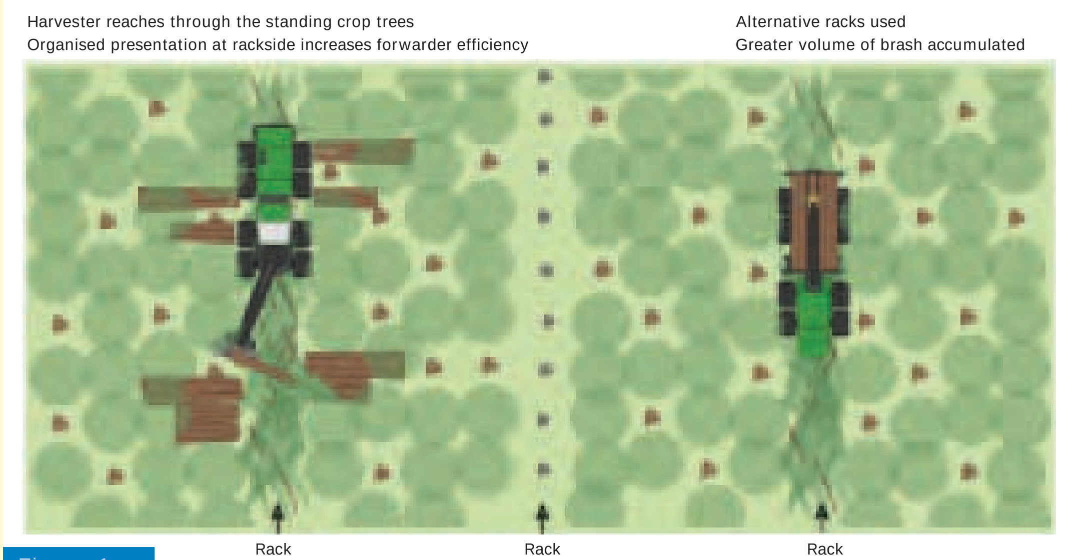


Figure 1

Using alternate racks for extraction maximises available quantities of brash and reduces the compacted area.

Risks from introduced pathogens

Joan Webber

Phytophthora ramorum, the cause of Sudden Oak Death in western USA, has been found at approximately 400 nurseries and garden centres and at a smaller number of parks and historic gardens across southern England.

Collaborative research between FR pathologists and colleagues at the Central Science Laboratory shows that *P. ramorum* is remarkably adaptable, affecting a large range of hosts and causing a variety of symptoms. Some trees have susceptible bark and can develop lethal, bleeding bark infections. Other trees or shrubs suffer only foliage infections or shoot death and though rarely seriously affected, provide the source of inoculum for bark infections on trees. Trees suffering from ramorum bleeding bark cankers have always been found close to infected rhododendrons (mainly *Rhododendron ponticum*), usually within 2–5 m.

Initial research work:

- tested UK tree species to assess which are most at risk of developing lethal bark infections;
- assessed which foliar hosts could be significant sources of spore inoculum.

Trees with susceptible bark include beech, American northern red oak, turkey oak and horse chestnut. Trees with susceptible foliage include holm oak, sweet chestnut and ash. These tests have proved to be very good predictors of susceptible hosts in the field, although the total number of infected trees is small. Currently only around 40 affected trees have been found and all, except one, are in Cornwall.

It is important to understand how *P. ramorum* reproduces, spreads, infects and survives under UK conditions in order to predict risk. Infective spores are probably produced on foliar hosts and natural dispersal can be local and limited through rain-splash and mists. Human activities may move the pathogen further afield through contaminated leaf litter or soil on shoes.

Figure 1

Phytophthora kernoviae causing (a) rhododendron wilt and (b) bleeding stem lesions on beech.

Recently another exotic *Phytophthora* species has been discovered and named *P. kernoviae* (after Kernow, the Cornish name for Cornwall). So far it has only been found in woodlands and gardens in Cornwall, one area of south Wales and in one nursery. It also infects rhododendron (Figure 1a) and in the past year has been found causing bleeding bark cankers on 40 beech trees (Figure 1b) and two native oaks close to *P. kernoviae* infected rhododendrons.

Assessing the risk from *P. kernoviae* is in its early stages, but it is clear that both *P. ramorum* and *P. kernoviae* represent a potentially serious threat to trees in the UK. Currently the Forestry Commission and Defra are putting measures in place to contain and eradicate this pathogen while the risks are evaluated more fully.

Risks posed by wood packaging materials in international trade

Hugh Evans

For many years, scientists in Tree Health Division have carried out research into the threats posed by exotic pests and diseases, most recent of which is the emerald ash borer beetle *(Agrilus planipennis)*, shown in Figure 1. For most of the damaging organisms already established in the UK, the pathway for invasion has been associated with wood, either as a product or as wood packaging material.

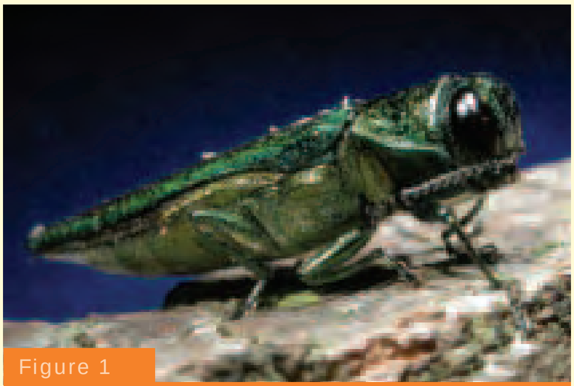


Figure 1

Adult emerald ash borer: *Agrilus planipennis* (David Cappaert: www.insectimages.org).

Rules to reduce the risks from these pathways have been developed and these are reasonably effective in well-regulated wooden products. However, wood packaging material is much more difficult to regulate because it ranges from fully manufactured materials such as pallets, through to completely raw wood used as dunnage. It has also been recognised by the International Plant Protection Convention that rules were needed specifically for wood packaging and these have been promulgated through the newly introduced International Standard on Phytosanitary Measures (ISPM) Number 15. This requires that wood is treated to kill any pest or disease organisms present before shipment. Currently the two methods of choice are heat treatment (HT) to reach a wood core temperature of 56 °C for 30 minutes or to carry out methyl bromide fumigation to an agreed standard.

With part funding by the Carbon Trust, FR has been working with BHR Group at Cranfield to assess methods for verifying that HT has been carried out to the required standard and also to develop procedures that minimise the treatment time and, consequently, energy required to heat the wood. This research has used a combination of mathematical modelling of heat penetration into the wood, using an Elasteq model developed by BHR scientists and both laboratory and industrial heating chamber experiments and tests by FR and BHR to test and verify heat penetration predictions.

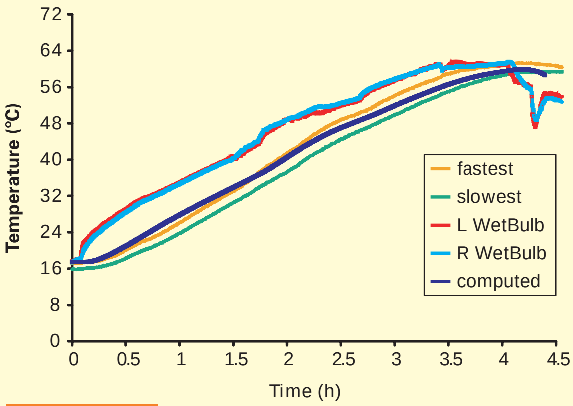


Figure 2

Heating profiles of pine with moisture content of > 35 %. The two chamber wet bulb profiles, the slowest and fastest heating wood pieces and the TimberTherm computed line are shown.

The work has now developed a beta version of the software, named TimberTherm, which has proved accurate for a range of timber species and dimensions. For example, Figure 2 shows the actual and predicted heat penetration curves for pine in an industrial heating chamber under standard loading. Verification was carried out using thermocouples placed in a number of pieces of wood within the chamber and the curves show the slowest and fastest heating pieces as well as the two chamber wet bulb curve profiles and the TimberTherm predicted curve.

Birch dieback in new native woodlands in Scotland

Sarah Green

INTRODUCTION

Birch (*Betula* spp.) is a major component of native woodlands throughout Scotland, and is valued increasingly as a resource for conservation, habitat and landscape purposes. There has also been recent interest in the potential of silver birch as a timber species in the UK (Malcolm and Worrell, 2001). Silver birch and downy birch are two of the more important broadleaved species in recent native woodland afforestation schemes in Scotland. The area of native woodland is projected to increase further with the continued take-up of the Scottish Forestry Grant Scheme. As a result, there are now large numbers of young birch trees on a wide variety of site types across Scotland. During the past few years, extensive dieback of birch has been reported in more than 20 native woodland planting schemes in Scotland. Affected trees appear to grow well initially, but approximately 5–10 years after planting begin to exhibit crown dieback. Symptoms include sunken cankers and fissures on stems and branches, and discrete lesions and tip dieback on young shoots. Although factors such as unsuitable provenance (area of origin) and site selection, poor silvicultural management and frost damage may contribute to this dieback, these symptoms suggest that attack by fungal pathogens may be important. A number of fungal pathogens have been found to cause shoot and stem lesions on birch in Finland and Canada, resulting in dieback or crown thinning (Arnold, 1967; Paavolainen *et al*., 2001). However, very little is known about the fungi associated with shoots of birch in the UK, or whether pathogenic shoot fungi are partly or wholly responsible for the symptoms of crown dieback. In 2002, FR initiated a study to investigate the fungal pathogens causing dieback of birch in Scotland; this article provides a brief overview of results from research conducted to date and is based on a recently published Information Note (Green, 2005).

Field surveys and pathogenicity tests

In May and September 2002, 30 diseased and 30 healthy young birch shoots were collected from each of five Woodland Grant Scheme (WGS) plantings in Scotland (Figure 1), making a total of 600 collected shoots. The fungi inhabiting these shoots were identified through a combination of isolation and incubation techniques. The most frequently occurring fungi were then inoculated onto birch seedlings in 2002 and 2003 to test their ability to cause disease on birch over subsequent growing seasons.

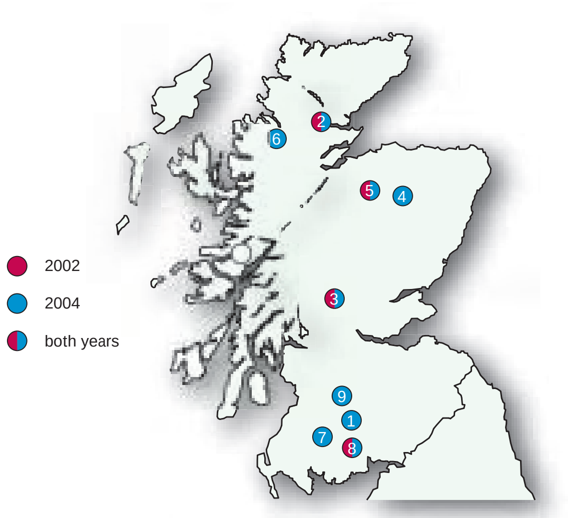


Figure 1

Map of Scotland indicating location of sites for the birch surveys in 2002 and 2004.

In 2004, 100 birch trees at each of nine WGS plantings in Scotland (Figure 1) were surveyed to evaluate the frequency of occurrence and severity of crown dieback, to record the incidence and severity of two fungi, *Anisogramma virgultorum* and *Marssonina betulae*, which were found to be pathogenic, and to determine whether a relationship exists between incidence of *M. betulae* foliar disease and incidence of other (non-*Anisogramma*) shoot/stem cankers. Eight of the sites were planted between 1989 and 1995 with some areas of more recent beating-up, and one site comprised late-1980s naturally regenerated downy birch of local origin.

Pathogenic fungi associated with birch shoots

At least 35 different fungal species were identified on young shoots of birch in the 2002 survey (Green, 2004). The majority of these fungi were non-pathogenic saprophytes or endophytes. Of the most frequently occurring fungal species from the 2002 survey which were inoculated onto birch in pathogenicity tests, three species caused significant disease and dieback: *Anisogramma virgultorum, Marssonina betulae* and *Discula betulina*.

Anisogramma virgultorum

Anisogramma virgultorum was first recorded on birch in the UK by Massee (1914), and has also been reported from other European countries and North America. This fungus was abundant on birch at four of the five WGS sites surveyed in Scotland in 2002. Inoculation studies conducted with *A. virgultorum* in Scotland have demonstrated that it is a primary pathogen on birch, with sexual spores, known as ascospores, infecting young, flushing shoots early in the growing season, stromatal cankers developing late in the growing season (Figure 2), and a large proportion of infected shoots dying back within the

Figure 2

Stromatal canker of *Anisogramma virgultorum* on a young shoot of downy birch.

year following infection (Green and De Silva, unpublished). Currently, little is known about the biology of this fungus. From observations, the fungal fruiting structures, known as perithecia, develop within the black, strip-like, stromatal cankers on current shoots by the autumn following spring infections, and mature ascospores are released, probably via rainsplash, over the subsequent winter and spring. Once ascospores have been discharged, the stromatal tissues dry up and drop out of the cankers, leaving deep fissures in shoots and branches (Figure 3), which are indicative of older infections by *A. virgultorum.*

Marssonina betulae

Marssonina betulae is a common foliar pathogen on birch throughout Europe, causing leaf spots as well as lesions on young shoots. The fungus infects leaves and young shoots in spring and summer via asexual spores called conidia, which are likely spread by rainsplash from overwintering infected leaf material. Previously, damage caused by this fungus was thought to be limited to leaves and young, small shoots, and its degree of aggressiveness was considered to be weak (Peace, 1962; Bäucker & Eisenhauer 2001). In this study, *M. betulae* was found inhabiting diseased shoots at all five WGS sites sampled in 2002, causing necrotic lesions on 63 % of diseased 4 to 5-month-old shoots collected in September (Green, 2004). Also, inoculation of silver birch seedlings with *M. betulae* resulted in the development of secondary stem cankers (Figure 4), which continued to expand months after initial infection, causing extensive shoot dieback and the death of some seedlings (Green, unpublished). These results indicate that *M. betulae* is more damaging to birch than the literature currently suggests.

Figure 3

Elongated fissures in dead shoots of silver birch indicative of an old infection by *Anisogramma virgultorum.*

Figure 4

Secondary cankers on a silver birch seedling inoculated with *Marssonina betulae*, taken 19 months after inoculation.

Discula betulina

Discula betulina is another common leaf spot fungus on birch (Bennell and Millar, 1984). The means by which this fungus initiates new infections in the spring is unknown, but once established, it is thought that conidia produced on leaf spots are spread via rainsplash to perpetuate the cycle of leaf infections during the summer. *Discula betulina* has not been reported previously on birch shoots. However, *D. betulina* was found on both diseased and healthy shoots of birch from all five sites surveyed in Scotland in 2002, indicating that it has an endophytic, or asymptomatic, phase in its host (Green, 2004). When seedlings were inoculated with this fungus, dieback of young shoots occurred, but it did not cause progressive disease and all inoculated seedlings subsequently recovered from infection (Green, unpublished). Although not considered to be a major cause of birch dieback, *D. betulina* may contribute to the problem as severe leaf infections can cause premature defoliation (Phillips and Burdekin, 1982) and this fungus may cause death of small shoots in combination with other stress factors.

Impact of pathogenic fungi on young birch surveyed in Scotland in 2004

Eight of the nine WGS sites surveyed in 2004 (Figure 1) were exposed sites with moderately wet acidic soils and seven of the sites lay above 250 m elevation. In terms of exposure and wetness the most extreme sites were numbers 4, 6 and 7, whereas number 8 was the only sheltered, brown earth site in the survey (Table 1, Figure 1). At six of the nine sites, at least half of all birch trees surveyed had 40 % or greater crown dieback (Table 1). In total, 61 % of silver birch (n = 291) and 41 % of downy birch (*n* = 608) had 40 % or greater crown dieback.

Overall, 57 % of the 900 trees surveyed had *A. virgultorum* and 28 % had *M. betulae*, with incidences of infection varying quite widely from site to site (Table 1). *Anisogramma virgultorum* occurred more frequently on downy birch (64 % infected) than on silver birch (40 % infected), whereas *M. betulae* occurred more frequently on silver birch (50 % infected) than on downy birch (17 % infected). The incidence of other (non-*Anisogramma*)

Table 1

The percentage of trees with 40 % or greater crown dieback, infected by *Anisogramma virgultorum* and infected by *Marssonina betulae* (*n* = 100 for all variables) at each of nine WGS sites in Scotland.

	% incidence		
Site number	≥ 40 % dieback	*Anisogramma*	*Marssonina*
1	27	82	5
2	33	60	35
3	63	19	46
4	50	32	47
5	58	50	60
6	57	72	28
7	62	43	8
8	53	96	8
9	24	56	15
Overall mean	51	57	28

Figure 5

'Other cankers' (non-*Anisogramma*), thought to be caused by *Marssonina betulae* on silver birch.

shoot/stem cankers (Figure 5) was also greater on silver birch (63 % affected) than on downy birch (30 % affected). There was a significant correlation ($P < 0.0001$) between the incidence of *M. betulae* foliar disease and incidence of other (non-*Anisogramma*) shoot/stem cankers, with 82 % of *M. betulae*-infected trees having these other cankers (Figure 5). This provides further evidence that *M. betulae* causes the sunken cankers on shoots and stems which are commonly seen on young birch in the field, resulting in shoot dieback. The severity of *A. virgultorum* and other cankers both correlated highly ($P < 0.0001$ for both disease variables) with severity of crown dieback, indicating that *A. virgultorum* and *M. betulae* are important causal agents of crown dieback of birch at these WGS sites in Scotland. *Discula betulina* was also commonly found causing leaf spots on silver and downy birch at all nine sites.

Other site factors and disease

Birch trees planted on particularly poor, exposed sites might generally be regarded as having increased susceptibility to fungal infection. However, the 2004 field survey indicated that the poorest site conditions do not necessarily result in the highest levels of disease. For example, the greatest incidence of *A. virgultorum* was at site number 8 (Table 1), the only sheltered, brown earth site in the survey. Both *A. virgultorum* and *M. betulae* are present in native populations of birch in Scotland. Therefore, variations in the frequency of these diseases from site to site could be partially explained by varying degrees of exposure to natural inoculum from surrounding areas together with local climatic variables, these being two important factors influencing the establishment and spread of disease on a site.

Birch provenance may also be an important factor determining susceptibility to these diseases, and responsible for some of the site by site variation in disease incidence. The exact provenance of the planting stock could not be determined accurately for the majority of sites surveyed, and it is possible that birch of non-local origin was used in a number of these WGS plantings. At some sites pockets of naturally regenerated downy birch were healthy despite the prevalence of disease at these sites. It cannot be assumed, however, that all naturally regenerated stock is more resistant since site number 9 is largely comprised of naturally regenerated downy birch of local origin, yet many trees were heavily diseased. A certain form of planted birch present at a number of sites appeared to be healthy despite having the same growth conditions as adjacent, heavily diseased birch trees. These were usually scattered individual trees (either silver or downy birch) with particularly dense, bushy growth form, small, round leaves and glabrous shoots. Such trees were phenotypically distinct from heavily diseased trees.

Future work towards managing birch dieback

This study has identified two pathogenic fungi, *A. virgultorum* and *M. betulae*, both of which play an important role in the dieback of young birch in Scotland. Only limited information is currently available on the inoculum source, life cycle and infection biology of these fungi, and further studies need to be undertaken in this area of work before management recommendations for reducing the establishment and spread of disease can be developed. We have already shown that *M. betulae* occurs much more frequently on silver birch than on downy birch and that the reverse appears to be true for *A. virgultorum*. Observations from the 2004 field survey indicated that further genetic variability within each birch species could influence disease expression. An investigation into the role of birch provenance and phenotype in determining susceptibility to *A. virgultorum* and *M. betulae* is now under way in order to try and identify less disease-susceptible stock for use in future planting schemes in Scotland.

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Interactions between floodplain woodland and the freshwater environment

Tom Nisbet

INTRODUCTION

Interest in the subject of floodplain woodland has expanded rapidly over the past 10–15 years. Attention initially focused on the high conservation value of this essentially lost habitat, with various groups embarking on a series of prominent site restoration schemes. This was followed by joint action to restore and create more wet woodlands, with specific targets set under the UK Biodiversity Action Plan. More recently, interest has shifted both nationally and internationally to consider the flood and pollution control functions of floodplain woodland.

Forest Research's involvement began in 1995 with a scoping study to assess the possible benefits and risks of restoring floodplain woodland in lowland Britain (Kerr and Nisbet, 1996). This drew attention to the need for further research to better understand and help quantify these effects. Work on investigating the role of floodplain woodland in flood control started in the late 1990s under the Forest Hydrology Programme. The first study looked at opportunities for planting floodplain woodland to help alleviate flooding in the River Parrett catchment in southwest England (Nisbet and Broadmeadow, 2003). A number of sites were identified and one of these was selected in 2003 to model the hydraulic impact of establishing a floodplain woodland.

This article presents the results of the initial modelling work and describes new studies designed to test predictions in the field. A number of related research topics are also described, including an experiment to better quantify the influence of riparian woodland shade on stream water temperature, the development of eco-hydrological guidelines to protect wet woodland habitats, and the implementation of a diagnostic tool for assessing the ecological status of river quality in functional terms.

The hydraulic impact of floodplain woodland

The use of floodplain woodland as an aid to flood control has been discussed for many years. Some flood defence engineers have argued that floodplain woodland would only be able to exert a small effect on flood flows, while others have expressed concern that any backing-up of floodwaters could adversely affect local properties. The high degree of uncertainty associated with these and other potential impacts has precluded any significant floodplain woodland planting to date.

The main mechanism whereby floodplain woodland could aid flood defence is by slowing the downstream passage of a flood peak, resulting in a lower but longer duration event. Floodplain woodland has naturally carried out this role in the past and its removal has probably contributed to an increase in flooding severity.

The delaying effect on flood flows is mainly due to the contribution of vegetation roughness (see Figure 1). The nature of the vegetation is important because of the type of frictional effects it produces. Thus, trees create more of a physical barrier than bushes because the latter can flatten during high flows whereas trees do not. The spacing and layout of trees, smoothness of trunks, presence of lower branches, level of undergrowth and amount of dead wood on the woodland floor all have an effect. By varying these factors, woodland management and design can exert a strong influence on woodland roughness and thus on the capacity of floodplain woodland to impede flood flows.

Figure 1

Fallen logs, branches and leaf litter collect to form debris dams which act to hold back and slow down flood flows.

Since there will be a long time lag between the planting of floodplain woodland and any significant effect on flood flows, there is an urgent need for research to quantify the effectiveness of this type of woodland as a mechanism of flood defence. In particular, information is required about the actual flood storage potential of floodplain woodland, the extent to which woodland could retard different sized flood peaks, and how any flood attenuation effect could be maximised through woodland design, including location, shape, size, age and species choice. The rarity of floodplain woodland in the UK and lack of hydrological data means that research must first focus on hydraulic modelling. The following section describes the results of initial work aimed at modelling the hydraulic effects of floodplain woodland at a test site in southwest England.

Case study: Parrett Catchment

The River Parrett is 59 km long and its main tributaries include the Rivers Tone, Isle, Yeo and Cary. It drains an area of over 1690 km^2, comprising around 50% of the land area of Somerset. A number of towns face a serious and recurrent flooding problem and the catchment is the location of a wider study to formulate a strategy and integrated plan for improving flood management. A key objective of the strategy is to explore how new woodland could help to alleviate downstream flooding in towns like Bridgwater.

A reach on the River Cary, 300 m upstream of the Environment Agency's gauging station at Somerton (No. 52011, NGR ST 498 291), was chosen as the study site. This was one of a number of areas in the Parrett Catchment identified as being potentially suitable for floodplain woodland restoration (Nisbet and Broadmeadow, 2003). The modelled river reach extends for approximately 2.2 km and has the potential to be completely forested.

The catchment area to the gauging station is approximately 82.4 km^2 and the highest recorded flow is 13.65 $m^3 s^{-1}$. The estimated 1 in 100 year flood or 1% annual probability event (a.p.e.) is 15.2 $m^3 s^{-1}$, which defined the inflow boundary condition for the model simulations. Topographic data for the study reach were obtained from the Environment Agency in the form of 2 m resolution LiDAR data and 10 surveyed cross-sections of the channel. The channel is approximately 16 m wide and 2 m deep. The potential flooded area extended mostly over the north bank of the river, reaching a maximum width of approximately 400 m.

Model simulations

The principle effect of floodplain vegetation is to increase surface roughness. Most models use Manning's roughness coefficient *(n)* to represent the energy lost in water flowing across the floodplain. There are a number of methods for calculating Manning's *n* and separate values are required for the river channel and floodplain.

Three contrasting scenarios were considered for the model simulations. The first represented the present land cover of pasture, the second a complete cover of thick broadleaved woodland along the wider north bank of the floodplain, and the third, a 500 m length section comprising 50 ha of woodland in the centre of the floodplain. The latter scenario allowed both the upstream and downstream impact of the woodland to be evaluated. Manning's *n* values of 0.035 and 0.15 were selected from the work of Chow (1959) as being typical for the pasture and woodland covers, respectively. An example of the type of woodland with this roughness value is shown in Figure 2.

Figure 2

Typical woodland type that would give a Manning's *n* roughness of 0.15 during a flood with a water depth of 1.25 m (Acrement and Schneider, 1990).

Two models were selected to evaluate the effects of floodplain woodland on flood flows. The first involved the 1D model called HEC-RAS that was originally developed by the US Army Corps of Engineers and is widely used by flood defence engineers in the UK. The second was the River2D model developed by the University of Alberta in the USA (Ghanem *et al.*, 1995). Both models used the channel geometry from surveyed cross-sections and topographic data from a 2 m resolution LiDAR survey. The latter was used to generate 10 m interval topographic transects for the 1D model.

A selection of the 1D model results is presented in Figure 3. Figure 3a shows that the presence of woodland along the entire length of the reach increased the flood level by as much as 270 mm. This raised the volume of flood storage by 71% and led to a marked delay of 140 min in the downstream passage of the flood peak (Figures 3b and 3c).

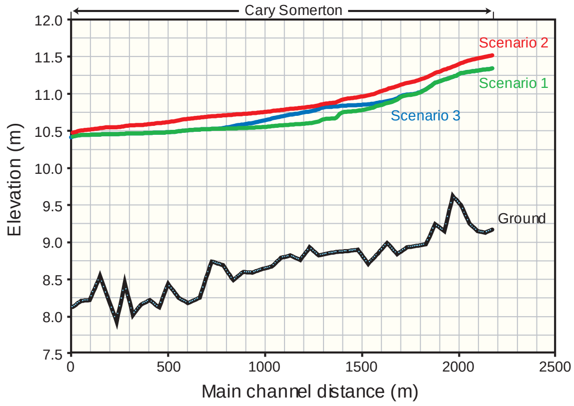
The central block of woodland had a similar but more localised effect on the flood level, which increased by 180 mm at the upstream edge. This led to a backing-up of water, with raised levels extending a distance of nearly 400 m upstream of the woodland. The effects on flood storage and flood peak travel time were much less than for the complete woodland cover, but still significant with 15% greater storage and a delay of 30 min, respectively.

The River2D model allowed a more detailed assessment of the effects of floodplain woodland on flood depth and water velocity. Figure 4a and b compares the profiles of these two parameters between the pasture and complete woodland scenarios. The effect of the woodland on flood depth was similar to the results of the 1D model, with a maximum increase of 190 mm. However, the horizontal extent of the flooding was relatively unchanged, probably because the topographical limit of the floodplain was already reached in many areas. The water velocity vectors show a reduction in flow velocity across a large part of the floodplain but especially in the upper end of the reach.

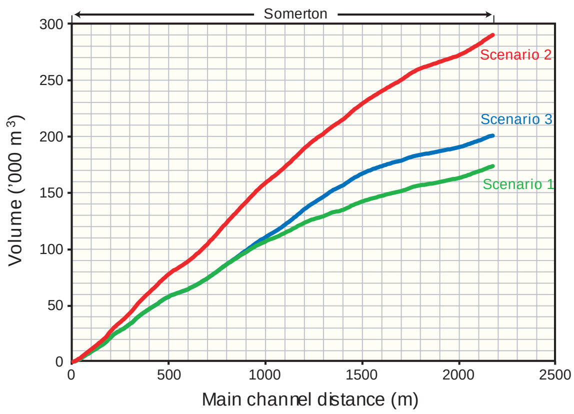
Figure 3

1D Model results.

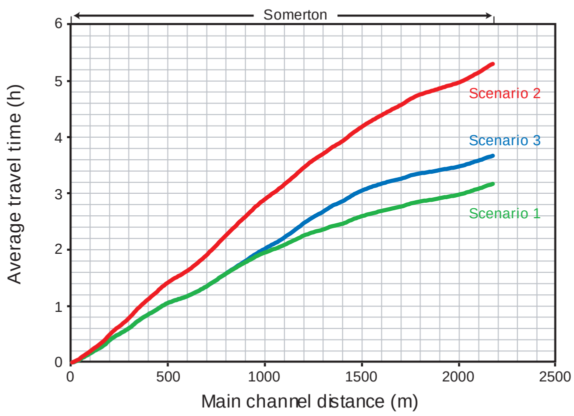
(a) Longitudinal profile displaying water and bed levels along the reach (wooded area for scenario 3 is located between 783 m and 1277 m).



(b) Flood storage volume with distance along the modelled reach.



(c) Average travel time for the downstream passage of the flood peak along the modelled reach.



Values for the woodland were generally in the range 0.04–0.07 $m\ s^{-1}$ in the lower half and 0.14–0.3 $m\ s^{-1}$ in the upper section, compared to 0.05–0.2 $m\ s^{-1}$ and 0.15–0.5 $m\ s^{-1}$ for the pasture, respectively. As expected, the velocity gradually decreased towards the outer edge of the flood.

The effect of the central block of woodland on flood depth is displayed in Figure 5. The results were similar to the 1D model with the water level raised by a maximum of 118 mm and a backwater effect that extended 300 m upstream of the woodland.

The magnitude of the predicted effects of both woodland scenarios is considered to be significant in flood management terms. For example, in the context of planning control, the Environment Agency regard a 50 mm rise in water level to be 'significant' in terms of the impact of building developments on the floodplain. The additional time generated by the predicted lag in the downstream progression of the flood peak would also be very valuable in terms of flood warning.

It is important to note that the size of the modelled floodplain woodland was relatively small in relation to the extent of the catchment of the River Cary. The 2.2 km reach comprised a total area of 133 ha of floodplain woodland in scenario 2, which is less than 2% of the total catchment area of 82 km^2. A much larger floodplain woodland or a series of similar sized woodlands in other parts of the catchment could therefore be expected to have an even greater response. Similarly, if this pattern was replicated across other tributary catchments it should be possible to exert a sizeable impact on flooding, even within a very large catchment such as the River Parrett.

A detailed analysis of the hydrographs of individual tributaries could identify where the restoration of floodplain woodland would exert the greatest benefit in terms of desynchronising sub-catchment contributions and therefore the size of the main flood peak. Desynchronisation, however, is likely to extend the flood hydrograph with possible

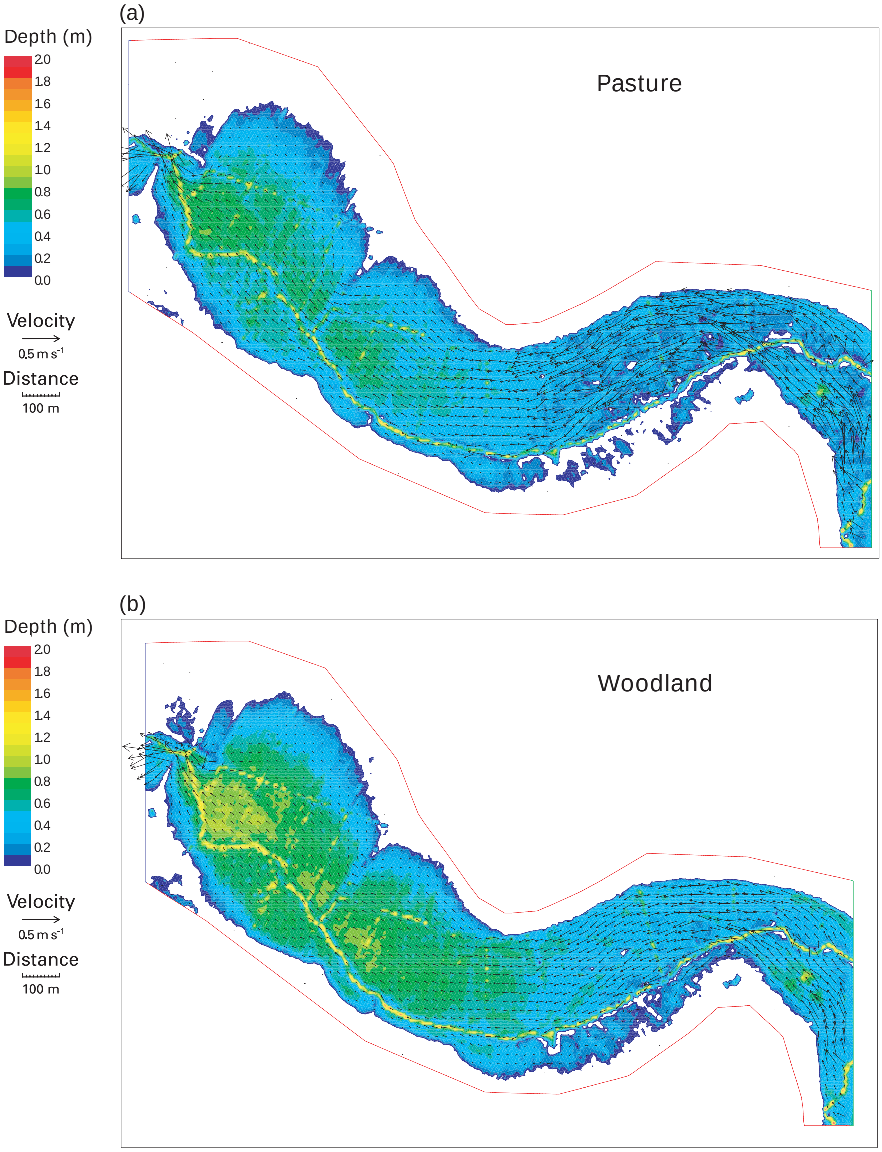


Figure 4

Plan view of flood depth and flow velocity: (a) assuming floodplain is covered by pasture (scenario 1); (b) for a complete cover of floodplain woodland on the north bank of the floodplain (scenario 2). Arrow length is proportional to velocity.

implications for longer duration or consecutive flood events. This concept is depicted diagrammatically in Figure 6.

The model predictions are based on using a roughness value associated with a dense stand of willows with limited amounts of dead wood on the woodland floor. It should be possible to create additional roughness by adopting management practices aimed at increasing levels of dead wood. Large woody debris forms a very important component of the roughness or flow resistance of both the floodplain and river channel, mainly arising from the formation of debris dams. The formation of multiple channels and pools typical of natural floodplain woodland could also be expected to enhance floodplain roughness and flood storage. The obstruction provided by individual trees and debris dams restricts water flow and contributes to scouring and channel development.

The backing-up of floodwaters upstream of a floodplain woodland could threaten local properties. Increased water levels of up to 190 mm were predicted to occur immediately above the forest. The implications of this factor need to be considered on a site by site basis guided by the results of modelling work.

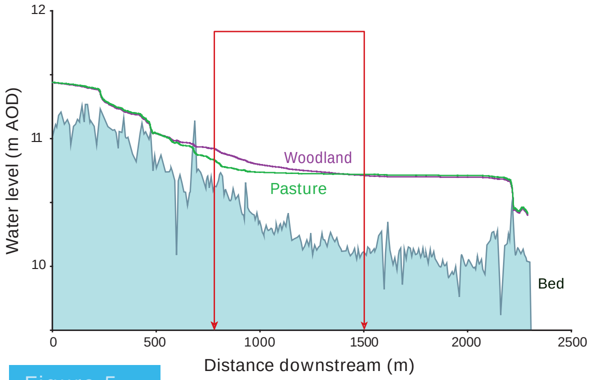


Figure 5

Longitudinal water surface profile along section of modelled river reach for scenario 3: woodland located between 790 and 1512 m.

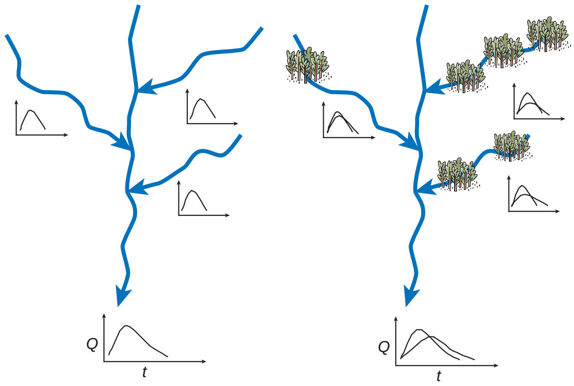


Figure 6

Conceptual diagram showing the cumulative effect of restoring floodplain woodland within a larger catchment on the flood hydrograph of individual tributaries and the main river. *Q*: river discharge; *t*: time.

Another potential threat posed by the restoration of floodplain woodland is the blockage of downstream structures such as bridges and culverts by woody debris. Further work is required to quantify the amount and nature of woody debris generated by floodplain woodland and the risk of this being washed out and moved downstream. Floodplain woodlands are thought to be reasonably retentive for large woody debris and it may be possible to enhance this function through management. One option could be to have a series of floodplain woodlands along a river system with the lowest one managed to maximise debris retention.

Conclusions

The findings of the initial modelling work suggest that there is considerable scope for using floodplain woodland as an aid to flood control. The scale of the modelled woodland was very small in relation to the size of the catchment, implying that a larger woodland block or a series of similar sized ones could exert a much greater downstream impact. In particular, if this pattern was replicated across other tributary catchments, it should be possible to influence flood flows even within very large catchments, such as the River Parrett.

A detailed analysis of the flood hydrograph would identify where the restoration of floodplain woodland would have the greatest benefit in terms of desynchronising sub-catchment contributions and therefore in attenuating the main flood peak. Desynchronisation, however, could extend the flood hydrograph with possible implications for longer duration or consecutive flood events.

Although it is very unlikely that floodplain woodland on its own would be able to provide complete protection for downstream towns or cities, it could make a valuable contribution alongside existing flood defences to tackling the increased risk of flooding associated with climate change. Similarly, it could have an important role to play in helping to manage smaller scale flooding problems where the high cost of constructing hard defences cannot be justified.

Future work

Work is under way to apply the models to other sites to test the transferability of the model predictions. One site involves Great Triley Wood near Abergavenny in south Wales. The small river that flows through this native floodplain woodland was instrumented at the beginning of 2005 to collect water level and velocity data during flood events. Although the site normally floods some 5 to 6 times per year, unfortunately, the relatively dry winter and spring have produced no events to date. Details of the instrumentation and layout are shown in Figure 7. Floodplain and channel cross-sections have been surveyed and measurements made to estimate the Manning's roughness coefficient for

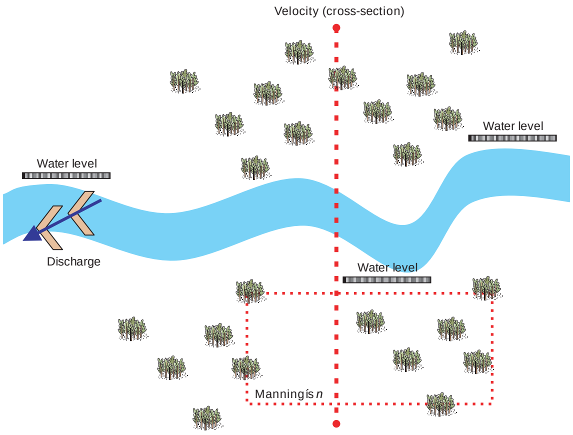


Figure 7

Conceptual diagram of floodplain woodland monitoring plot.

the floodplain woodland. The 1D model has been set up for the site and will be run for different sized flood events. In due course, these predictions will be compared to observations in order to test the performance of the model.

Three other sites have been selected on the River Laver, north of Ripon in Yorkshire. This is part of a much larger joint Defra/Environment Agency/English Nature/Forestry Commission pilot project to develop multi-functional approaches to flood risk management at the catchment scale. The sites are currently non-wooded but have been identified as holding some potential for converting to floodplain woodland. They will shortly be instrumented with water level recorders to provide baseline data for assessing future change. The intention is to set up both the 1D and 2D models for each site to investigate the potential impact of establishing several floodplain woodlands on flood flows in the River Laver and future flood risk in Ripon.

Investigating the influence of riparian shade on stream water temperature

One potentially adverse effect of climate warming is increased thermal stress for freshwater fish. Fish, and salmonids in particular, are very sensitive to changing temperature, with possible effects on the timing of spawning, fish growth rates and even survival. Salmonid fish require temperatures of between 5 and 15 °C for normal growth and rises above 21 °C can be lethal. Observations in recent years show that this tolerance limit can be significantly breached in smaller rivers during summer periods, especially in southern England.

Riparian woodland may have an increasingly important role to play in limiting such effects through the provision of shade, especially if climate warming continues as predicted. Judicious management of riparian woodland offers a means of maintaining water temperatures within a favourable range for salmonid fish and other sensitive freshwater fauna. A joint field study with Southampton University has recently been set up in the New Forest to evaluate the cooling effect of riparian shade. Ten sites with variable levels of shade on the Dockens Water and Ober Water have been instrumented to characterise the thermal regime and assess the effects of shading on streamwater temperature and on fish populations, including fish survival, growth rates and behaviour. The results will help to determine whether thermal stress poses a serious problem in small watercourses and if so, how riparian woodland management could help to protect the freshwater biota from future rises in water temperature.

Eco-hydrological guidelines for wet woodland

Wet woodland has been identified as a priority habitat requiring protection in the UK. The rarity and high conservation value of many wet woodlands has resulted in them being selected as Special Areas of Conservation (SACs) under the EU Habitats Directive. This designation requires all competent authorities to assess plans and projects that could affect the nature conservation value of these sites in order to ensure that their ecological integrity will not be adversely affected. Unfortunately, knowledge is lacking about the potential impact of a range of human activities, such as water abstraction, on the condition of these sites and on the specific ecological requirements of the wet woodland habitats and species. In particular, there is an urgent need to define scientifically robust eco-hydrological targets for the two Annex 1 wet woodland habitats: residual alluvial forests and bog woodlands.

As a first step, Forest Research was contracted by English Nature to provide an overview of the current state of the science relating to the eco-hydrological requirements of wet woodlands, and to scope out the direction of future research to facilitate ecological target setting.

The findings of this work have been written-up in a final report to English Nature (Barsoum *et al.*, 2005). Proposals for future work range from the need to better characterise and define the existing wet woodland resource to more in-depth studies to support the development, extension and testing of eco-hydrological targets.

Rivfunction

RIVFUNCTION is a pan-European research project which aims to develop and communicate a diagnostic tool for assessing the ecological status of river quality in functional terms. The method is based on litter decomposition and is widely applicable to national and regional agencies responsible for implementing the EU Water Framework Directive. The EU WFD explicitly recognises the importance of ecosystem function when defining the ecological status of aquatic systems. However, an effective assessment method does not exist currently. RIVFUNCTION seeks to fill this gap and provide a more complete assessment of ecological status, facilitating the development of improved water management policies. The objectives of the project are:

- To test whether leaf decomposition is a good indicator of functional integrity.
- To evaluate the response of leaf decomposition to eutrophication and riparian forest management.
- To develop an assessment tool, including methodology and threshold values for litter decay rates which define different ecosystem status classes.

The project is funded by the European Commission under the Fifth Framework Programme and involves 11 research partners from 8 countries. Field experiments are being conducted at 200 paired sites across 12 Ecoregions. Forest Research is primarily involved in translating the results into practice and promoting the use of the assessment tool amongst end users (Broadmeadow *et al.*, 2005).

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Innovative tests for nursery management Unravelling molecular events in dormancy and cold hardiness of tree seedlings to inform operational practice

Mike Perks

THE COLDTREE PROJECT: INTRODUCTION

The COLDTREE project is a first step towards the development of molecular diagnostic tests for cost efficient reforestation and nursery logistics. Sustained yield from Europe's commercially exploited forests requires a supply of millions of seedlings annually (see Figure 1). The planting stock requirement for reforestation, new woodland creation and urban forestry projects is almost 1.7 billion tree seedlings and ornamental woody plants annually in the EU, comprising a total value of £1.4 billion (€2 billion), the bulk of which is produced by European forest tree nurseries. Nursery logistics require a tight scheduling of operations to be able to deliver healthy seedlings to the planting site. A critical step in a modern nursery production chain is the transfer of seedlings to cool or frozen storage. Storage is required to prevent winter damage, to maintain planting stock in an inactive condition for extended periods, and to ensure plant quality where supply is for geographically distinct planting sites. Efficient management requires that operational handling of seedlings, including transfer to cold storage, is implemented at a time that ensures continued plant health while maximising operational flexibility. Lifting and storage of insufficiently hardened plants reduces vitality and may lead to cold damage, dehydration and fungal infection. To prevent this kind of damage, and its adverse economic effects on nurseries and end-users, it is of particular importance that nursery managers are able to determine accurately the peak physiological condition of seedling trees for lifting or transfer.

Assessing seedling quality

Despite the economic importance of such decisions, nursery managers still often rely on traditional (morphological) methods to identify ‘plant movement windows’ (Mohammed, 1997), i.e. the start of operational practices in winter, cold storage etc.

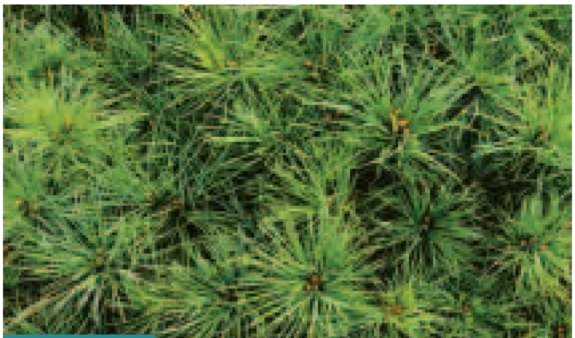

Figure 1

Aerial view of containerised Scots pine (*Pinus sylvestris* L.) seedlings.

Recently, several physiological measurement techniques have been proposed, some of which are used operationally. However, the number of nurseries in Europe utilising these techniques is limited because the methods are either unreliable, labour intensive or technically demanding and the minimum test period (dependent on specific test) can vary from 2 to over 14 days (Puttonen, 1997). Furthermore techniques developed and routinely applied in UK bare-root nurseries (e.g. root electrolyte leakage, REL; McKay, 1992) are unreliable when applied to containerised production systems. In nursery practice, where lifting opportunities can be severely limited by rainfall, frost and snow, such delays can significantly reduce the number of plants lifted at peak physiological condition. In spring, plants start reversing the processes that protect them during winter before there is a visible sign of regrowth; consequently if they are put into cold storage too late in spring, they experience damage, particularly to the root system.

Efficient post-planting establishment and cost-effective nursery management therefore require tools for rapid and reliable determination of the physiological condition of forest tree seedlings such as those shown in Figure 1.Ideally these test procedures should not require high levels of investment or technical knowledge.

Molecular diagnostic tools

To develop such tools a detailed understanding of the cellular and molecular processes underlying cold hardiness and dormancy processes is required (Li *et al.,* 2004). Unravelling the gene expression pattern as a seedling acquires the hardened state will reveal key processes that can be used as indicators to describe the physiological condition of the tree (cf. Pearce, 1999; Thomashow, 1999).

Investigation of these processes and identification of candidate genes was the primary goal of the COLDTREE project (Box 1). Eventually, this effort could result in molecular tests based on the presence or absence of specific messenger RNAs or proteins, that will allow a rapid evaluation of the physiological state of the seedling and will facilitate afforestation and reforestation logistics. Such 'techniques of tomorrow' are not yet available to forest tree nurseries. Little knowledge of the molecular nature of the intertwined processes of dormancy and hardiness in woody species exists. In order to identify molecular mechanisms involved in winter hardening in woody plants the COLDTREE project participants employed the powerful cutting-edge technology of cDNA microarrays, also known as DNA chips, which allows the monitoring of thousands of mRNAs simultaneously (see Figure 2).

Box 1

COLDTREE project: summary of objectives.

To identify novel physiological and genetic techniques indicative of the onset of winter hardiness and dormancy in woody species and, using cDNA microarrays, to postulate a conceptual model describing the molecular events underlying these processes.

To select a set of key genes, of which the expression patterns can be used to describe the stages of dormancy and hardiness.

To evaluate the merits of these key genes as molecular diagnostic tools for nursery practice and improved establishment.

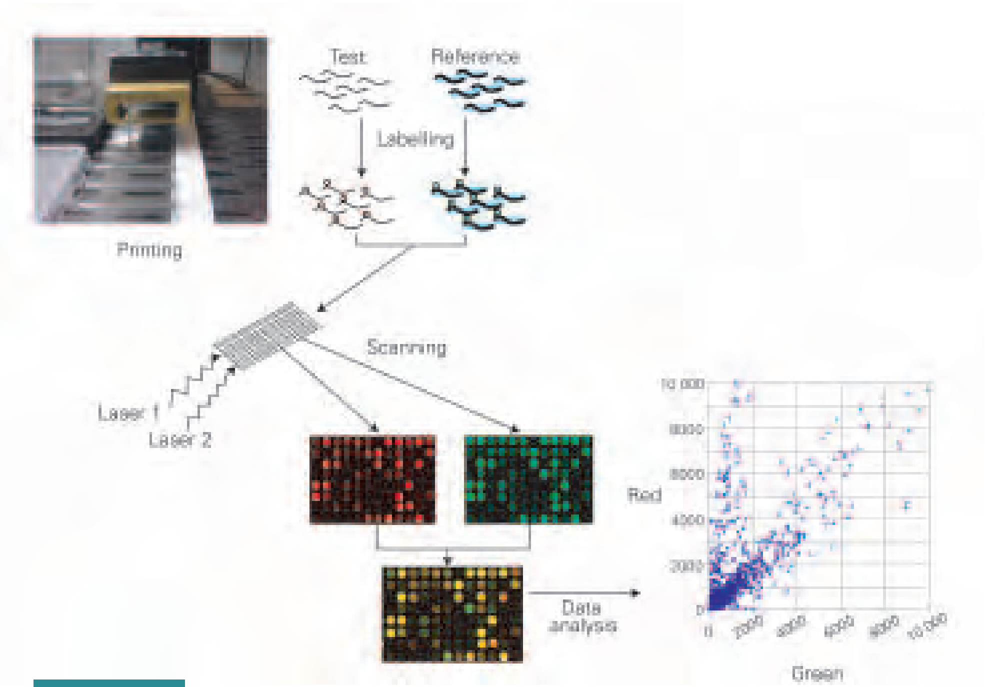

Figure 2

Schematic of the microarray probe technology. A 'chip' with 1500 wells has target genes inserted. The plant tissue extract is introduced to each well and if the target gene is functioning (upregulated) or switched off (downregulated) fluorescence occurs when laser-scanned.

This technique was used to detect gene transcripts characteristic for the dormant or active phases in Scots pine *(Pinus sylvestris)* and common beech *(Fagus sylvatica)*. These two economically important forest trees were chosen as model species to represent coniferous and deciduous European trees. Relevant mRNAs were selected and characterised to unravel molecular pathways involved in the process of winter hardening. Seedlings were grown in climate-controlled environments for the initial identification of relevant genes. Outdoor trials were also performed to detect the effect of climatic conditions, geographical location (across a north European ecocline) and provenance on the underlying molecular processes. Plant materials (buds, shoots and roots) collected during these trials were analysed both physiologically, employing physiological assessments of cell damage, and for gene expression, by cDNA microarrays and polymerase chain reaction (PCR) technology. Together, this data allowed the creation of a detailed picture of physiological and molecular events characteristic of the onset and release of cold hardiness and dormancy, and the effect of environmental factors on these processes.

Furthermore, the research resulted in a set of selected genes with a strong predictive value for cold acclimation and dormancy in the tested plant species. These genes can be used for the future development of an 'off-the-shelf' plant hardiness test-kit that will support nursery management decisions and facilitate forestation logistics.

cDNA microarray

Several cDNA libraries, either enriched for cold tolerance or dormancy related genes, were used to construct a cDNA microarray for pine bud tissue. Fifteen hundred clones were sequenced and blasted and contig-analyses were made to ensure the maximum number of different genes.

To test the cDNA microarray five preliminary hybridisations were performed using samples that represent the extremes from the physiological spectrum that will be analysed in the COLDTREE programme (Figure 3). These tests resulted in clearly distinguishable gene expression patterns. Different groups of genes could be identified, some associated with cold stress, some associated with dormancy, and some specific to release of dormancy.

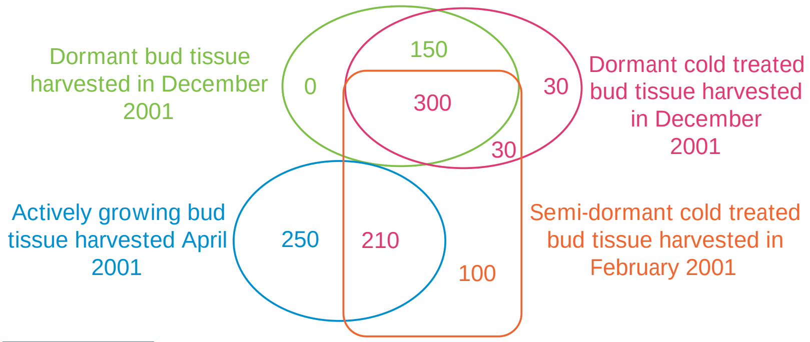

Figure 3

Gene expression collected from plants obtained under four different conditions was measured relative to a reference sample. Groups of genes that show expression levels that are higher than the reference are indicated in this Venn diagram. Circles represent samples, numbers in circles indicate the number of genes that are upregulated. Overlapping regions indicate genes that are upregulated in more than one sample.

COLDTREE achievements

Molecular monitoring of forest tree seedling quality will aid in the development of improved planning in the forestry sector. At present, it is not uncommon for 10–20% of seedlings in new plantations to die. Frost damage or desiccation during storage of insufficiently hardened plants often causes poor establishment. Therefore, better characterisation of seedling cold hardiness will ensure an enhanced quality of planting stock. This project enhanced existing knowledge of the fundamental cellular and molecular processes underlying winter dormancy and cold hardiness development in woody species. The cDNA microarray technology provided a new experimental tool enabling global searches on the function of genes, a capability which is only just starting to penetrate the field of plant molecular biology. The techniques used were eminently suited for the unravelling of functional gene networks and interlinked molecular pathways that determine the complex physiological processes involved.

COLDTREE project outline

The COLDTREE work plan used two model species for the development of the cDNA microarray. To identify relevant clones, the expression information was compared with data derived from thorough physiological analysis of the seedlings. For rapid detection of the selected genes RT-PCR assays were developed. Employing quantitative detection (via real-time monitoring of accumulating fluorescence) these assays can be used to obtain detailed information on the expression profile of the selected genes, collected from seedlings produced under operational conditions.

The work of the COLDTREE project was divided into three phases.

Phase 1

In the first two years climate room experiments were conducted by Forest Research (FR) and the Danish Institute of Agricultural Sciences (DIAS) in order to produce pine and beech seedlings in which the processes of dormancy and cold tolerance development were separated as far as possible. To this end three climate regimes were used:

- constant daylength and decreasing temperature;
- constant temperature and decreasing daylength;
- constant growth-permissive temperature and constant daylength (i.e. control).

DIAS focused on beech and FR on pine, but in both cases the experimental set-up was the same, except for the daylength and temperature cues which differ for pine and beech. In the second trial season climate room experiments assessed the combined effect of decreasing temperature and decreasing daylength with each partner assessing dormancy (by assessment of days to budbreak, DBB) and cold hardiness test (by assessment of root and shoot electrolyte leakage, REL/SEL) of excised root and shoot parts. To enable molecular investigation of the developmental processes, RNA from bud and root samples was taken according to a common protocol. The RNA was shipped to Plant Research International (PRI, University of Wageningen, Netherlands), for the preparation of the microarray probe.

Concurrently, the Agrotechnological Research Institute (ATO, Netherlands) pre-selected 1500 putative dormancy related genes from several pine cDNA expression libraries and isolated the corresponding inserts. PRI sequenced the 1500 cDNAs, and selected a subset to ensure the highest number of unique genes. Supplemented with several known conserved genes and a set of controls, these were used to construct a cDNA microarray; for the analysis of gene expression independent samples were used to challenge the microarray.

From each sample two probes were constructed, using different fluorescent dyes. The screenings data were analysed in comparison to the physiological data obtained from experimental trials to identify a set of 20–30 transcripts involved in either dormancy, cold hardiness, or both.

Phase 2

Once information from selected transcripts became available, these were used to design PCR primers for the development of reverse transcription–polymerase chain reaction (RT–PCR) assays with fluorescent detection markers. The PCR-based assays enable rapid and reliable detection of specific gene expression to be performed. Assessments of dormancy and hardiness development were conducted from September to December/January. In RNA samples the presence of relevant transcripts were monitored using PCR assays. This data aided the selection of six key genes which were descriptive of the physiological condition of pine and beech with respect to dormancy and cold hardiness. Additionally, the development of the PCR assays is a first step towards implementation of the knowledge gained within the project for the development of an operational test.

Phase 3

The key genes selected in phase 2 were evaluated in forest tree nurseries in the UK, Denmark, Sweden and The Netherlands. The trials identified the potential future benefit of molecular diagnostic tests for hardiness and dormancy, based on gene expression.

All data derived from the physiological and molecular analyses have been combined in a single searchable database allowing linkage of physiological, expressional, functional and sequence information. This combination of data offers a profound insight into the molecular pathways involved in the onset (and release) of winter hardening in *Pinus sylvestris* and *Fagus sylvatica*. Information on the influence of climate, environment and provenance on the expression of the genes concerned is now available, and continues to contribute to the definition of those molecular events underlying the onset and development of dormancy and cold hardiness in woody species.

We have communicated the project results to the sector, via a UK demonstration workshop for nurserymen. The main focus of this workshop was the significance of the results for facilitating nursery management by highlighting the potential of RT-PCR assays, and newly developed shoot-based physiological assessments of cold tolerance, for informing operational decision-making.

Project proposals have been implemented with the specific aim of developing 'off the shelf' molecular diagnostic tests for use in nurseries, based on the results from the COLDTREE project.

Acknowledgements

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Yield models for short rotation coppice of poplar and willow

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INTRODUCTION

For more than 20 years Forest Research has been testing combinations of tree species and silvicultural systems suited to the production of large volumes of woodfuel or wood fibre. This has lead to the development of reliable yield assessment techniques capable of quantifying wood production in novel silvicultural systems. Early species trials showed that willow and poplar varieties planted at very close spacing and managed as a regularly and frequently harvested coppice stand provided some of the highest yields per given area of land. Woody crops managed in this way are known as short rotation coppice (SRC).

Biomass crops and production systems are now recognised as serious options in agriculture and forestry. In England, the establishment of commercial plantations of willow and poplar SRC (Figure 1), along with other energy crops such as Miscanthus (elephant grass), is supported by the Energy Crop Scheme (ECS) administered by the Department for Environment, Food and Rural Affairs (Defra). Similar grants administered by the FC are available in Scotland. Additionally, as from 1 April 2009, the UK-wide 'Renewables Obligation' managed by the Department of Trade and Industry (DTI) will ensure that power generators wishing to co-fire coal with non-fossil fuels will source at least a proportion of this fuel from dedicated biomass crops and forests. In return, power generators receive tradable 'Renewable Obligation Certificates' (ROCs).

Government support for biomass

Government support is given to sustainably managed energy crops because they are ‘carbon lean’ (see Figure 2), i.e. compared with fossil fuels, only small quantities of greenhouse gases are emitted per unit of energy produced from the biomass. This contributes towards government meeting its ambitious and, following the ratification of the Kyoto Protocol, legally binding commitments to reduce CO_2 emissions by 10 % (based on 1990 emission levels) by 2010. Further international support for the development of biomass derived heat and power was given at the G8 summit held at Gleneagles in 2005, where the intention to create a Global Bioenergy Partnership was announced.

Unlike some other renewable and carbon lean technologies such as wind and wave farms, the potential energy within woodfuel can be stored and used ‘on demand’. Woodfuel is also transportable and can be used in several forms including woodchips, wood powder, pellets or, after processing, liquid fuel. However, as with many other fuel and fibre producing systems, in order to maximise land use efficiency, biomass production and financial return, suitable combinations of species and site need to be identified and reliable techniques for monitoring and predicting yield are required. Such information is of use to a large range of energy crops ‘stakeholders’ including existing and potential government grant assisted energy crop producer groups, independent growers, fuel users and project planners.

Figure 1

A short rotation coppice willow plantation.

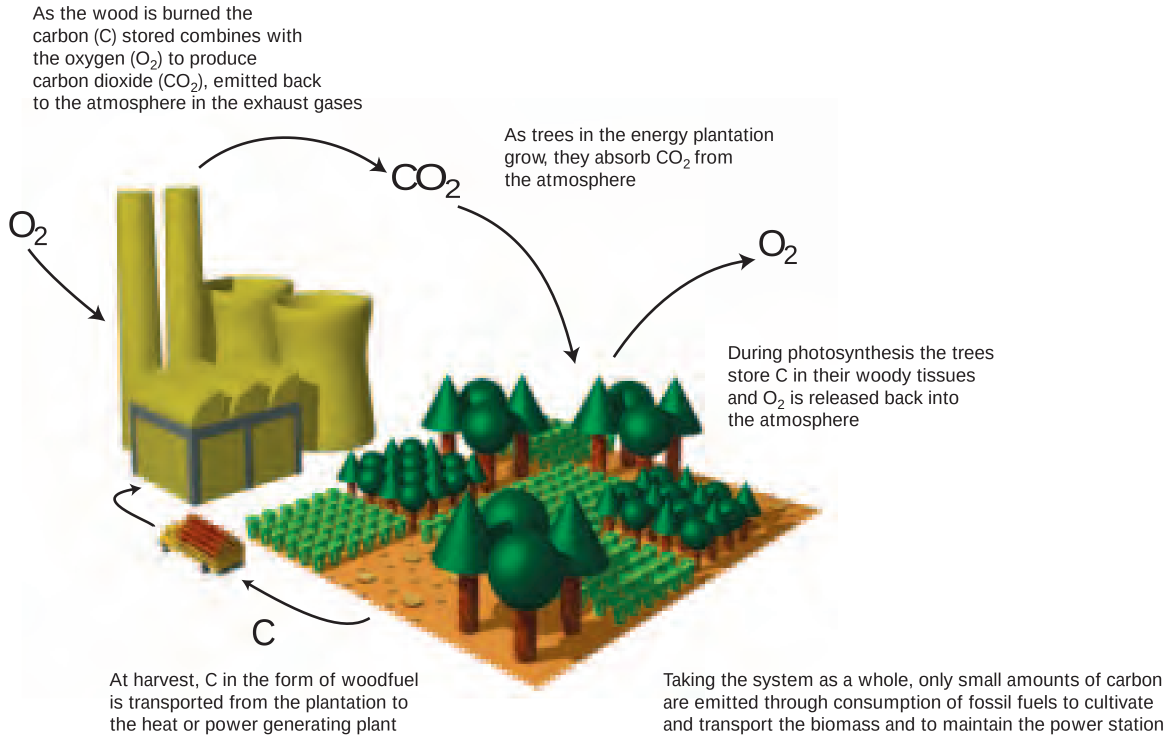

Figure 2

The carbon cycle of a woodfuelled heat or power generation system (adapted from Matthews and Robertson, 2002).

The site/yield research programme

Against this background, in 1994 the Forestry Commission (FC), Defra, DTI and the Department of Agriculture and Rural Development, Northern Ireland (DARDNI) funded a research programme aimed at establishing relationships between site characteristics and variations in performance amongst a selection of willow and poplar varieties. The principal objectives of this programme were to:

- Establish field experiments at a wide range of sites across the UK
- Develop a minimally destructive method of assessing standing biomass
- Monitor insect pests and fungal pathogens
- Collect soil and meteorological data and relate these to variations in yield
- Create a database to hold the information collected
- Develop empirical and process based yield models
- Develop suitable graphic user interfaces for the completed models.

Sites and varieties used

In spring 1995, 24 experiment sites were successfully established and in the following year a further 25 sites were planted (Figure 3). Three experimental designs were used. The first and most numerous type contained two sub-experiments. The first sub-experiment contained three poplar varieties exhibiting different growth and form characteristics. Each variety was grown in three monoclonal plots containing 100 individuals. The second sub-experiment contained three willow varieties, also developed from different parent species, planted according to the same experiment design. Data from these sites, known as ‘Extensive Pure’ trials, were used to assess the suitability of the chosen varieties on a wide range of site types, and to provide the main source of information for the development of minimally destructive yield assessment methods.

The second experimental design also contained monoclonal plots of three willow and three poplar varieties. In addition plots containing a mixture of the same three willow or three poplar varieties were

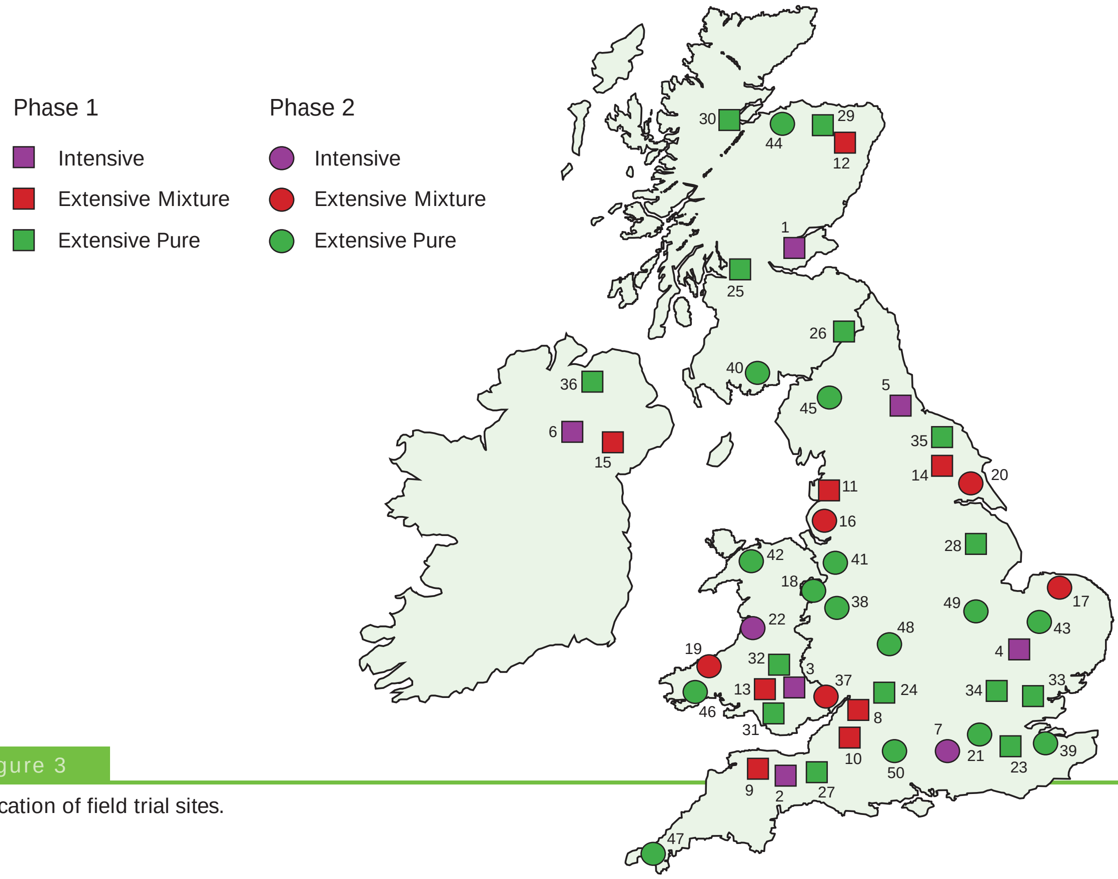

Figure 3

Location of field trial sites.

Table 1

Willow and poplar varieties used in the field experiments.

Poplar variety name	Parentage	Willow variety name	Parentage
Beaupré*	*Populus trichocarpa* x *Populus deltoides*	Jorunn*	*Salix viminalis* x *Salix viminalis*
Gibecq	*P. deltoides* x *P. nigra*	Jorr	*S. viminalis* x *S. viminalis*
Fritzi Pauley	*P. trichocarpa*	Orm	*S. viminalis* x *S. viminalis*
Trichobel*	*P. trichocarpa*	Ulv	*S. viminalis* x *S. viminalis*
Boelare	*P. trichocarpa* x *P. deltoides*	Germany*	*S. burjatica*
Raspalje	*P. trichocarpa* x *P. deltoides*	Q83*	*S. triandra* x *S. viminalis*
Unal	*P. trichocarpa* x *P. deltoides*	Spaethii	*S. spaethii*
Hoogvorst (690386)	*P. trichocarpa* x *P. deltoides*	Dasyclados	*S. caprea* x *S. cinerea* x *S. viminalis*
Hazendans (690394)	*P. trichocarpa* x *P. deltoides*	ST/2481/55	*S. triandra* x *S. cinerea* x *S. viminalis*
v71015/1	*P. trichocarpa* x *P. deltoides*	Delamere	*S. aurita* x *S. cinerea* x *S. viminalis*
v71009/1	*P. trichocarpa* x *P. deltoides*	Bebbiana	*S. sitchensis*
v71009/2	*P. trichocarpa* x *P. deltoides*	V789	*S. viminalis* x *S. caprea*
Gaver	*P. deltoides* x *P. nigra*	Ashton Stott (Stott 10)	*S. burjatica* x *S. viminalis*
Ghoy*	*P. deltoides* x *P. nigra*	Ashton Parfitt (Stott 11)	*S. burjatica* x *S. viminalis*
Balsam Spire (TT32)	*P. trichocarpa* x *P. balsamifera*	Bjorn	*S. viminalis* x *S. schwerinnii*
Columbia River	*P. trichocarpa*	Tora	*S. viminalis* x *S. schwerinnii*

* Variety present in all experiment types. Varieties without this symbol were planted at the 'Intensive' sites only.

established. Data from these plots were used to investigate the effect of multi-clonal mixtures on the incidence and severity of insect and disease infestations along with differences in yield between single variety and multi-variety plantations. Sixteen 'Extensive Mixture' sites of this type were established.

The third and final experimental design contained 16 willow and 16 poplar varieties derived from a wide range of parent species. The varieties used at the other two site types were included to act as 'benchmarks' against which other varieties could be compared. Data from these large experiments was used to inform the calibration of yield models to represent a wide range of growth characteristics. This is important as new willow and poplar varieties become commercially available on a regular basis as plant breeders develop higher yielding or pest resistant clones. Seven of these large 'Intensive' sites were established. The varieties used in all three experiment types are shown in Table 1.

In addition to these field based experiments, trials were also established in nurseries at Headley in Hampshire and Newton in Morayshire. At these sites fertiliser, irrigation and pesticides were applied judiciously to remove some of the environmental factors that could limit plant growth in the field and mask the inherent production potential of the varieties tested. A range of physiological measurements including shoot respiration, sap flow and gas exchange was taken on the three willow and three poplar clones planted. These data were used during the parameterisation of process based yield models.

Crop silviculture

At each site, pre-planting ground preparation was carried out using standard agricultural ploughs and power harrows. Chemical weed control was used to minimise the effect of weed competition on the developing coppice. Once a suitable seed bed had been created 25 cm long willow and poplar cuttings were planted by hand in spring/early summer. Planting followed a twin row design, reflecting commercial practice. Planting density was just less than 10 000 cuttings per hectare, again following commercial practice at the time (commercial plantations are now generally established at around 15 000 cuttings per hectare). At the end of the first growing season all above ground growth was cut back to approximately 10 cm above ground level. This operation, the essence of coppicing, encourages the development of multiple stems in the following spring.

The coppice was then managed on a three-year cutting cycle with harvests occurring at the end of the third and sixth growing season following cut back. At the end of the second cutting cycle, final assessments were made and the experiments closed. A commercial harvester was used at one of the larger 'Intensive' sites at the end of the second cutting cycle (Figure 4).

Figure 4

Harvest at the end of the second three-year cutting cyle.

Data collection and storage

An extensive range of crop and site variables were quantified at each site. Data were collected mainly by staff from the Technical Support Unit. The variables assessed can be classified into four groups, as shown in Table 2. Data were stored in a dedicated database, purpose designed for this project.

Table 2

Assessments and surveys carried out at field and nursery based experiment sites.

Shoot allometry	Site characteristics	Crop architecture	Crop physiology
Coppice stool survival	Air and soil temperature	Above and below ground carbon allocation	Shoot respiration
Number of shoots per stool	Rainfall	Canopy development	Root respiration
Shoot diameter	Relative humidity		Leaf nitrogen content
Shoot length	Solar radiation		Gas exchange
Shoot dry weight	Soil chemistry (i.e. nitrogen, potassium, phosphorus content)		Sap flow
	Soil physical properties (i.e. sand, silt and clay content)		

Minimally destructive yield estimation

The assessments shown in the first column of Table 2 are fundamental to the monitoring of growth patterns, biomass accumulation and ultimate yield in crops such as SRC. These data enable modellers to construct site, clone and age-specific relationships between shoot diameter, shoot length and shoot dry weight (Matthews, 1995; Matthews *et al.,* 2002). Once these relationships are established it is possible to estimate the total shoot oven-dry biomass present in research plots. These results are then up-scaled into more tangible estimates of oven-dry tonnes. To date, limited validation has shown that these estimates are accurate to within +/- 10% when applied to research scale plots.

This work is of fundamental importance as it allows researchers, growers and suppliers to estimate the standing biomass of a crop prior to harvest. Without the development of these relationships it would not be possible to make annual assessments of above ground biomass production, which are essential for the development of growth models.

Empirical modelling

Once a full set of standing biomass figures was available for each site/variety/age combination, statisticians were able to investigate the large variation in yields observed over the life time of the field experiments. Examples of variations in standing biomass amongst sites and varieties is shown in Table 3. Data collected during the site characterisation monitoring and assessment process (column 2, Table 2) were used to explain this variation. The models developed can account for approximately 70% of the variation observed in the field. However, this analysis has shown that variation in yield cannot be explained by quantifying and analysing a limited number of simple measurements such as rainfall and nutrient availability. Instead, yield is governed by complex interactions amongst a large number of site variables that will prove impractical for a grower to quantify. Despite these limitations the models generated represent the current state-of-the-art predictive SRC yield models available to growers and planners and provide a solid foundation for future development.

Process modelling

Whereas the standing biomass and empirical models developed during this research programme are likely to be of immediate use to SRC growers and producer groups, a process model based on data collected during crop architecture and physiology assessments (columns 3 and 4 in Table 2) may be of more interest to researchers and plant breeders. Process models can be used to explore how crops respond to climate change or help evaluate new varieties prior to commercial release. The downside is that these models require comprehensive parameterisation for each variety of interest. This can lead to time consuming and costly data collection programmes. During this programme the ForestGrowth process model originally developed by Evans *et al.* (2005) for use with high forest species was parameterised for

Table 3

Examples of variations in standing biomass between sites, varieties and crop ages.

Site	Clone	Standing biomass, oven-dry tonnes per hectare					
		Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1	Bjorn	11.2	29.3	34.8	12.2	21.6	47.5
1	Stott10	12.1	35.2	43.7	13.3	21.6	46.2
1	Germany	10.5	35.7	41.5	12.7	17.8	45.4
6	Bjorn	5.0	18.5	28.0	6.9	15.9	25.9
6	Stott10	9.4	25.6	33.3	5.6	13.1	20.5
6	Germany	4.8	14.2	22.2	3.2	6.0	9.9
7	Bjorn	3.4	11.7	21.1	8.9	22.4	31.3
7	Stott10	3.4	12.1	20.1	6.9	11.8	19.4
7	Germany	2.1	8.9	15.9	3.0	6.5	13.9

several SRC varieties using data collected from both the field-based and nursery-based experiments.

One of the most important aspects of the development of this model for use on SRC was the adaptation of the canopy architecture module to account for differences observed in canopy structure and carbon allocation between high forest and SRC canopies. This module also needed to accommodate the frequent harvesting and re-growth associated with SRC. As originally configured, this module was unable to re-create the complex, multi-layer canopy found in SRC plantations. However, using field data and the 3D-CPCA validation tool developed by Casella and Sinoquet (2003) as part of a European funded research project, a new light interception module was constructed. A comparison of output from 3D-CPCA and ForestGrowth canopy models is shown in Figure 5.

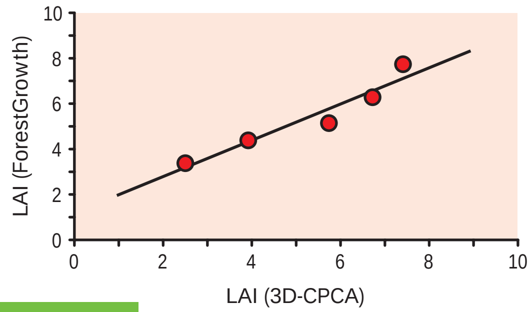

Figure 5

Comparison of leaf area index (LAI) values for short rotation coppice generated by 3D-CPCA (*x* axis) and ForestGrowth (*y* axis) canopy models.

Key outputs

One of the most important outputs from this research programme are standing biomass estimates for more than 3000 site, variety and age combinations. These estimates are of great interest to coppice growers and researchers and form the basis for empirical predictive yield models. Growers are similarly interested in summaries of the incidence of insect and disease infestation generated using possibly the largest SRC pest dataset collected to date. Examples of disease summary maps for rust (*Melampsora* spp.) are shown in Figure 6.

Finally, the development of user interfaces that allow SRC growers to use data collected from their own plantations to make estimates of standing biomass and predict yield represents a significant step forward and could assist with on-farm cash flow predictions, crop management and the planning of renewable energy projects. A screen shot of one of the current user interfaces is shown in Figure 7.

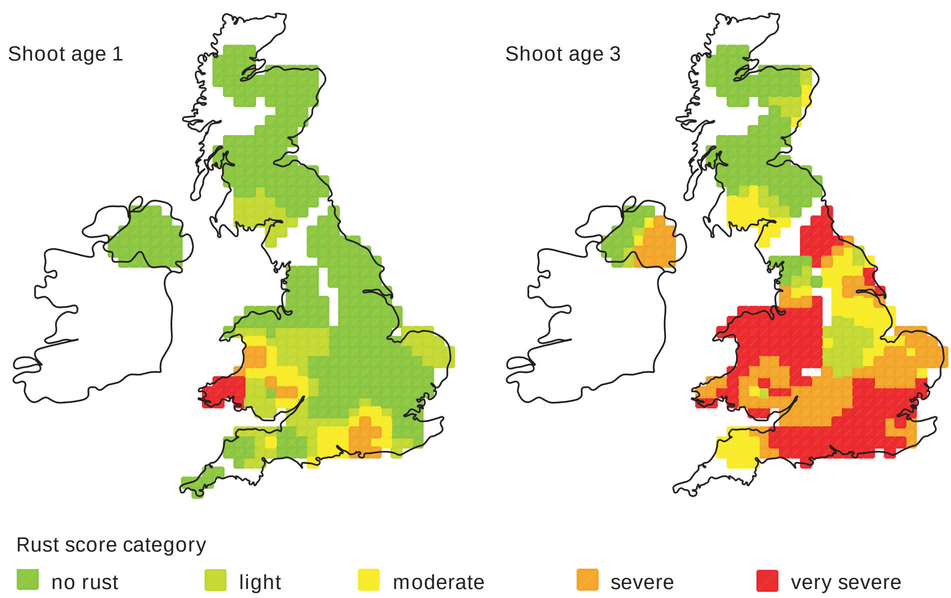

Figure 6

Maps showing the incidence of *Melampsora* spp. on the foliage of 1-year-old and 3-year-old shoots of the poplar variety 'Beaupré'. The estimates presented on a 20 x 20 km square grid are based on a statistical analysis of the survey data.

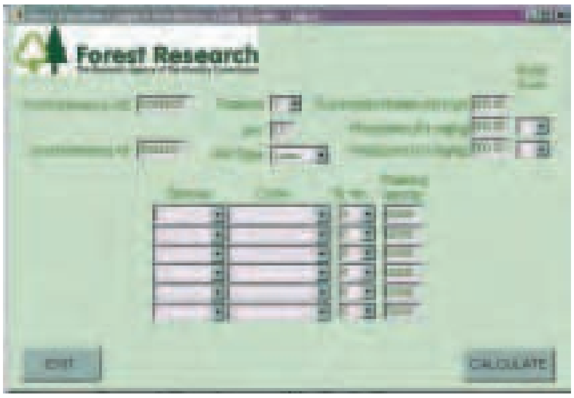

Figure 7

Screen shot of a yield model user interface during the development phase.

The future

The methods devised to estimate yield at the experiment level can be used with reasonable confidence on very small stands of SRC, however further development is required before models can accurately reflect variations of crop survival and vigour found in larger, more variable commercial plantations. Consultation with industry is required to ensure that future developments are relevant and applicable to the commercial world. For example, since the conception of this research programme commercial planting densities have increased and some growers are moving away from the standard 'cut back after one year, then leave for three years' silviculture in an attempt to reduce management costs and improve farm cash flow.

Some of the varieties used in this research programme have been planted commercially but are being superseded with new willow varieties offering increased yield, improved insect and disease tolerance or greater drought resistance. These varieties may open up site types that were previously unsuitable or only marginal for SRC production. The yield models constructed during this research programme could be reparameterised to incorporate these new varieties.

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Landscape ecology: emerging approaches for planning and management of forests and woodlands within Britain

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BACKGROUND

The need to develop a ‘landscape’ approach has been a common demand in many recent statements of British forest policy and identified as a major challenge facing forest managers. Such statements reflect a trend towards broader scale spatial and temporal planning – and the need for, and difficulties of, integrating multiple uses. Arguably, some of these themes can be traced back to the developments in landscape design and land use allocation of the late 20th century. Before these developments, much forest management had been characterised (or caricatured) as assembling a set of decisions taken at the stand scale, i.e. the basic unit of management. That the simple accumulation of such decisions was inadequate to deliver requirements at broader scales was first identified in the aesthetics of landscapes – and triggered the pioneering work of Sylvia Crowe and the introduction of ‘landscape design’. Subsequent responses to these landscape-scale demands included development of forest design principles, indicative forest strategies and *Forest & water guidelines*. With further broadening of management objectives, the demand to develop new approaches has accelerated. In particular, there is a growing realisation that conservation and enhancement of biodiversity cannot be achieved by a stand level approach or a rare site protection policy, nor can it be guaranteed by concentrating on landscape aesthetics and assuming that ecological benefits are linked. Organisms and ecological processes are not constrained by management or ownership boundaries, and hence there has been the need to develop an approach to landscape ecology.

Introduction

This article describes recent developments of an ecological approach for landscapes, and suggests likely applications and future refinements. Land use plans and indicative strategies based on such principles are finding increasing application throughout the USA and Europe including, recently, the UK. Before describing the work, it is worth observing that though fashionable, the use of the term 'landscape' is often applied rather loosely, and can include landscapes as:

- A focus of attention, and a perceived quality – 'landscape planning', landscape character areas, landscape view.
- A spatial scale and extent – expressed in geographic terms as the 'landscape scale', often of several square kilometres.
- An arena within which to target action, for example the Forest Landscape Restoration initiative.
- An entity with structural elements of patch, mosaic and corridor, reflecting a mix of ecosystems and habitats (for example, Figure 1).

Such diversity of definition is also prevalent in the discipline of landscape ecology. Some consider it to be very broadly based, integrating a wide range of interests in the landscape including cultural values. Thus landscapes are often characterised as having three particular facets of interest – structure, function and change. *Structure* describes the composition and configuration of distinct elements in the landscape; *function* describes the interaction between the structures through ecological processes (for example, biodiversity function is often related to the movement and viability of particular species within these structures); and *change* (whether driven internally or externally) as driving the interaction between them. Other landscape ecologists espouse a much narrower focus on the interaction between landscape pattern, landscape process and the distribution and abundance of organisms (Figure 2).

Our subsequent discussion will consider landscape ecology as a basis for understanding the spatial and temporal dynamics of the landscape by considering the inherent ecological structures (often based on elements such as patch, corridor, matrix) which promote different ecological functions. We will consider landscapes primarily as an entity with the most appropriate landscape scale being determined by the particular research issue being addressed, and a focus on landscapes with trees – existing or planned. It is interesting to note that as recently as 1998, the focus of landscape ecology research in British woodlands was in the area within the forest boundary but is now more likely be considered within catchments or other topographic, or administrative, units. The appropriate scale may therefore vary from the forest (several square kilometres), through to the catchment or region (tens to hundreds of square kilometres) or to whole country (hundreds to thousands of square kilometres).

Figure 1

Woodlands within a mosaic of other open habitats on the Isle of Wight.

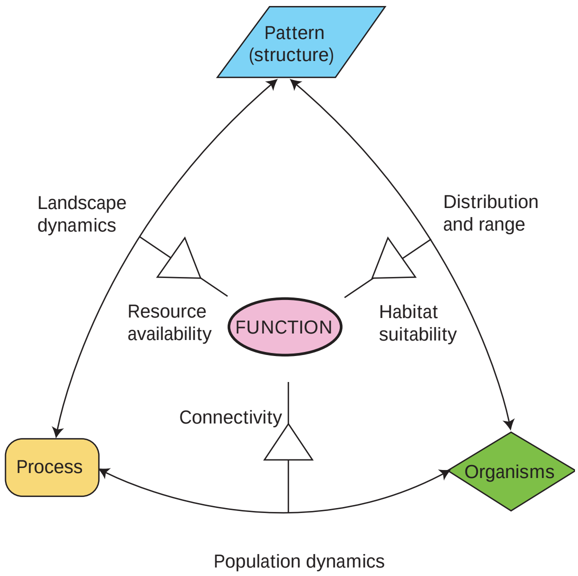

Figure 2

Flowchart describing the interaction of pattern, process and abundance/distribution of organisms within landscapes.

The drive towards a landscape approach

Policy drivers

There are a number of policy drivers demanding a landscape approach:

- The Convention of Biological Diversity, and subsequent commitments to conservation of biodiversity at the landscape scale.
- The application of EU Habitat and Species Directives, and the commitment to UK Biodiversity Action Plan targets (especially habitat action plans).
- The pursuit of forest landscape restoration, e.g. FC/WWF initiatives, and creation of Forest Habitat Networks.
- The evolution of Land Use policies, e.g. the Common Agricultural Policy and Water Framework Directive, demanding approaches at landscape scale – and integration across land uses.
- The proposal to develop adaptation strategies for climate change.
- The desire for targets and indicators to measure and monitor policy delivery for most of the above.

Practice drivers

Changes in forest and woodland management are also demanding landscape approaches:

- Developments of ecosystem approaches, adopted from North America and Scandinavia.
- Development in operational forest design and strategic planning.
- Demands for targeting of grant aid to deliver public good, and the associated involvement of multiple stakeholders in these decisions.
- Demands of single species conservation, e.g. wide-ranging species such as red squirrel, black grouse, capercaillie, golden eagle.
- Increased availability of Geographic Information Systems and associated tools, including Ecological Site Classification.
- Changes in management practice, e.g. restructuring, and attempts to prioritise habitat restoration.

Research drivers

Scientific progress has also contributed to the need to scale up:

- Conceptual developments in the application of island biogeography, and species–area relationships.
- Empirical findings of responses of plants and animals to landscape-scale structures and processes (including metapopulation dynamics).
- A greater understanding of abiotic processes within landscapes, and the extent to which they vary enormously with short distances.

Overall, these drivers are creating pressure for guidance and support in three areas:

Landscape change: methods to identify past and future landscape development.

Landscape analysis: methods to characterise current/future (and sometimes past) landscapes.

Landscape planning and evaluation tools: integrated techniques for use by practitioners to guide policy and practice.

Recent approaches to landscape ecology in British forests

This section provides a brief overview that illustrates the development of landscape ecology approaches, which we have also summarised in Table 1.

Landscape change – dynamic modelling

Many demands for a landscape approach relate to considerations of future options – and not just description of the present or change between past and present. Deciding what landscape change may occur is sometimes simple; for example, in the case of planned landscape change resulting in transformation of agriculture into woodland. However, many of the landscapes of interest are semi-natural, and ecological dynamics also govern the evolution of habitats (extent and quality) over time – and space!

The development of sophisticated computer models of landscape dynamics has been possible in areas where land use allocation is relatively fixed, and habitat dynamics have a greater influence on character and composition of a landscape. A study conducted in Glen Affric has developed a simulation model (Hope, 2003), the result of which can be subject to analysis by a variety of means. Lessons learnt include the lack of knowledge and understanding on some key landscape processes, such as herbivore impacts, and lack of data on habitat character, and importance of initial conditions.

Landscape analysis – landscape metrics

Landscape structure, e.g. formed by a mosaic of habitats, is a very visible attribute and with the availability of digital maps is increasingly susceptible to pattern analysis (Figure 3). A suite of metrics has been developed by a number of authors for summarising and analysing the structure of landscapes. They are conceptually attractive – and often seen as an appealing solution to the demands for targets and indicators.

Table 1

Recent approaches to landscape ecology in British forests.

Aspect of landscape ecology	Technique	Implementation and interpretation	Reference
Establishing landscape change (in terms of extent of habitats/elements)	Land use analysis	Simple re-classification of landscape elements – e.g. conversion of agriculture to woodland. Subjective and may be simplistic.	Ferris and Purdy, 2003a
	Landscape dynamic modelling	Complex spatio-temporal modelling requiring considerable source data and effort. Difficult to validate.	Hope, 2003
Analysing landscape structure	Landscape metrics	Produces sets of measures summarising pattern of landscape structure. Simple to calculate but may be difficult to interpret ecologically.	Ferris and Purdy, 2003b
Analysing landscape function	Habitat suitability analysis	Analyses landscapes for extent of suitable habitat for target species. Habitat quality information may be missing, and knowledge of relationships may be questionable.	Poulsom *et al.*, 2005
Analysing both structure and function	Landscape evaluation: Diaz approach	Subjective approach that contrasts situation with natural landscapes. Difficult to apply to heavily modified landscapes.	Bell, 2003
	BEETLE modelling	Quantitative, analytical approach. Requires dialogue over assumptions and objectives.	Watts *et al.*, 2005

However, there are a number of difficulties that have emerged during test applications in Britain and elsewhere. In particular, their interpretation depends upon assumption of strong linkage between pattern and process, and there is relatively little evidence to support this. The proliferation of potential measures leads to confusion, and there is substantial redundancy between measures (e.g. studies have shown that a potential field of 60 might be whittled down to less than 10). The technical ease of application via GIS may mean that they are uncritically deployed. Finally, there are problems with some where the assumptions may not be supported by the most recent evidence from ecological studies.

Some of these shortcomings can be overcome and in particular by a clear consideration of the purpose of applying the metric (or indicator), and an acceptance of the assumptions. An example of this can be seen in Table 2. It would seem best to treat these metrics as relative measures rather than absolutes and embed them in a process involving active discussion of underpinning assumptions.

An alternative form of analysis is to consider the suitability of the landscape for particular target or valued species. This can be an appropriate form of assessment for conservation measures for the particular species, but is sometimes used in the assumption that such action will create greater benefits. As a result many such models are single species models – and their use therefore depends upon the degree to which that species represents the wider target (biodiversity!). Unfortunately, there is a growing body of evidence to suggest that such an assumption is rarely met.

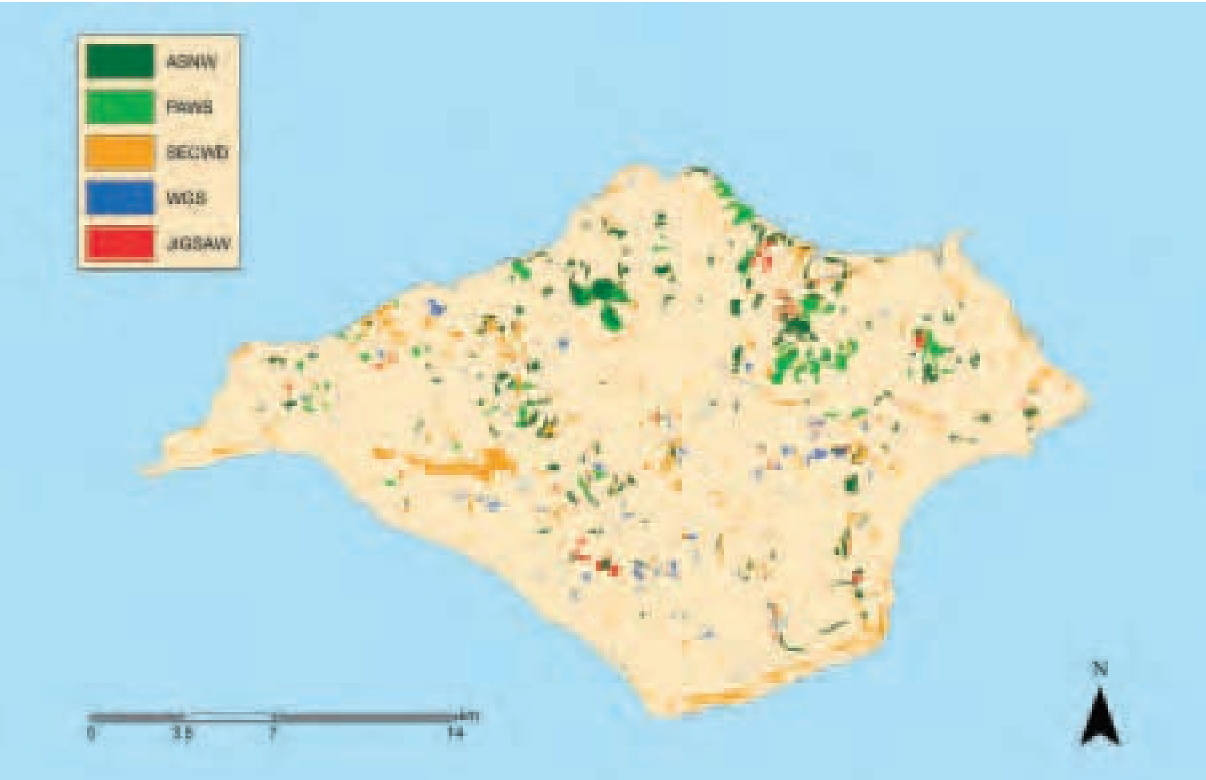

Figure 3

Map showing different woodland assemblages on the Isle of Wight – suitable for analysis of the success of planting schemes using metrics and other landscape evaluation tools. ASNW: ancient and semi-natural woodland, PAWS: plantations on ancient woodland sites, SECWD: secondary woodland – other broadleaved woodlands, WGS: woodlands established under the Woodland Grant Scheme (not spatially targeted at defragmentation), JIGSAW: woodlands established under the JIGSAW grant scheme targeted at defragmentation.

Landscape evaluation

Decision-makers require integrated methods to evaluate alternatives and identify desired future conditions. An approach based on North American landscape analysis was tested in Affric and Sherwood (Bell, 2003). A key driver here was the need to develop the forest design concept to accommodate ecological aspects. The concept was to link an analysis of the structure of the landscape to knowledge of 'flows', i.e. movements of animals and resources, and ultimately develop a view of desired future condition. Limitations were exposed due to lack of natural template in highly modified landscapes of Britain – and the complication imposed by cultural dimensions leading to many potential desired future conditions. A similarly subjective, though integrative, approach has been developed for some forest habitat networks.

An emerging approach to evaluation – BEETLE

Experience from the above and developments elsewhere have led us to conclude that we need to give a greater emphasis to assessment of landscape function – but the challenge is how to achieve this! FR ecologists have participated in the development and application of each of the approaches identified in the preceding section (Table 1). The particular focus of our current effort is in developing approaches that assist with decision-making at the strategic or tactical level, namely regional strategies or forest design plans. This has involved the development of an approach called BEETLE – Biological and Ecological Evaluation Tools for Landscape Ecology, which includes the adoption of a functional (rather than simply structural) approach, incorporating the concepts of habitat carrying capacity and landscape permeability. The details of this approach can be found in Watts *et al.* (2005).

Connectivity rather than connectedness

A distinction has to be made between the physical connectedness of habitats, which has often been used in design of networks and is analysed through various metrics, and connectivity which depends upon the ability of species to disperse through landscapes.

Table 2

Example of potential ecological indicators for calculation of anticipated effects of land use change in case study areas within the VisuLands project.

Concept and indicator	Scale	Suggested metric	Other possible metrics	Under pinning ecological assumption	Inference from increase in relative value	Inference from decrease in relative value
Landscape composition: proportion	Class	Class area (ha), number of classes and % of landscape	Shannon's diversity index	Amount of particular habitat and mix of habitats within a landscape controls available niches	Habitat (class or set of classes) achieving greater dominance – positive if a valued habitat, negative if not a valued habitat	Habitat (class) becoming less common – negative if a valued habitat, positive if not. Are there thresholds?
Landscape composition: patch size	Class, landscape	Mean patch size (ha), standard deviation, and number by class, and for landscape	Average perimeter–area ratio	Amount of contiguous habitat influences its suitability for certain species	Improved conditions for species specialist to that habitat type (class); at landscape scale – increased homogeneity (needs local assessment of positive/negative)	Poorer conditions for specialists, better conditions for generalists, and species of edges
Landscape configuration: patch shape	Class	Perimeter–area ratio	Fractal dimension	Core area of a habitat is the most valuable for characteristic species	Improved conditions for core habitat and species that benefit from those conditions	Poorer condition for habitat and for species that use the core areas of such habitats

Named species or generic species?

A feature of the BEETLE approach is the use of focal species. These are the target for the calculations, but not necessarily of the intended conservation action. They have proved very useful as a discussion device, akin to metrics but enabling assumptions to be more explicit. One particular aspect to the development has been the consideration of whether to use specific (named) species or generic species; species can also be distinguished as habitat generalists and habitat specialists. Each categorisation has its advantages and disadvantages in considering landscape evaluation, and choice may depend upon scale of application, existence of data on real species and on purpose of analysis.

Recent applications

We have developed and applied the approach to a number of case studies which have ranged substantially in scale and objective, as shown in Table 3. An example of the mapped output from this form of analysis is provided in Figure 4.

Key lessons

The science and policy/practice demands have moved rapidly in the past 5 years. Part of the maturing of the debate is to understand that previous simplicity was an illusion, and that with increased knowledge comes an enhanced understanding of the complexity of ecology of landscapes. It seems no longer credible to be working towards a single tool that provides a single form of landscape ecological analysis. Similarly the pursuit of a single metric – or indeed landscape threshold – seems inappropriate. There is a developing conflict between demand for simplification (by policymaker and practitioner) and increasing evidence of complexity. Our evaluation approach attempts to strike a compromise and answer the question posed, without resorting to unnecessary complexity.

It is crucial that the purpose of the evaluation is specifically articulated. The approach to design a simple habitat network in a static landscape at a large scale is very different from the production of a complex spatially explicit population model in a temporal landscape at a very fine scale – they are very different research questions. We have found that evaluation is particularly successful through discussion with a steering group and could be developed further into public participation.

Table 3

Examples of applications of the BEETLE approach.

Purpose	Approach	Location
Analysis of forest expansion scenarios	Relative change, no focal species, metrics appropriate, planned temporal change in landscape	Isle of Wight
Analysis of national habitat network strategy	Extensive scale, limited data availability, general connectivity an objective, static landscape, generic species appropriate	Wales
Analysis of regional habitat network strategy	More spatial/species data, smaller catchment/region scale, specific focal species, static landscape	Borders, West Lothian
Analysis of core sites for special species	Species specific (red squirrel) habitat suitability and defendability analysis	Scotland and north England
Analysis of balance between forest and open ground	More spatial/species data, smaller catchment/region scale, specific focal species	Affric, Sunart, Mull
Analysis of implication of landscape dynamics on rare species conservation (lichen: *Bryoria furcellata*)	Temporal landscape, specific species question, lots of species data, high time, cost, uncertainty	Affric
Analysis of forest design options	Specific focal species, static/temporal landscape, high quality landcover data	Clocaenog, north Wales

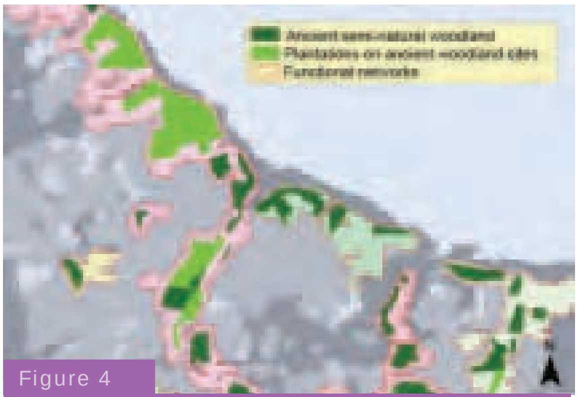

Figure 4

An example from a landscape evaluation using the BEETLE approach showing habitat networks around woodlands in part of the Isle of Wight.

Future development

There are a number of limitations to widespread deployment of our approach, in particular: the availability of data (for example on habitat quality); the lack of species-specific knowledge; the difficulty of providing evidence of model validation; and the technical difficulty of making the process more automated.

We plan to refine the BEETLE approach to address the limitations identified above. Evaluation approaches that integrate such ecological analysis with analysis of other landscape values are likely to be required and are being provisionally examined within the VisuLands project (www.forestresearch.gov.uk/visulands). Other developments also have considerable potential to add to the progression of landscape ecology in Britain, in particular:

- Molecular techniques will facilitate the study of gene flow within landscapes, providing perhaps the best option for validating a number of the models developed on theoretical rather than data-model grounds.
- A broadening of the target species, to include pest and pathogen, may also enhance understanding rather than limiting study to species of conservation concern.
- Remote-sensing and further inventory/census should provide enhanced data availability – not just of extent, but hopefully also of habitat quality.
- There are new methods of integrating multiple data layers and views.

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National and international links

The two maps reflect the range of networks we have been generating both nationally and internationally. The national map (Figure 1) shows FR's links with a wide range of UK universities and associated scientific organisations. The international map (Figure 2) shows our extensive links across Europe; in addition to this we have wider global links with New Zealand, USA, Canada and China.

National

Many of our programmes, individual and collaborative, are funded by other government agencies, UK research councils, universities and commercial organisations; these include Defra, DTI, NERC, SNH, English Nature, the Environment Agency, and the Universities of Sheffield, Southampton and London. We also collaborate with other universities countrywide, including Aberdeen, Edinburgh, Napier, Stirling, Lancaster, Bangor, Cardiff, Oxford, Cambridge, Exeter, Portsmouth, Reading, Surrey and Sussex.

Figure 1

UK links.

Figure 2

European links.

International

Key European links include:

- INRA, France
- Brussels Free University, Belgium
- BBA, Germany
- INIA, Portugal
- Department of Forest Protection, Austria
- CSIC in Spain
- JRC in Italy
- METLA in Finland

Further across the globe we are working with:

- USDA in several areas of the USA
- SCION in Rotorua, New Zealand
- Canadian Forest Service, e.g. Victoria, British Colombia
- Forestry University Beijing, China
- Madeira National Park, Madeira

Major research programmes undertaken by Forest Research

Programmes funded by the Forestry Commission

Biometrics, Surveys and Statistics Division

Sample plots

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

Ewan Mackie

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.

Remote sensing

Juan Suárez

Evaluate the potential of remote sensing techniques for operational use in British forest management.

National inventory of woodlands and trees

Steve Smith

Undertake the FC national survey of woodland 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.

Ecology Division

Lowland native woods

Ralph Harmer

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

Biodiversity evaluation and indicators

Jonathan Humphrey

Synthesise datasets from the biodiversity assessment project, identify potential biodiversity indicators, and disseminate findings.

Forest habitat management

Jonathan Humphrey, Russell Anderson and Helen Armstrong

Investigate and provide guidance on the management of forests for biodiversity through developing old growth stands, utilising cattle grazing and managing open ground habitats.

Species Action Plans

Alice Broome, Roger Trout, Chris Quine and Brenda Mayle

Undertake research in support of Forestry Commission commitments to the species Biodiversity Action Plans and provide advice on appropriate management of woodland habitats for these species.

Landscape ecology

Kevin Watts and Chris Quine

Improve understanding of how biodiversity responds to management at the landscape scale, and translate this into practical management guidance for forest design.

Ecological site classification and decision support systems

Duncan Ray

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

Squirrel management

Brenda Mayle

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

Deer population ecology and management

Robin Gill, Helen Armstrong and Brenda Mayle

Provide a sustainable basis for deer management in UK woodlands by investigating and developing new techniques and models of impacts and damage, population dynamics of deer, and deer density assessment.

Tree protection

Roger Trout

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

Improvement of broadleaves

Ned Cundall

Selection/testing of selections at population, family and clonal level: oak, ash, sycamore, beech, birch.

Genetic conservation

Joan Cottrell

Study of genetic variation and gene flow in natural populations. Assessing the level of adaptive variation in the field trials of populations of native species.

Environmental and Human Sciences Division

Soil sustainability

Elena Vanguelova

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, Tony Hutchings and Danielle Sinnett

Improve methods of establishing woodland and management practices on disturbed (brownfield) sites, taking into account changes in forestry and land-use policy, planting opportunity, environmental impacts, mining practices and technology. Develop best practice guidelines.

Forest hydrology

Tom Nisbet

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

Effects of air pollution on trees

Dave Durrant and Andy Moffat

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

Climate change

Mark Broadmeadow

Predict and model the impacts of climate and wider environmental change on tree growth by experimental work in open-top chambers and in forest stands. Interpret published climate change scenarios and develop guidance on future species suitability, both for production woodland management and native woodland restoration. Identify interactions between forests, woodland management and the changing global environment.

Carbon

Mark Broadmeadow

Develop a network for monitoring carbon stocks and stock changes of woodland in the UK. Maintain one of only three long-term carbon flux monitoring stations in woodland in the UK, measuring carbon fluxes and constructing a carbon budget for a stand of lowland broadleaf woodland. Research the contribution that wood (including bioenergy production) and wood products can make to climate change mitigation.

Environmental change network

Sue Benham

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

Historic environment

Peter Crow

Develop methods, tools and guidance to aid the day to day management of historic environment features such as archaeological evidence, veteran trees and historic woodlands/landscapes.

Social Research

Paul Tabbush, Elizabeth O'Brien, Max Hislop and Suzanne Martin

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

Forest Management Division
Incorporating Technical Development

Integrated establishment systems for the uplands

Alan Harrison, Mike Perks and Colin McEvoy

Integrated studies of the effect of nursery practice, seedling physiology, plant handling methods, site preparation and maintenance upon tree establishment.

Silvicultural effects on timber quality

Barry Gardiner, Jason Hubert, Elspeth Macdonald and Shaun Mochan

Investigate the impact of silvicultural practices on timber quality in conifers, especially spruce. Main emphasis is impact of site factors (e.g. exposure, fertility) on quality.

Silviculture of upland native woodlands

Richard Thompson and Colin Edwards

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

Alternative silvicultural systems in conifer forests

Bill Mason, Colin Edwards and Sophie Hale

Evaluate canopy structure manipulation to promote suitable microclimates for seedling establishment and facilitate natural regeneration to enable wider use of alternative silvicultural systems to patch clearfelling (continuous cover forestry).

Stability of stands

Barry Gardiner, Bruce Nicoll , Alexis Achim 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.

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 and poplar research

Ian Tubby

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

Silvicultural systems

Gary Kerr

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

Seed and seedling biology

Peter Gosling and Richard Jinks

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

Selection and testing of conifers

Steve Lee

Undertake plus-tree selection, progeny testing. Breeding/production populations. Demonstration of realised gain. Development of techniques for marker aided selection. Species involved: 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.

In vitro propagation and phase-change biotechnologies

Allan John

Investigate tissue culture systems for multiplication of Sitka spruce.

Forest Reproductive Material Regulations

Sam Samuel

Devise methods for inspection of material proposed for registration. Maintain the National Register of Basic Material.

Origin and provenance of conifers

Sam Samuel

Identification of suitable origins of conifer species. Key species: Sitka spruce, Douglas fir.

Technical Development

Large-scale forestry harvesting

Colin Saunders

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

Large-scale ground preparation, seed sowing and planting

Steve Morgan, Andy Hall and Bill J. Jones

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

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

Andy Hall and Duncan Ireland

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

Forestry operations on derelict and reclaimed land

Bill J. Jones

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

Wood for energy

Andy Hall, Paul Webster and Duncan Ireland

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

Chemical weeding

Bill J. Jones

Evaluate equipment, application techniques and safety.

Reduction in the use of chemicals

Bill J. Jones and Paul Webster

Examine equipment and methods that offer opportunities for non-chemical weed control.

Health and safety

Bill M. Jones and Colin Saunders

Review techniques and procedures for management of health and safety of machine operators.

Tree Health Division

Plant health

Hugh Evans, Nick Fielding and Christine Tilbury

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

Restocking pests

Stuart Heritage

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

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 Norway and Sitka spruces.

Integrated Forest Management

David Wainhouse, Roger Moore and Hugh Evans

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

Mechanisms of tree resistance to insect attack

David Wainhouse

Investigate mechanisms of resistance of young conifers to the pine weevil. Determine the relative importance of genetic and environmental factors in resistance expression. Develop these aspects to contribute to an Integrated Forest Management 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.

Tree diseases: diagnosis and provision of advice

David Rose and Sarah Green

Diagnose disease in trees and provide advice and information on disease identification, management and control. Provide information on decay in standing trees, and on management of veteran trees.

Tree health monitoring

Steven Hendry

Monitor the health of the nation's trees and raise awareness of tree health issues.

Risks from altered pathogens

Clive Brasier

Investigate changes in pathogen behaviour and evaluate the potential impact of such changes in relation to plant health and Pest Risk Analysis.

Non-chemical protection

Joan Webber

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

Fomes root and butt rot of conifers

Katherine Thorpe

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

Phytophthora diseases of trees

Clive Brasier, Joan Webber and Sandra Denman

Investigate pathogenic *Phytophthora* species of alder and oak to determine their impact and the opportunities for management and control.

Programmes part funded by the European Commission

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

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

Compression wood in conifers.

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

Mechanised logging operations.

Development of improved pest risk analysis techniques for quarantine pests, using pinewood nematode *Bursaphelenchus xylophilus* in Portugal as a model system.

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

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

Forest condition surveys.

Forest Focus review.

Gene flow in oaks.

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

Integrating ecosystem function into river quality assessment and management.

Intensive monitoring of forest ecosystems.

Urgent conservation management for Scottish capercaillie.

Visualisation tools for public participation in the management of landscape change.

Risk analysis for *Phytophthora ramorum.*

Timber cladding, northern periphery.

Biomass based climate change mitigation through renewable energy.

Reintegration of coal ash disposal sites and mitigation of pollution in the West Balkan area.

Programmes funded by individual organisations

Carbon Trust
Heat treatment of timber.

CCW/FCW
Woodland habitat network strategy for Wales.

Department for Environment, Food and Rural Affairs
Species boundaries on Phytophthora.

Yield models for energy coppice of poplar and willow.

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

English Nature
Woodland restoration – comparison of inventory data.

Environment Agency
CCF – environmental good practice.

Phytophthora disease of alder.

EPSRC/Sheffield
Urban greening.

Novel compost.

Climate change.

INRA
Interaction between winds and forests.

Madeira National Park
Mammal control.

Natural Environment Research Council/Imperial College
Terrestrial carbon dynamics.

Office of the Deputy Prime Minister
Monitoring the health of non-woodland trees.

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

Scottish Natural Heritage
Balancing upland and woodland strategic priorities.

Forest habitat network.

SCRI
Woodcore samples.

Sheffield University
CTCD data management.

Southampton University
Short rotation coppice (poplar).

USDA
Phytophthora ramorum.

Research contracts awarded by Forest Research

Avon Vegetation Research
Forestry herbicide evaluation.

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

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

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

Fountain Forestry
Water monitoring, Halladale.

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

Imperial College, London
Control of decay in utility poles.

Development of a biological control agent for Dutch elm disease.

Conservation of Xylophagous beetles and their parasitoids in Britain's woodlands.

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 Abertay, Dundee
Cryopresentation of Sitka spruce tissues.

University of Birmingham
Woody debris in forest aquatic habitats.

University of Bristol
Use of landscape features and habitats by lesser horseshoe bats: management implications.

University of Leeds
Atmospheric boundary layer over forests.

Chemical transport in forests.

University of Reading
Tree root response to acidification.

Soil variability.

Soil quality indicators in forestry.

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

Molecular studies of quantitative traits in Sitka spruce.

University of Stirling
Habitat use of working forest by capercaillie.

Paleoecology of Glen Affric.

Identification and analysis of spider samples obtained from Forest Research's Biodiversity Assessment plots.

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

Drought tolerance in poplars.

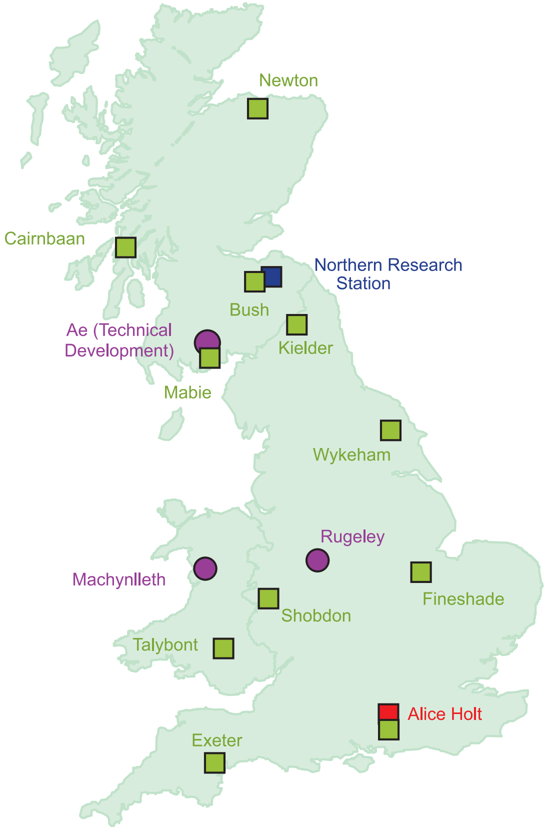
University of Ulster
Feeding ecology of the large pine weevil.

Impact of defoliating insects on forests.

University of York
Carbon stocks in UK soils and their vulnerability to climate change.

Forest Research people

Staff as at 31 March 2005, in Divisions and Technical Services based at:
- Alice Holt
- Northern Research Station
- Ae Village, Midlands and Wales
- Field Stations



Chief Executive
- Professor Jim Lynch, BTech, PhD, DSc, CSci, CChem, FRSC, CBiol, FIBiol, FIBiotech, FRSA

Chief Research Officer
- Professor Peter Freer-Smith, BSc, PhD, DSc

Personal Secretaries
- Claire Holmes*
- Sue Jones, BA, MA*
- Sue Stiles

Head of Northern Research Station
- Chris Quine, MA, MSc, MICFor, PhD

Personal Secretary
- Madge Holmes

Quality Assurance Manager
- Kate Fielding

Human Resources and Administration
- Ken Charles, FMS, *HR and Administration Director*
- Christopher Baker, BSc
- Andrew Davies
- Wendy Groves
- Janet Lacey
- Heather Russell*
- Mandy Sennett*
- Sally Simpson*
- Amanda Smith*
- Mike Wheeler
- Maureen Wilkes*
- Mike Young
- Martin Abrahams, *Head of Administration at NRS*
- Gerry Cockerell
- Evelyn Hall
- Esther Ker
- Linda Legge
- Roz Shields*

Finance and IT
- Tony Cornwell, FCMA, *Finance and IT Director*
- Jane Smyth, BSc
- Laura Caless
- Dai Jeffries, BSc
- Carol Knight*
- Timothy Knight, BSc
- Carole Martin
- Corinne Russell
- Janet Turner
- Wayne Blackburn, BSc
- Alec Gaw, BSc*

Communications
- Xanthe Christophers, BSc, PhD, *Communications Director*
- Jenny Claridge, BSc, ARCS
- George Gate
- David Georghiou, BA
- Eleanor Harland, MA, DipLib
- Alison Melvin, BA
- Catherine Oldham, BA, MA, DipLib, MCLIP
- Thelma Smalley*
- Sally Taylor
- John Williams
- Glenn Brearley
- Kirsten Hutchison, MA

*Denotes part-time.

KEY: Alice Holt · Northern Research Station · Ae, Midlands and Wales · Field Stations

Biometrics, Surveys and Statistics Division

- Professor Sam Evans, MA, PGDip, PhD, PhD, *Head of Division*
- Catia Arcangeli, MSc, PhD
- Miriam Baldwin, HND, BSc, MSc
- Eric Casella, MSc, PhD
- Joy Cornwell
- Ian Craig
- Carol Foden*
- Paul Henshall, BSc
- Tracy Houston, BSc, MIS
- Makihiko Ikegami, BSc, MSc, PhD
- Ewan Mackie, BSc, MSc
- Robert Matthews, BSc, MSc
- Geoff Morgan, BSc, MSc, PhD
- Lyn Pearce*
- Jane Poole, BSc, MSc
- John Proudfoot
- Tim Randle, BSc
- Marc Sayce
- Paul Taylor, MA, MSc, MPhil
- Ian Tubby, BSc
- Christopher Vials, BSc
- Stephen Bathgate, BSc, BSc, PGDip
- Christine Brown
- Graham Bull
- Shona Cameron
- Lynn Connolly*
- Tom Connolly, BSc, PhD
- Justin Gilbert, BSc
- Daniel McInerney
- Andrew Peace, BSc
- Lynn Rooney*
- Juan Suárez-Minguez, BSc, MSc
- Esther Whitton

Ecology Division

- Chris Quine, MA, MSc, MICFor, PhD, *Head of Division*
- Stuart A'Hara, BSc, MSc, PhD
- Russell Anderson
- Helen Armstrong, BSc, PhD
- Heather Bishop
- Alice Broome, BSc
- Tracy Brown, BSc, MSc
- Robert Coope
- Joan Cottrell, BSc, PhD
- Jason Hubert, BSc, PhD
- Jonathan Humphrey, BSc, PhD
- Liz Poulsom, MSc
- Duncan Ray, BSc
- Louise Sing, BA, MSc
- Richard Thompson
- Andy Brunt
- Helen Chester
- Mark Ferryman
- Robin Gill, BSc, MSc, PhD
- Matthew Griffiths, BSc, MSc
- Ralph Harmer, BSc, PhD
- Andrea Kiewitt, BSc, MSc
- Brenda Mayle, MSc
- Jacqui Neal
- Roger Trout, BA, PhD
- Kevin Watts, BSc, PhD

Environmental and Human Sciences Division

- Andy Moffat, BSc, PhD, *Head of Division*
- Lorraine Adams, BSc
- Nadia Barsoum, BSc, PhD
- Sue Benham, BSc
- François Bochereau, BSc, MSc
- Mark Broadmeadow, BSc, PhD
- Samantha Broadmeadow, BSc, MSc
- Sylvia Cowdry*
- Peter Crow, BSc, MSc
- Cecile De Munck, BSc, MSc
- Dave Durrant, BA
- David Edwards, BSc, MSc, MSc, PhD
- Tony Hutchings, MSc
- Lorna Johnstone
- Caroline Kilbride, BSc
- Anthea McRiley, BSc
- Tom Nisbet, BSc, PhD
- Liz O'Brien, BSc, PhD
- Tom Ormesher, BSc
- Rona Pitman, BSc, PhD
- Geoffrey Sellers, BSc, MSc, PhD
- Danielle Sinnett, MSc
- Paul Tabbush, BSc, MSc, FICFor
- Huw Thomas, BSc, MSc
- Rene van Herwijnen, MSc, PhD
- Elena Vanguelova, BSc, MSc, PhD
- Ernest Ward, BSc, MSc, CChem, MRSC
- Christine Whitfield*
- Matthew Wilkinson, BSc, MSc
- Matthew Williams, BSc
- Elizabeth Young, BSc
- Max Hislop, MICFor
- Suzanne Martin, BSc, PhD

*Denotes part-time.

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

Forest Management Division
Incorporating Technical Development

- Bill Mason, BA, BSc, MICFor, *Head of Division*
- Professor Barry Gardiner, BSc, PhD, FRMetS
- Allan John, BSc, PhD
- Steve Lee, BSc, PhD, MICFor
- Sam Samuel, BSc, PhD
- Bruce Nicoll, BSc
- Elspeth MacDonald, BSc, MSc
- Colin Edwards, BSc
- Alan Harrison, BSc
- Sophie Hale, BSc, PhD
- Mike Perks, BSc, MSc, PhD
- Shaun Mochan, MSc
- Rob Sykes
- Alexis Achim, BSc
- Cathleen Baldwin
- Colin McEvoy, BA
- Matilda Crumpton Taylor
- Jenna Tadman
- Rachel Parsonson
- Stephane Berthier, PhD
- Vicky Cunningham, BSc
- Peter Gosling, BSc, PhD
- Lorelie Ives
- Richard Jinks, BSc, PhD
- Gary Kerr, BSc, FICFor, PhD
- Matt Parratt, BSc
- Victoria Stokes, BSc, PhD
- Christine Woods, BA
- Ian Willoughby, BSc, MBA, MICFor

Technical Development
Ae, Scotland

- Bill Jones, *Head of Technical Development*
- Bill J. Jones
- Steve Morgan
- Finlay McAllister, BA, BSc
- Ian Murgatroyd
- Norma Nicholson*
- Joyce Rammell, BSc
- Colin Saunders

Midlands

- Andy Hall
- Duncan Ireland, BSc
- Paul Webster

Wales

- David Jones, EngTech, AMIAgrE

Tree Health Division

- Hugh Evans, BSc, DPhil, FRES, *Head of Division*
- Professor Clive Brasier, BSc, PhD, DSc, Emeritus
- Sara Brough, BSc
- Anna Brown, BSc, PhD
- Sandra Denman, BSc, MSc, PhD
- Gillian Green, BSc*
- Anthony Jeeves
- Martin Jukes, CBiol, MIBiol
- Susan Kirk
- Carol Lishman*
- Elizabeth Orton, BA, MSc
- David Rose, BA
- Joan Rose
- Shirley Stephens*
- Nigel Straw, BSc, PhD, FRES
- Christine Tilbury, BSc
- Kath Thorpe, BA, MSc, DPhil
- David Wainhouse, MSc, PhD, FRES
- Joan Webber, BSc, PhD
- David Williams, BSc, PhD
- Sarah Green, BSc, PhD
- Steven Hendry, BSc, PhD
- Stuart Heritage, MBA, CBiol, MIBiol
- Grace MacAskill
- Roger Moore, BSc, PhD
- Heather Steele, BSc*

Field Stations
Technical Services Unit

- Janet Dutch, BSc, PhD, *Head of Unit*

North
Engineering Services

- David Brooks, *Head of Engineering Services*
- James Nicholl
- John Strachan

Bush, Inver and Bush Nursery

- David Anderson, *Head of Stations*

Bush

- Colin Gordon
- Hamish Howell
- Nelson Innes
- Gavin Mackie
- Steven Osborne, BSc
- Steven Sloan

Inver

- Nick Evans
- Bill Rayner

*Denotes part-time.

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Bush Nursery

- David Clark, *Nursery Manager*
- John Armstrong
- Graeme Crozier
- Alan Purves

Cairnbaan

- Dave Tracy, BSc, *Head of Station*
- Pauline Simson, BSc

Kielder and Mabie

- Dave Watterson, *Head of Stations*

Kielder

- Terry Gray
- Mike Ryan
- Len Thornton

Mabie

- James Duff
- Joanna McGregor*
- Harry Watson
- James White

Newton and Lairg

- Alistair MacLeod, *Head of Stations*

Newton

- Hazel Andrew*
- Allison Cowie
- Andrew Kennedy, BSc
- Fraser McBirnie
- Stuart McBirnie
- Hugh MacKay, BSc
- Stephen O'Kane
- Colin Smart

Lairg

- Alexander Bowran
- Calum Murray
- Duncan Williams

South

Alice Holt

- Jamie Awdry
- Bob Bellis
- Sue Bellis
- Tony Bright
- Rory Cobb
- Norman Day
- Kate Harris
- Steve Coventry
- Ian Keywood
- Vicky Lawrence
- Tony Martin
- Doug Nisbet
- Jim Page
- Bill Page

Alice Holt Workshop

- John Davey
- Mike Johnstone

Exeter

- Alan Ockenden
- Anthony Reeves
- Barnaby Wylder*

Fineshade and Thetford

- Dave West, *Head of Stations*
- Elizabeth Richardson

Thetford

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

Shobdon

- Nick Fielding, *Head of Station*
- Jason Jones
- John Price
- Sharon O'Hare*

Talybont

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

Wykeham

- Nicola Corney
- Alex Hill
- Patricia Jackson
- William Riddick

*Denotes part-time.

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PhD Students linked with Forest Research

Sarah Archibald (Imperial College London)
David Beattie (Imperial College London)
Sophie Bertin (University of Edinburgh)
Helen Billiald (Sussex University)
Lois Canham (University of Stirling)
Fiona Caryl (University of Stirling)
Vanessa Castan-Broto (University of Surrey)
Jo Clark (University of Wales, Bangor)
Julia Cox (Surrey University)
Lauren Crawford (Imperial College London)
Richard Curtis (University of Gloucester)
Monica De Ioanni (University of Molise)
Heike De Silva (University of Aberdeen)
Hannah Drewitt (University of Durham)
Helen Ellison (Imperial College)
Ruth Fitzgerald (Reading University)
Priya Gadepalle (University of Surrey)
Samantha Gale (Abertay University)
Rachel Gaulton (Edinburgh University)
Caroline Hacker (Imperial College London)
Nicole Harris (Southampton University)
Iain Hartley (University of York)
Jack Johnston (Ulster University)
Tessa Knight (University of Bristol)
Bruce Lamond (Edinburgh University)
Lucy Marchant (Reading University)
Paul McLean (University of Glasgow)
Jo Mortimer (Reading University)
Gloria Olaya (Edinburgh University)
Vini Peteira (Imperial College London)
Jennifer Seaman (University of Sheffield)
Helen Sellars (University of Liverpool)
Tim Silverthorne (University of Surrey)
Juan Suárez-Minguez (University of Sheffield)
Suzanne Swanwick (Cranfield University)
Janine Tan (Ulster University)
Louise Timms (Imperial College London)
Alessandra Timarco (Reading University)
Ed Wallington (Edinburgh University)
Axel Wellpot (University of Edinburgh)
Jeremy Wingate (University of Surrey)
Georgios Xenakis (Edinburgh University)

Research associate

Steve Petty, PhD

Accounts for the year ended 31 March 2005

Contents

Foreword

1. Basis of Accounts

These accounts are prepared in accordance with a direction given by HM Treasury in pursuance of section 7 of the Government Resources and Accounts Act 2000.

2. Status

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

Forest Research remains part of the Forestry Commission, which is a cross border Government Department responsible for forestry throughout Great Britain. The relationship between Forest Research, the Forestry Commissioners and Forestry Ministers is described in the *Framework Document*, revised and published in September 2003.

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

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

Two organisational reviews took place during 2002 and 2003 that impacted on the Agency's status and operational arrangements.

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

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

The stage two report of the Agency's Quinquennial Review, which addressed the issues on implementing the outcomes of the stage one review and the devolution review, was approved by Ministers and a new Framework Document was put in place in September 2003.

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

Forest Research has been designated a GB entity. For Resource Accounting purposes Forest Research is within the departmental boundary. Its accounts are consolidated into the Forestry Commission England/GB accounts.

3. Aims and Objectives

The aim of Forest Research is set out in the Framework Document. It is to support and enhance forestry and its role in sustainable development, by providing high quality research and development in a well-run organisation.

The objectives of Forest Research are listed on page 4 of the Annual Report.

4. Review of Activities

This is Forest Research's eighth year of operation as an Agency. Forest Research produced a net operating surplus of £382,000 on its Income and Expenditure Account, excluding the notional cost of capital. A comparison of income and expenditure with the previous year's results shows that:

- staff costs increased by £402,000 (5.0%)
- other management costs increased by £135,000 (6.5%)
- materials and services costs increased by £256,000 (10.9%)
- income from Forestry Commission customers increased by £303,000 (2.7%)
- income from external customers increased by £462,000 (28.0%)
- the notional cost of capital increased by £25,000 (6.5%)

The net deficit for the year after the cost of capital charge of £409,000 and depreciation was £27,000, representing a cost recovery rate of 99.8%. Within this performance, unplanned early retirement costs of £135,000 were absorbed.

After adjusting the total deficit for items not involving the movement of cash and for capital expenditure, bank account movements and income, the net cash outflow for the year was £371,000, which was funded by the Forestry Commission. The primary cause of the net cash outflow was the delay to payments for research work done for the European Commission in 2003 and 2004. The EC have contracted to make these payments during 2005–06.

Additions to fixed assets in the year were £398,000.

5. 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.

6. Post Balance Sheet Events

There are no post balance sheet events.

7. Supplier Payment Policy

Forest Research observes the principles of the late payment of commercial debts (interest) Act 1998. Unless otherwise stated in the contract, we aim to pay within 30 days from the receipt of goods and services, or the presentation of a valid invoice, whichever is the later. An analysis for 2004–05 indicates that 99.9% of payments to suppliers, including those made using the Government Procurement Card, were paid within the due date. Arrangements for handling complaints on payment performance are notified to suppliers on orders.

8. 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.

9. Management

The Ministers who had responsibility for the Forestry Commission, including Forest Research, during the year were:

Rt. Hon. Margaret Beckett MP	*Secretary of State for the Department for Environment, Food and Rural Affairs*
Ben Bradshaw MP	*Parliamentary Under Secretary (Commons), Department for Environment, Food and Rural Affairs*

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

Jim Lynch	*Chief Executive*
Peter Freer-Smith	*Research Director*
Ken Charles	*Head of Human Resources and Administration*
Tony Cornwell	*Finance and IT Director*
Bill Mason	*Head of Forest Management Division*
Sam Evans [a]	*Head of Biometrics Division*
Hugh Evans [a]	*Head of Tree Health Division*
Chris Quine [a]	*Head of Ecology Division*
Andy Moffat [a]	*Head of Environmental and Human Sciences Division*

[a] New Heads of Division joined the Management Board in July 2004 following restructuring of the Agency.

The Chief Executive is appointed on a fixed term basis following public advertising of the post. The term of the appointment, and provision for its termination, are governed by the Civil Service Commissioners' Recruitment Code.

Remuneration of board members who hold senior staff group posts is determined by the Forestry Commission's Senior Pay Committee in accordance with guidelines prescribed by the Cabinet Office. Other board members' remuneration is determined by the standard processes set out in the Forestry Commission's pay and grading system.

Further details on remuneration are set out in notes 3.1 to 3.3 to these accounts.

10. Auditors

These accounts are prepared in accordance with a direction given by the Treasury in pursuance of Section 7 of the Government Resources and Accounts Act 2000. They are audited by the Comptroller and Auditor General. The fee for statutory audit services in respect of these accounts was £21,500. There were no further assurance or other non-audit services.

Professor J.M. Lynch
Chief Executive and Agency Accounting Officer
9 December 2005

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

Under Section 7 of the Government Resources and Accounts Act 2000 the Treasury has directed the Forestry Commission to prepare a statement of accounts for Forest Research for each financial year in the form and on the basis set out in the accounts direction. The accounts are prepared on an accruals basis and must give a true and fair view of the Forest Research state of affairs at the year-end and of its income and expenditure, recognised gains and losses 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, as set out in the *Resource accounting manual*, 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 Principal Accounting Officer, has designated the Chief Executive of Forest Research as the Accounting Officer for the Agency. His relevant responsibilities as Agency Accounting Officer, including his responsibility for the propriety and regularity of the public finances and for the keeping of proper records, and for safeguarding the Agency's assets, are set out in the Accounting Officers' Memorandum, issued by the Treasury and published in *Government accounting* (The Stationery Office).

Statement on Internal Control

1. Scope of responsibility

As Agency Accounting Officer, I have responsibility for maintaining a sound system of internal control that supports the achievement of Forest Research policies, aims and objectives, whilst safeguarding the public funds and departmental assets for which I am personally responsible, in accordance with the responsibilities assigned to me in *Government accounting*.

The Director General is the Deputy Chairman of the Forestry Commissioners and the senior official in the Forestry Commission. In addition to his role as a Commissioner, he is the Principal Accounting Officer, formally responsible to Parliament for the financial affairs of the Forestry Commission, including the Agency. In practice, the Director General's role in relation to the Agency is delegated to the Chief Executive as Agency Accounting Officer.

The Chief Executive of the Agency is responsible, normally through the Director General, to the Forestry Commissioners for the management of the Agency. The Chief Executive has a right of access to the Commissioners, and to Forestry Ministers, and will meet them at least once a year. The Director General designates the Chief Executive as Agency Accounting Officer, responsible for the Agency's accounts and financial procedures, and for the proper, effective and efficient use of resources provided to the Agency within the terms of the Framework Document and in pursuit of the agreed Corporate Plan objectives and targets. The Chief Executive is a member of the Forestry Commission's Executive Board.

In particular, the Chief Executive is responsible for:

- preparing the Agency's Corporate Plans and for achieving the targets set in them;
- appointment and organisation of the Agency's staff, and deployment of other resources to achieve the aims and objectives;
- maintaining financial and management information systems to assist in the monitoring and control of performance;
- preparing and submitting the Agency's Annual Report and Accounts;
- establishing and chairing an Agency Executive Board comprising senior managers within the Agency.

The Director General and Chief Executive are liable to be summoned to appear before the Public Accounts Committee to answer for their respective responsibilities. It will be for Ministers to decide who should represent them at other Parliamentary Committee hearings. In practice, where a Committee's interest is confined to the day-to-day operations of the Agency, Ministers will normally regard the Chief Executive as the person best placed to appear on their behalf.

2. The purpose of the system of internal control

The system of internal control is designed to manage risk to a reasonable level rather than to eliminate all risk of failure to achieve policies, aims and objectives; it can therefore only provide reasonable and not absolute assurance of effectiveness. The system of internal control is based on an ongoing process designed to identify and prioritise the risks to the achievement of the Agency's policies, aims and objectives, to evaluate the likelihood of those risks being realised and the impact should they be realised, and to manage them efficiently, effectively and economically. The system of internal control has been in place in the Agency for the year ended 31 March 2005 and up to the date of approval of the Annual Report and Accounts, and accords with Treasury guidance.

3. Capacity to handle risk

The Agency has taken a positive approach to risk management, which it feels is entirely appropriate to its role and remit. Risk management is the responsibility of every member of staff in Forest Research. Everyone has a role to play in managing the risks within their own area of authority. Risk awareness and responsibility lies in parallel with the structure of Forest Research's objectives. At every level of objective there is an equivalent delegation of responsibility of associated risk.

The resources available for managing risk are finite and so the aim is to achieve an optimum response to risk, prioritised in accordance with the evaluation of risk. The system of internal control incorporates risk management. The system encompasses a number of elements that together facilitate an effective and efficient operation, enabling Forest Research to respond to a variety of operational, financial and commercial risks. These elements include:

- Policies set by the Board of Commissioners and the Forest Research Executive Board. Written procedures support the policies where appropriate.
- Comprehensive regular reporting to the Executive Board designed to monitor key risks and their controls. Decisions to rectify problems are made at their regular meetings.
- Planning and budgeting system used to set objectives, agree action plans and allocate resources. Progress towards meeting plan objectives is monitored regularly.

The Forestry Commission has a departmental Risk Improvement Manager who chairs a Risk Management Group comprising a risk champion from each part of the organisation and an Internal Audit representative. During the year, the Head of IT Services of Forest Research has acted as risk champion for the Agency, including responsibility for maintenance and enhancement of the risk register.

4. The risk and control framework

Forest Research is committed to a process of continuous development and improvement: developing systems in response to any relevant reviews and developments in best practice in this area. In particular, in the period covering the year to 31 March 2005 and up to the signing of the accounts Forest Research has:

- Agreed to restructure the methodology and format of the Agency's risk register to more clearly identify inherent and residual risk together with the control framework in place to manage this within an acceptable level. A working group was set up to take this forward and the revised methodology is to be discussed at the next meeting of the Forestry Commission Risk Management Group at the end of July 2005.
- Endorsed a revised Forestry Commission risk policy statement presented to the Forestry Commission Executive Board in February 2005. The Forestry Commission Audit Committee agreed that the revised statement, incorporating changes debated by the Committee, should be tabled at a future meeting of the Board of Commissioners. This is planned for September 2005.
- Updated the existing Forest Research risk register to reflect newly identified potential risks and appropriate control measures for agreement by Executive Board members in June 2005.

The size and membership of the Forestry Commission Audit Committee is designed to represent all parts of the Forestry Commission. The Chief Executive of Forest Research is a member of the Committee which met three times during the year, in April, September and December 2004, to consider a range of reports from management, internal audit and external audit. As part of the governance framework, the Board of Commissioners received oral reports from the Committee Chair on business during the year and a more formal annual report on the discharge of its duties in June 2005.

The Audit Committee, in the main, deals with higher level issues concerning control and governance. The Agency Chief Executive was provided with more detailed advice on the work of Internal Audit in particular, and control in general, via the Agency's Internal Control Committee (ICC). The ICC's objectives are:

- to provide a forum for senior management to discuss internal control and audit matters;
- to promote understanding of the internal audit role and objectives;
- to assist the Head of Internal Audit in defining the scope of audit coverage and assessing priorities.

The Committee met three times during the year, in April 2004, December 2004 and March 2005 to receive reports on internal audit activity, risk management and feedback on the work of the Audit Committee.

5. Review of effectiveness

As Agency Accounting Officer, I have responsibility for reviewing the effectiveness of the system of internal control. My review of the effectiveness of the system of internal control is informed by the work of the internal auditors and the executive managers within the Agency who have responsibility for the development and maintenance of the internal control framework, and comments made by the external auditors in their management letter and other reports. I have been advised on the implications of the result of my review of the effectiveness of the system of internal control by the Executive Board, the Audit Committee and the ICC and a plan to address weaknesses and ensure continuous improvement of the system is in place.

The Head of Internal Audit has prepared an annual report and assurance statement to me as the Agency Accounting Officer. The report includes an overall assessment of the adequacy and effectiveness of risk management, control and governance within the Agency. The Director General as Principal Accounting Officer has received a similar report and assurance statement including any comments specific to the Great Britain core responsibilities. The overall opinion is that internal control within Forest Research continues to provide substantial assurance that material risks to the achievement of objectives are adequately managed.

A review of the structure, interactions and functioning of the Forestry Commission's corporate governance framework was undertaken during 2004–05 by Internal Audit and the Corporate and Forestry Support Division. It covered the decision-making bodies at both Great Britain level and within countries and agencies. During the review, Internal Audit referred to two best practice guides, the draft Code of Good Practice on corporate governance in government departments and the CMPS toolkit on maximising board effectiveness. The Forestry Commission's Executive Board will now consider the recommendations before proposing changes for approval by the Board of Commissioners. A separate review will be undertaken of the structure, relationship and work of the Audit Committee and ICCs during 2005–06.

Forest Research implemented an internal reorganisation of the Agency's management structure in July 2004 with consequential appointments of new Heads of Division, a revised Research Strategy, and preparation for implementation of a formal quality assurance scheme. During 2005–06, the ongoing work will include updating management responsibility for risk to fully incorporate the new Heads of Division, where appropriate. Under present arrangements, I rely on the organisational structure for managing risk with clear responsibilities at every level, supported by a Risk Management Group whose role is to assist in the development of good risk management practice throughout the Forestry Commission. During 2005–06, the Agency will introduce a framework of Certificates of Assurance to further support my review of effectiveness of the system of internal control.

6. Significant internal control problems

The bank accounts held by the Forestry Commission serve all parts of the Commission including Forest Research. It is vital that the Forestry Commission can reconcile transactions in its accounting ledger with the associated cash transactions recorded in its commercial bank accounts and its account with the Office of the Paymaster General.

During 2004–05, the Finance and Accounting shared service did not complete the necessary periodic reconciliations between the ledger and bank accounts within the scheduled timescale. The main problem arose from system changes made in July 2004 to further automate and improve the processes involved. When the problem was identified, the Forestry Commission employed an additional, external resource to cover the backlog. Internal Audit reviewed the work and confirmed that the reconciliations as at March 2005 were complete, accurate and valid and that the system in use stood up to scrutiny. During the review, Internal Audit identified some areas for improvement to help the audit process which will feed into a wider review of banking arrangements initiated by senior management. The Forestry Commission Finance Director has confirmed that the reconciliations for 2005–06 are up to date.

Professor J.M. Lynch
Chief Executive and Agency Accounting Officer
9 December 2005

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 99 to 115 under the Government Resources and Accounts Act 2000. These financial statements have been prepared under the historical cost convention as modified by the revaluation of certain fixed assets and the accounting policies set out on pages 102 to 104.

Respective responsibilities of the Agency, the Chief Executive and Auditor

As described on page 92, the Agency and Chief Executive are responsible for the preparation of the financial statements in accordance with the Government Resources and Accounts Act 2000 and Treasury directions made thereunder and for ensuring the regularity of financial transactions. The Agency and Chief Executive are also responsible for the preparation of the other contents of the Annual Report. My responsibilities, as independent auditor, are established by statute and I have regard to the standards and guidance issued by the Auditing Practices Board and the ethical guidance applicable to the auditing profession.

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

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

I review whether the statement on pages 93 to 96 reflects the Agency's compliance with Treasury's guidance on the Statement on Internal Control. I report if it does not meet the requirements specified by Treasury, or if the statement is misleading or inconsistent with other information I am aware of from my audit of the financial statements. I am not required to consider, nor have I considered, whether the Accounting Officer's Statement on Internal Control covers all risks and controls. I am also not required to form an opinion on the effectiveness of the Agency's corporate governance procedures or its risk and control procedures.

Basis of audit opinion

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

I planned and performed my audit so as to obtain all the information and explanations which I considered necessary in order to provide me with sufficient evidence to give reasonable assurance that the financial statements are free from material misstatement, whether caused by error, or by fraud or other irregularity and that, in all material respects, the expenditure and income have been applied to the purposes intended by Parliament and [the financial transactions] conform to the authorities which 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 the Forest Research Agency at 31 March 2005 and of the net deficit, total recognised gains and losses and cash flows for the year then ended and have been properly prepared in accordance with the Government Resources and Accounts Act 2000 and directions made thereunder by Treasury; and
- in all material respects the expenditure and income have been applied to the purposes intended by Parliament and the financial transactions conform to the authorities which govern them.

I have no observations to make on these financial statements.

John Bourn
Comptroller and Auditor General
16 December 2005
National Audit Office
157–197 Buckingham Palace Road
Victoria
London SW1W 9SP

Income and Expenditure Account for the year ended 31 March 2005

	Notes	2004–05 £000	2003–04 £000
Income			
Income from research, development and survey services			
Forestry Commission customers	2	11,489	11,186
Non-Forestry Commission Customers			
European Union		1,133	844
Other		980	807
Total income		13,602	12,837
Expenditure			
Staff costs	3	8,399	7,997
Other management costs	4	2,210	2,075
Materials and services	5	2,611	2,355
Total expenditure		13,220	12,427
Net operating surplus/(deficit)		382	410
Notional cost of capital	8	(409)	(384)
Net (deficit)/surplus for the year		(27)	26
Transferred to General Fund		(27)	26

Statement of Total Recognised Gains and Losses for the year ended 31 March 2005

	2004–05 £000	2003–04 £000
Net (deficit)/surplus for the year	(27)	26
Revaluation surplus/(loss) for the year	404	376
Total recognised gains/(losses)	377	402

The notes on pages 102 to 115 form part of these accounts.

Balance Sheet as at 31 March 2005

	Notes	2004–05 £000	2003–04 £000
Fixed assets			
Tangible assets	6	11,114	10,731
Intangible assets	7	50	36
		11,164	10,767
Current assets			
Stocks and Work in Progress	9	462	536
Debtors	10	1,406	613
Cash at banks and in hand	11	548	512
		2,416	1,661
Creditors – amounts falling due within one year	12	609	715
Net current assets		1,807	946
Provisions for liabilities and charges	13	78	150
Total assets less current liabilities		12,893	11,563
Taxpayers' Equity			
General Fund	14	7,852	6,926
Revaluation Reserve	15	5,041	4,637
		12,893	11,563

Professor J.M. Lynch
Chief Executive and Agency Accounting Officer
9 December 2005

The notes on pages 102 to 115 form part of these accounts.

Cash Flow Statement for the year ended 31 March 2005

	Notes	2004–05 £000	2003–04 £000
Reconciliation of net deficit to net cash flow from operating activities			
Net (deficit)/surplus for the year		(27)	26
Notional cost of capital	8	409	384
Depreciation	4, 6 & 7	518	485
Loss/(Profit) on disposal of assets		-	11
Decrease/(Increase) in stocks and work in progress		74	(374)
(Increase)/Decrease in debtors		(793)	418
(Decrease)/Increase in creditors		(106)	55
(Decrease)/Increase in provisions		(72)	150
Non-cash inter-country transfers		24	(16)
Less (increase) in capital creditors		(38)	(28)
Net cash (outflow)/inflow from operating activities		(11)	1,111
Cash flow statement			
Net cash (outflow)/inflow from operating activities		(11)	1,111
Capital expenditure and financial investment			
Tangible fixed assets additions		(375)	(340)
Intangible fixed assets additions		(23)	(36)
Increase in capital creditors		38	28
Capital expenditure		(360)	(348)
Total net cash (outflow)/inflow		(371)	763
Financing			
Cash deficit/(surplus) transferred to/funded by Forestry Commission		407	(251)
Increase/(decrease) in cash		36	512
Reconciliation of net cash flow to movement in net funds			
Increase in cash and bank		36	512
Net funds at 1 April 2004		512	-
Net funds at 31 March 2005		548	512

The notes on pages 102 to 115 form part of these accounts.

Notes to the Accounts

Note 1. Accounting Policies

1.1 Form of Accounts

In accordance with Section 7 of the Government Resources and Accounts Act 2000, the accounts are drawn up in a format agreed and approved by Treasury. They are prepared in accordance with the 2004–05 *Resource accounting manual* (RAM) issued by HM Treasury, under the historical cost convention modified by the inclusion of the valuation of assets.

The accounting policies contained in the RAM follow UK Generally Accepted Accounting Practice for companies (UK GAAP) to the extent that it is meaningful and appropriate to the public sector.

The particular accounting policies adopted by the Agency are described below. They have been applied consistently in dealing with items considered material in relation to the accounts.

1.2 Tangible 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.

Staff payroll costs and expenditure on materials, consumables, etc, of systems development software, for general use within the Agency, are recognised as tangible fixed assets. There was no relevant in-house development activity in the year 2004–05.

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

1.3 Valuation of Assets

In accordance with UK GAAP, professional valuation of non-forest land and buildings shall be undertaken on a five-yearly basis with a formal review in the third year. The first five-yearly valuation shall be undertaken at 31 March 2008.

In 2004–05, professionally qualified staff employed by the Commission carried out a review into the use of the indices provided by the District Valuer. The review concluded that the use of the indices provided a reasonable restatement of the current value of non-forest land and buildings. The indices were therefore used to restate values as at 31 March 2005 and shall be used in each year until the professional valuation at 31 March 2008.

Other tangible fixed assets are revalued annually using a range of appropriate indices as provided by the Office for National Statistics.

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

1.4 Depreciation

Freehold land is not depreciated.

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

Freehold Buildings – 20 to 80 years.

Research and office equipment – 3 to 20 years.

1.5 Intangible Fixed Assets

Form 1 April 2003, purchases of software with an acquisition value of £1500 are recognised as intangible fixed assets and amortised over their expected useful lives to a maximum of seven years. Software purchases with an acquisition value of less than £1500 are also treated as intangible fixed assets, on a pooled asset basis, the amount being material. Prior to 1 April 2003, all costs of software were charged to the Income and Expenditure Account in the period in which they were incurred.

1.6 Stocks and Work in Progress

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.

1.7 Provision for Bad and Doubtful Debts

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

1.8 Research and Development

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

1.9 Cost of Capital Charges

Charges, representing the cost of capital utilised by the Agency, are identified on the Income and Expenditure Account. The charge is calculated at the Government's standard rate of 3.5% in real terms on the average carrying amount of all assets, except for cash balances, less liabilities.

1.10 Corporation Tax

Forest Research is not subject to corporation tax.

1.11 Value Added Tax

The Forestry Commission is registered for Value Added Tax (VAT) and accounts for it on a Great Britain basis, including any Agency activity. Income and expenditure shown in the accounts is net of any recoverable VAT. Non-recoverable VAT is charged to the accounts in the year in which it is incurred.

1.12 Foreign Currencies

Transactions in foreign currencies are recorded at the rate ruling at the time of the transaction. Monetary assets and liabilities denominated in foreign currencies at the balance sheet date are translated at the rates ruling at that date. Translation differences are recorded in the Income and Expenditure account.

1.13 Insurance

In accordance with normal Government accounting practice, the Forestry Commission carries its own insurance risks.

1.14 Pensions

Past and present employees are covered by the provisions of the Principal Civil Service Pension Scheme (PCSPS), which is a defined benefit scheme and is unfunded. The Forestry Commission recognises the expected cost of providing pensions on a systematic and rational basis over the period during which it accrues benefits from employees' services by payment to the PCSPS of amounts calculated on an accruing basis. Liability for payment of future benefits is a charge on the PCSPS. Further information on pensions is provided in note 3 to the accounts.

1.15 Provisions

Forest Research provides for legal or constructive obligations which are of uncertain timing or amount at the balance sheet date on the basis of the best estimate or the expenditure required to settle the obligation. Where the effect of the time value of money is significant, the estimated risk-adjusted cash flows are discounted using the real rate set by HM Treasury (currently 3.5%).

1.16 Third Party Assets

Forest Research acts as co-ordinator for a number of projects partially funded by the European Commission. The duties of co-ordinators include receiving funds on behalf of partners for onward transmission once work programmes have been approved. In 2002–03 these monies were disclosed on the face of the accounts. As the result of a ruling by Treasury that these are third party assets, which neither the Agency or government more generally has a direct beneficial interest in, the sums concerned are not recognised in the accounts.

Note 2. Income from Forestry Commission and Forest Enterprise

2.1 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 £10.1 million. Costs established in one year are used to determine project charges for future years. The Agency also provides research and survey services for Forest Enterprise and other parts of the Forestry Commission on a full cost recovery basis.

Income from Forestry Commission customers consisted of:

	2004–05	2003–04
	£000	£000
Research, development and other services to:		
Forestry Commission	10,432	10,808
Forest Enterprise	1,057	378
	11,489	11,186

Note 3. Staff Costs and Numbers

3.1 Employee costs during the year amounted to:

	2004–05	2003–04
	£000	£000
Wages and Salaries	6,955	6,618
Social Security Costs	539	506
Employer's Superannuation Costs	904	864
Agency Staff Costs	1	9
	8,399	7,997

Average number of employees (full-time equivalents)

	2004–05	2003–04
	278	278

Staff were covered by the Principal Civil Service Pension Scheme (PCSPS) which is an unfunded multi-employer defined benefit pension scheme but the Forestry Commission is unable to identify its share of the underlying assets and liabilities. The scheme actuary valued the scheme as at 31 March 2003. Details can be found in the resource accounts of the Cabinet Office: Civil Superannuation (www.civilservice-pensions.gov.uk).

For 2004–05, employers contributions of £904,000 were payable to the PCSPS (2003–04: £864,000) at one of four rates in the range 12% to 18.5% of pensionable pay, based on salary bands. The scheme actuary reviews employer contributions every four years following a full scheme valuation. From 2005–6 the salary bands will be revised and the rate will be in a range between 16.2% and 24.6%. The contribution rates reflect benefits as they are accrued, not when the costs are actually incurred, and reflect past experience of the scheme.

Employees can opt to open a partnership pension account, a stakeholder pension with an employer contribution. No Agency staff have yet taken this option.

3.2 The total remuneration, excluding pension contributions of Professor Jim Lynch, Chief Executive, the highest paid member of the Board, was £80,138.64. The Chief Executive is an ordinary member of the Pension Scheme.

3.3 The salary and pension entitlements of the management board members is shown below.

Name	1 Salary including performance pay £000	2 Benefits in kind (rounded to the nearest £100) £	3 Real increase in pension and related lump sum £000	4 Total accrued pension at age 60 and at 31/3/05 and related lump sum £000	5 CETV @ 31/3/04 £000	6 CETV @ 31/3/05 £000	7 Real increase in CETV after adjustment for inflation and changes in market investment factors £000	8 Employer contribution to partnership pension account including risk benefit cover £
2004–05								
Jim Lynch	80–85		0–2.5	0–5	12	31	15	0
Peter Freer-Smith	60–65	1600	0–2.5 plus lump sum of 0–2.5	15–20 plus lump sum of 50–55	233	254	5	0
Ken Charles	45–50		0–2.5 plus lump sum of 2.5–5.0	15–20 plus lump sum of 55–60	318	349	16	0
Tony Cornwell	40–45		0–2.5	0–5	51	62	9	0
Bill Mason	50–55		0–2.5 plus lump sum of 0–2.5	15–20 plus lump sum of 50–55	280	302	9	0
Sam Evans [a]	40–45		0–2.5 plus lump sum of 2.5–5.0	0–5 plus lump sum of 10–15	42	58	13	0
Hugh Evans [a]	55–60	300	0–2.5 plus lump sum of 2.5–5.0	20–25 plus lump sum of 65–70	348	382	15	0
Chris Quine [a]	45–50		0–2.5 plus lump sum of 2.5–5.0	10–15 plus lump sum of 40–45	162	192	18	0
Andy Moffat [a]	50–55		0–2.5 plus lump sum of 2.5–5.0	15–20 plus lump sum of 45–50	202	238	23	0

[a] New Heads of Division joined the management board in July 2004 following restructuring of the Agency.

2003–04

Jim Lynch (wef 1/7/2003)	50–55	–	0–2.5	0–5.0	0	10	9	0
Peter Freer-Smith	60–65	1000	0–2.5 plus 2.5–5.0 lump sum	15–20 plus 50–55 lump sum	225	248	13	0
Ken Charles	40–45		0.25 plus 2.5–5.0 lump sum	15–20 plus 50–55 lump sum	288	318	16	0
Tony Cornwell	40–45		0–2.5	0–5	37	49	9	0
Bill Mason	40–45		0–2.5 plus 2.5–5.0 lump sum	15–20 plus 50–55 lump sum	256	280	11	0

CETV: Cash Equivalent Transfer Value.

Salary

Salary includes gross salary and performance bonuses.

Pension

Pension benefits for the management board are consistent with other Forestry Commission employees and are provided through the Principal Civil Service Pension Scheme (PCSPS).

Benefits in kind

The monetary value of benefits in kind shown in the table at note 3.3 covers benefits provided by the employer that are treated as taxable income by the Inland Revenue. They are in respect of the Car Provision for Employees Scheme.

3.4 Pension schemes

Pension benefits are provided through the CSP arrangements. From 1 October 2002, civil servants may be in one of three statutory based 'final salary' defined benefit schemes (classic, premium or classic plus). The schemes are unfunded with the cost of benefits met by monies voted by Parliament each year. Pensions under these three schemes are increased annually in line with changes in the Retail Price Index. New entrants after 1 October 2002 may choose between membership of premium or joining a good quality 'money purchase' stakeholder arrangement with a significant employer contribution (partnership pension account).

Employee contributions are set at the rate of 1.5% of pensionable earnings for classic and 3.5% for premium and classic plus. Benefits in classic accrue at the rate of 1/80th of pensionable salary for each year of service. In addition, a lump sum equivalent to three years pension is payable on retirement. For premium, benefits accrue at the rate of 1/60th of final pensionable earnings for each year of service. Unlike classic, there is no automatic lump sum but members may give up (commute) some of their pension to provide a lump sum. Classic plus is essentially a variation of premium, but with benefits in respect of service before 1 October 2002 calculated broadly as for classic.

The partnership pension account is a stakeholder pension arrangement. The employer makes a basic contribution of between 3% and 12.5% (depending on the age of the member) into a stakeholder pension product chosen by the employee. The employee does not have to contribute but where they do, the employer will match these up to a limit of 3% of pensionable salary (in addition to the employer's basic contribution). Employers also contribute a further 0.8% of pensionable salary to cover the cost of centrally-provided risk benefit cover (death in service and ill health retirement).

Further details about the CSP arrangements can be found at the website www.civilservice-pensions.gov.uk

Columns 5 and 6 of the table at note 3.3 show the member's Cash Equivalent Transfer Value (CETV) accrued at the beginning and end of the reporting period. Column 7 reflects the increase in CETV effectively funded by the employer. It takes account of the increase in accrued pension due to inflation, contributions paid by the employee (including the value of any benefits transferred from another pension scheme or arrangement) and uses common market valuation factors for the start and end of the period.

A CETV is the actuarially assessed capitalised value of the pension scheme benefits accrued by a member at a particular point in time. The benefits valued are the member's accrued benefits and any contingent spouse's pension payable from the scheme. A CETV is a payment made by a pension scheme or arrangement to secure pension benefits in another pension scheme or arrangement when the member leaves a scheme and chooses to transfer the benefits accrued in their former scheme. The pension figures shown relate to the benefits that the individual has accrued as a consequence of their total membership of the pension scheme, not just their service in a senior capacity to which the disclosure applies. The CETV figures, and from 2003–04 the other pension details, include the value of any pension benefit in another scheme or arrangement which the individual has transferred to the CSP arrangements and for which the CS Vote has received a transfer payment commensurate to the additional pension liabilities being assumed. They also include any additional pension benefit accrued to the member as a result of their purchasing additional years of pension service in the scheme at their own cost. CETVs are calculated within the guidelines and framework prescribed by the Institute and Faculty of Actuaries.

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 loans with an outstanding balance of £2,500 or more to five individual members of staff at 31 March 2005. The total outstanding value of all loans (11) was £41,675.65

Note 4. Other Management Costs

Other management costs are stated after charging:

	2004–05	2003–04
	£000	£000
Auditors' remuneration	22	21
Travel and subsistence	468	458
Staff transfer expenses	15	20
Training	131	112
Building maintenance	411	381
Utilities	251	259
Computer supplies	85	77
Premature retirement costs	135	-
Employer liability provisions and payments	55	157
Depreciation of fixed assets	518	485
Loss on disposal of fixed assets	-	11
Other expenditure	119	94
	2,210	2,075

Included within Other Management Costs are charges from the Forestry Commission and Forest Enterprise amounting in total to £116,000 (2003–04: £82,000).

Note 5. Materials and Services

Materials and services are stated after charging:

	2004–05	2003–04
	£000	£000
Materials and supplies	800	711
Central services from Forestry Commission	722	456
Vehicle lease charges from Forestry Commission	401	435
Contractors	335	402
Commissioned research	147	138
Publications	44	57
Protective clothing	20	18
Miscellaneous expenditure	142	138
	2,611	2,355

Included within Materials and Services are charges from the Forestry Commission and Forest Enterprise amounting in total to £1,123,000 (2003-04: £904,000).

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

Note 6. Tangible Fixed Assets

	Freehold Land and Buildings	Machinery and Equipment	Total
	£000	£000	£000
Valuation:			
At 1 April 2004	9,466	3,811	13,277
Additions	95	280	375
Disposals	-	(8)	(8)
Transfers (note 14)	117	-	117
Revaluation	418	15	433
At 31 March 2005	10,096	4,098	14,194
Depreciation:			
At 1 April 2004	343	2,203	2,546
Provided in year	192	317	509
Disposals		(8)	(8)
Transfers (note 14)	4	-	4
Revaluation	23	6	29
At 31 March 2005	562	2,518	3,080
Net book value:			
At 31 March 2005	9,534	1,580	11,114
At 31 March 2004	9,123	1,608	10,731

Fixed assets were revalued as at 31 March 2005 in accordance with accounting policies. The valuation includes the principal research stations at Alice Holt Lodge near Farnham in Surrey and the Northern Research Station, Roslin near Edinburgh, with net book values of £6.4 million and £2.7 million respectively at 31 March 2005.

Note 7. Intangible Fixed Assets

	2004–05	2003–04
	£000	£000
Valuation		
Balance at 1 April	36	-
Additions	23	36
As at 31 March	59	36
Depreciation in year	9	-
Balance at 31 March	50	36

Intangible fixed assets relates wholly to purchased software. Prior to 1 April 2003 software costs were charged to the income and expenditure account in the period they were incurred. From 1 April 2003, software has been recognised as an intangible fixed asset.

Note 8. Cost of Capital

Notional cost of capital based on 3.5% of average total assets, excluding bank balances, less current liabilities employed in 2004–05 amounted to £409,421 (2003–04: £384,287).

Note 9. Stocks and Work in Progress

	2004–05	2003–04
	£000	£000
Research Work in Progress	462	536
	462	536

Note 10. Debtors

	2004–05	2003–04
	£000	£000
Amounts falling due within one year		
EU debtors	906	236
Other Trade debtors	251	167
Other debtors	26	21
Prepayments	201	136
	1,384	560
Amounts falling due after one year		
House purchase loans	22	53
	1,406	613

Note 11. Cash at banks and in hand

The following balances at 31 March are held at commercial banks and cash in hand

	2004–05	2003–04
	£000	£000
Opening balance at 1 April	512	-
Net change in balances	36	512
Balance at 31 March	548	512

As part of its normal activities Forest Research maintains Sterling and Euro bank accounts primarily used for the receipt of income from non-Forestry Commission customers. These accounts are cleared to the Commission's main account on a regular basis. Sums held in these accounts on behalf of partners in European Commission projects are treated as third party assets and not included in the balances shown.

Note 12. Creditors: amounts falling due within one year

	2004–05	2003–04
	£000	£000
Payments received on account	297	241
Trade creditors	311	441
Other creditors including taxation and social security costs	1	33
	609	715

Funds held on behalf of partners in European Commission projects are treated as third party assets and not recorded on the face of the accounts (see note 1.16). At 31 March 2005 the amount held in Forest Research Bank accounts on behalf of partners was £345,791.36 (31 March 2004: £348,884.55).

Note 13. Provisions for Liabilities

	2004–05	2003–04
	£000	£000
Employer liability claims		
Balance brought forward	150	-
Utilised in year	(150)	-
Provided in year	-	150
Balance carried forward	-	150
Early departure costs		
Provided in year	94	-
Utilised in year	(5)	-
Unwinding of discount	(11)	-
Balance carried forward	78	-

Note 14. General Fund

	2004–05	2003–04
	£000	£000
Balance brought forward	6,926	6523
Transfer from revaluation reserve – disposed assets	-	127
Movement in year		
Net (deficit)/surplus for year	(27)	26
Transfer of fixed assets from other Forestry Bodies	113	133
Cash deficit/(surplus) from/to Forestry Commission	407	(251)
Non-cash inter-country transfers	24	(16)
Notional cost of capital	409	384
Balance carried forward	7,852	6,926

Transfers of fixed assets from other parts of the Forestry Commission were buildings at the Northern Research Station site.

Note 15. Revaluation Reserve

	2004–05	2003–04
	£000	£000
Balance brought forward	4,637	4,388
Transfer to General Fund – disposed assets	-	(127)
Revaluation surplus for the year ended 31 March 2005		
Land and Buildings	395	376
Machinery and Equipment	9	-
Balance carried forward	5,041	4,637

Note 16. Related Party Transactions

During the year, Forest Research has had a significant number of material transactions with the Forestry Commission and Forest Enterprise agency who are regarded as related parties.

In addition, Forest Research has had various material transactions with other Government Departments and other central Government bodies. Most of these transactions have been with the Department of Trade and Industry and the Department for Environment, Food and Rural Affairs.

Professor Jim Lynch, Chief Executive, is Distinguished Professor of Life Sciences at the University of Surrey. The value of payments to the University for services provided in the year to 31 March 2005 was £32,207.60. Sam Evans holds a visiting professorship at the University of Sheffield, with which £5,389.74 was spent on research services. Other members of staff hold professorships at UK and foreign universities but no financial transactions took place with these in 2004–05.

Note 17. Losses Statement

Losses totalled £4,230 from 1 case (2003–04 - £2,769 from 2 cases). Special payments totalled £12,268 from 14 cases (2003–04: £14,985 from 49 cases).

Note 18. Financial Instruments

FRS 13: *Derivatives and other financial instruments* requires disclosure of the role which financial instruments have had during the period in creating or changing the risks an entity faces in undertaking its activities. Because of the way in which government departments are financed, the Agency is not exposed to the degree of financial risk faced by business entities. Moreover, financial instruments play a much more limited role in creating or changing risk than would be typical of the listed companies to which FRS 13 mainly applies. The Agency has no powers to borrow or invest surplus funds and financial assets and liabilities are generated by day-to-day operational activities and are held not to change the risks facing the Agency in undertaking its activities.

Liquidity risk

The Agency is not exposed to significant liquidity risks because its net revenue and capital resource requirements are financed by resources voted annually by the UK Parliament.

Interest rate risk

The Agency is not exposed to interest rate risk.

Foreign currency risk

The agency has commercial relations with foreign customers and the European Commission, having dealings in foreign currencies and the Euro as well as Sterling. The treatment of gains and losses arising from transactions in foreign currencies is described at note 1.12 to the accounts. The Agency is therefore exposed to foreign currency risk, but the risk is not significant, with income from these sources being no more than 9% of the Agency's total income.

Note 19. 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 £382,000, which, after allowing for the cost of capital represented a cost recovery of 99.8% (2003–04: 100.2%).

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