Forest Research

ANNUAL REPORT AND ACCOUNTS 2003–2004

Forest Research
The research agency of the Forestry Commission

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

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and Section 5 of the Exchequer and Audit Departments Act 1921

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Forest Research
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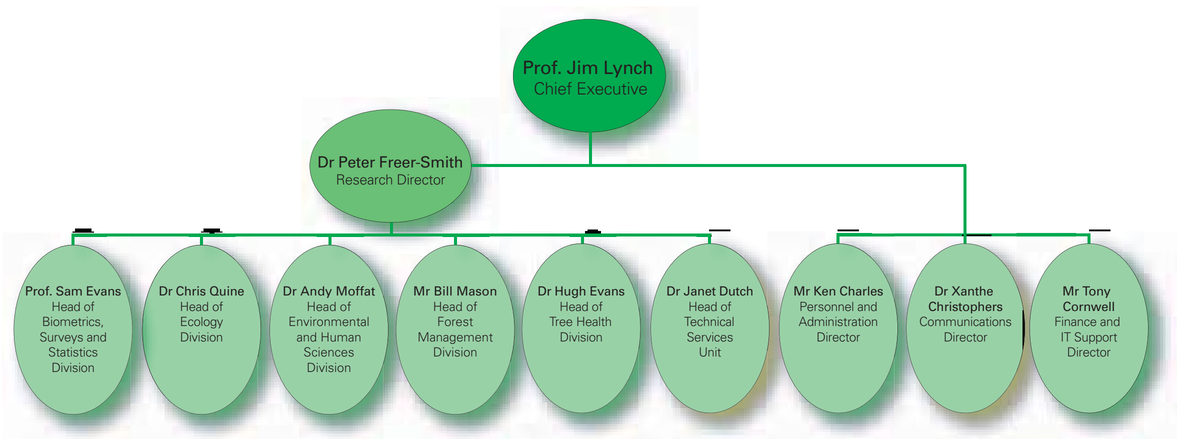
Forest Research Organisation 2004



During the compilation period of this Annual Report (spring 2003–spring 2004) the organisation structure shown on pages 141–145 was in place. The new organisation structure shown above was implemented in June 2004.

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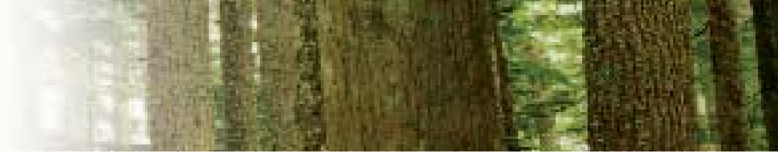
Foreword

by Professor David Read, Vice-President and Biological Secretary of The Royal Society

Having spent a forty-year research career investigating the biology of roots and their microbial symbionts I find it refreshing now to be involved, as Chair of the Forestry Commission's Advisory Committee on Forest Research, in considerations of the bigger picture. Not that I make any apology for my subterranean past! It is arguable that foresters pay too little attention to that part of the system that supports and sustains the crop. We forget at our peril that, as a colleague in the Swedish forest industry recently put it to me – 'Halva skogen finns unter ytan' – half the forest lies under the ground!

So, what do I see as the broader picture? We live in a landscape which, until 5000 years ago, was almost entirely covered by trees. Unfortunately the human inhabitants of these islands have not been the best custodians of this forest heritage. By the early part of the 20th century deforestation had reduced forest cover to around 3% of the land surface, and today we can claim little more than 12%. This is well below the value sustained by our European neighbours where the average, for example, of all 25 EU countries is 35%. The new accession countries are also much better endowed with forest resource.

Belated recognition that we had failed to manage our forests in a sustainable way led governments to encourage afforestation programmes, albeit with only modest financial support, through the 20th century, but under conditions which placed considerations of timber yield above all else. Such constraints forced our predecessors in the forestry industry to concentrate on the selection, planting and rapid harvesting of fast growing species most of which were of non-native origin. It was an approach that was entirely justifiable in strategic and economic terms and was underpinned as a successful venture by rigorously executed programmes of forest research. However, as an exercise, it failed to win the hearts and minds of a public which had become largely urbanised on the one hand but increasingly environmentally aware on the other. While pure stands of Sitka spruce (or of Corsican pine) might make sense in economic terms because of the speed with which they



reached the time for clearfelling, they were not the most attractive to people who sought recreational refuge in rural environments. As someone who has enjoyed working in intensively managed boreal forest environments overseas, I have never understood why UK foresters got such bad press for their endeavours to establish productive timber crops, while agriculturalists were able, with relative impunity, to clothe the countryside with pure stands of equally alien plants. Why should the alien maize or rape (a cultivar as far removed from *Brassica napus* as one could possibly get!) escape these strictures?

Whatever, the reasons for these public perceptions, things are set to change. We will of course continue to require that our forests are productive, after all, timber remains among the top three raw material imports to the UK and as such represents a serious threat to our balance of payments. But yield will not necessarily be the driving consideration. The age in which economic factors were the sole determinant of forest succession seems set to be replaced by one that seeks to optimise the broader benefits of forests for the community. These benefits will rightly continue to emphasise productivity, but with this aspect tempered by the requirement to grow trees in ways that are more sensitive to the needs of the environment in general and of people in particular.

The notion that UK forests should be managed as multifunctional ecosystems is gaining increasing impetus. What, more specifically, are these additional functions and how will they be achieved? They derive in part from the visions established by essentially political conventions such as those of Kyoto and Rio, that forests must serve both as ‘sinks’ for excess carbon dioxide and as refuges of biodiversity. These require, respectively, increased longevity of forest stands and greater sensitivity in their processes of management and felling. The perhaps fortuitous fact that these new functions contribute to enhance the amenity value of forest environments for a people increasingly blessed with disposable income and leisure time should not escape our notice.

The new functions will be achieved by what, for the UK at least, are novel processes of silvicultural management, most notably involving diversification of stand structure and selective felling regimes. Collectively these approaches, which are often referred to as continuous cover forestry, while having great promise, also present enormous challenges to the forestry industry. This again is where Forest Research comes in, but the questions posed are more diverse in nature than those, essentially productivity based challenges which faced our predecessors. They involve, among many facets of sustainability, understanding of interactions between different tree species, and between the trees and their associates on the forest floor and in the canopy, knowledge of carbon dynamics, advanced modelling capabilities that enable prediction of long-term outcomes, and last but not least, the capacity to communicate with the public on the landscape and amenity aspects of proposed and developing management schemes.

What heartens me as incumbent to the Chair of the Advisory Committee is the openness, from top to bottom, with which the new ideas are being embraced by Forest Research. I have discussed these developments with innovative young and older members of the organisation who are not only enthusiastic about meeting the new challenges but are also prepared to work in an interdisciplinary way to enable fulfilment of the goals involved. The same vision has been demonstrated by those assembling the Advisory Committee itself. I am fortunate to be joined by colleagues with a wealth of experience from the pure and applied sciences, from industry and from the social sector, and so am confident that with this breadth of knowledge we shall be able effectively to assist Jim Lynch and his staff as they carry out the underpinning research required to enable realisation of the exciting new goals of forestry.

David Read

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 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 Forestry Commission with Forestry Group 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 2003–04, 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 an essential component 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 *(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 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 the inside back cover of this Report. The Agency employs *c.* 300 people, not including visiting scientists and sandwich students. FR has published a Corporate Plan for the period 2003–2006 and copies are available from the Library at Alice Holt Lodge.

Chief Executive's Introduction

One year on...

As I embark upon my second year as Chief Executive at Forest Research, I have been reflecting on what challenges the organisation and its staff are likely to face in the year ahead.

The past year has been a demanding one but, although both the forestry sector and the UK science base face considerable challenges, the year has been characterised, above all, by the wealth of new opportunities which have arisen.

- We have enthusiastic endorsement from FC's new Director General, and from the Commissioners, to build the reputation of FR as a leading international centre of excellence for forest research.
- A large number of organisations, ranging from universities to blue chip companies, have expressed enthusiasm to work more closely with FR in projects which will show how forestry can assist innovation and add value to other sectors, such as health and natural resource management.
- Many practitioners' genuine desire to manage land sustainably offer significant opportunities for FR, whose staff's skills span such a wide range of disciplines. Forestry has a crucial role to play in effective integrated land use and other land users can learn much about sustainability from forestry.

I am simultaneously pleased and concerned that staff are working so hard to secure these opportunities. The ability to prioritise well will be one of the chief skills required by us all during the coming year. I believe that one of our most compelling priorities must be to build excellent long-term collaborations.

Innovation is critical if forestry as an industry is to flourish. Clearly stakeholders in the industry have ideas to input, but researchers also, by the very nature of their training and expertise, can input significantly. In consultation for future programmes it is therefore important that the researchers are seen as equal partners in the stakeholder fraternity.

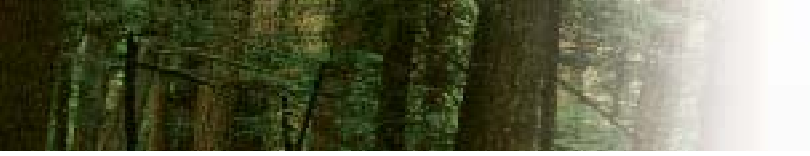
When I joined the Agency I felt that the management structure was complex, did not facilitate communication, and was outwith the modern idiom of scientific organisations. The new structure outlined in this report (page 2) is simpler and we were fortunate in apportioning quality staff to truly represent the range of disciplines and skills which are needed to interact with our business portfolio.

As we strive hard to realise our potential achievement in science and its applications we need help and advice. Our Advisory Board has always been helpful to us and we are very grateful for the service given by our retiring members: Professor Hugh Miller, Professor Michael Usher and Dr Peter Savill. We are lucky that our new board led by Professor David Read, Vice-President of the Royal Society, represents leaders in the areas of science relevant to us. I am delighted that David has written our Foreword this year.

Long-term collaborations succeed only when there is true symbiosis. Whatever the topic, we first need to critically assess what FR can offer its clients and collaborators and to assess whether FR's planned course of actions will keep it at the forefront of the field in question. This requires FR to be constantly alert to its external horizons. We then need to strike a careful balance between giving customers value for money and not under-pricing the cost of our participation. In short, we require financial and scientific excellence in equal measure. The opportunity cost of participating in projects which do not meet both criteria is simply too high.

One of the highlights of our year was to be invited to exhibit at the prestigious Royal Society Summer Exhibition for which the competition to exhibit is intense and represents the best of exciting British Science. Our entry from the Tree Health Division entitled 'Biological cruise missile: beetle vs beetle in forest protection' was admired by many eminent people from all walks of life. Equally satisfying have been our multiple engagements out in the field such as our contributions to the woodfuel debate and social engagement within forestry. We will strive to reach as many stakeholders as possible with our message. (Update, October 2004: this will be facilitated by the appointment of a new Director of Communications, Dr Xanthe Christophers, who comes to us with extensive experience of communication particularly with her work in the Department for International Development (DFID) forestry programme).

I am also pleased that the Agency achieved its key corporate targets for the year, as shown in the table on page 10.



Targets and achievements over the past five years

Performance measure		1999/00	2000/01	2001/02	2002/03	2003/04	
Customer satisfaction	Target	95%	96%	96%	97%	90%	**TARGET MET**
	Achieved	96%	97%	97%	98%	97%	
Peer-reviewed papers	Target	38	43	48	48	45	**TARGET MET**
	Achieved	43	48	48	48	45	
Unit cost/research day (unweighted) 98/99 = 100	Target	94	94	94	92	90	**TARGET MET**
	Achieved	86	82	81	79	78	
Unit cost of support services	Target	98	96	94	92	89	**TARGET MET**
	Achieved	95	92	86	84	82	
Cost recovery	Target	100%	100%	99%	100%	100%	**TARGET MET**
	Achieved	100%	101%	100%	100%	100%	
Reports, FC Publications and articles	Target	-	-	-	-	25	**TARGET MET**
	Achieved	-	-	-	-	25+	
Income from customers other than FC	Target	-	-	-	-	£1.5m	**TARGET MET**
	Achieved	-	-	-	-	£1.65m	
Review of silvicultural & entomology programmes	Target	-	-	-	-	Complete	**TARGET MET**
	Achieved	-	-	-	-	Complete	

2003–04 Research highlights

This year's research highlights are again presented by interdisciplinary theme. This reflects the way in which we have increasingly been working. These team contributions summarise many of the year's main findings, put them in the context of the overall programme and direct the reader to full accounts of the research. This introductory section of the report is followed by seven main articles which provide a comprehensive account of selected subjects where important issues have arisen and where major progress has been made.

Together the research highlights and main articles thus provide a comprehensive account of the results of FR's research programmes as completed during 2003–04 (a list of these is provided on pages 134–139). The portfolio of FR's work reflects the UK and international aspiration to achieve sustainable forestry. The need for research and scientific understanding in order to protect forestry has recently been re-emphasised by the amount of work required on *Phytophthora ramorum, Dothistroma pini, Cameraria ohridella* and other pests and diseases. Our work in the area of social forestry has continued to expand, reflecting an ongoing and exciting change in forestry. As for the protection work, new EU consortiums have been developed and funded to take forward our social forestry research and significantly better progress will result in both areas. Equally the development of sustainable forest management continues to raise applied research questions, and the work described on direct seeding of Sitka spruce is a good illustration of how progress can be made through close joint working with the forestry industry (Forest Enterprise in this instance). For our biodiversity work the close links with the conservation bodies have been particularly helpful in recent years with excellent work on native woodlands, protected species and woodland birds now under way.

FR's relatively new interest in the establishment of woodland on contaminated land has also formed the basis for new collaborations and funding. Monitoring, data management and modelling continue to be developed across the range of our programmes and a number of decision support systems are now available, with others being developed. The timber quality and genetic conservation programmes are producing important results and the planning of the new National Inventory of Woods and Trees (NIWT2) has gone well. Adjusting forestry practice in response to climate change, consideration of carbon dynamics, the development of woodfuel and economic appraisal are areas where our efforts are likely to intensify over the next few years. Finally, effective knowledge transfer and exploitation of research results have been receiving, and will continue to receive, increased attention.

New Advisory Committee on Forest Research

Five exciting new appointments have been made to the Advisory Committee on Forest Research. These appointments will increase the diversity of science advice and help FR to generate the innovation which is necessary to serve its stakeholders. I am extremely pleased that some of Britain's most eminent scientists have chosen to work with us in this capacity. The Advisory Committee now comprises eleven members with Professor David Read, FRS, as Chairman of the expanded board. David is Head of the University of Sheffield's Department of Animal and Plant Studies. The other four new members are: Professor Roland Clift, FREng, OBE, who is Director of the Centre for Environmental Strategy at the University of Surrey; Professor Paul Jarvis, FRS, Emeritus Professor of Forestry and Natural Resources at the School of Geo Sciences in the Institute of Atmospheric & Environmental Sciences at the University of Edinburgh; Professor Catherine Ward-Thompson, Director of OPENSpace research centre and Research Professor in Landscape Architecture at Edinburgh College of Art; and Professor David Evans, who was Head of Research & Technology at Syngenta International AG and now a consultant in the field of novel crop management solutions.

Six existing members of the committee were reappointed: Dr Christine Cahalan, Dr Peter Freer-Smith, Dr Steve Gregory, Professor Michael Jeger, Professor Brian Kerry and Professor Jim Lynch.

Thanks have been extended to three outgoing members of the Committee, all of whom have been generous with their time and highly supportive of Forest Research, and with whom FR will continue to have links in the future: Professor Hugh Miller, Professor of Forestry at the University of Aberdeen; Dr Peter Savill, Reader in Forestry at the Oxford Forestry Institute; and Professor Michael Usher, Department of Environmental Sciences at the University of Stirling.

Finance

Income in the year increased by 2.6% compared to the previous year. Within this an increase in Forestry Commission income of £353,000 was offset by a minor reduction in income from non-FC sources of £24,000 (1.4%). There was a 6% increase in payroll costs but reductions in other costs held the overall increase in operating expenditure to 4.6% over 2002–03 levels.

The target net operating surplus for the year of £384,000 was exceeded by £26,000, resulting in a full cost recovery performance of 100.2% against the target of full cost recovery (100%).

Capital investment at £348,000 covered a wide range of scientific and technical purchases including, notably, cryo-preservation and chemical analysis equipment, updated data capture systems as well as IT equipment and laboratory and office refurbishments.

A continuing programme of capital investment in infrastructure, facilities and equipment is essential if we are to maintain the high quality and cost effectiveness of our research.

People

The total number of staff employed by the Agency at year end excluding sandwich students and visiting scientists was 278 full-time equivalents.

Clive Brasier (Pathology) was awarded the honorific title ‘Fellow of the American Phytopathological Society’, for his outstanding contributions to plant pathology. Duncan Ray was made Deputy Co-ordinator of IUFRO work group 4.11.03 (information management and information technologies). Andy Moffat became a member of the international working group ‘Geoscience for Land Use and Sustainable Development’ under the auspices of the International Union of Geological Sciences. Paul Tabbush was confirmed as a Director of the Landscape Research Group which encourages education, research, interest and the exchange of information for public benefit, in landscape and its related fields.

Several staff were awarded higher degrees: Russell Anderson received an MSc (with distinction) in Forest Science at Edinburgh University; Elaine Abbott was awarded a distinction for her Napier University MSc thesis on the evaluation of young plantations as a habitat for fritillary butterflies; Joyce Rammell gained a BSc in Natural Sciences and won the Shot and Discus competitions at the Civil Service Athletics Championships and the Hammer Throw at the Scottish Championships.

Ken Williams retired in September 2003 after a total of 32 years with the Commission in Wales. Ken worked with Research & Surveys Branch initially at Betwy-y-coed Research Office and latterly at Gwydyr Uchaf (Llanrwst), as part of the Talybont Survey Team. After 10 years with FR Ned Cundall left Tree Improvement to join his family on Vancouver Island. Ned’s work included the evaluation of seed sources in ash, oak, sycamore, beech and birch in a series of nation-wide trials. Ned was also instrumental in FR’s membership of the European initiative on forest genetic resource, EUFORGEN.

Ernest Ward, Head of the Chemical Analysis Section at Alice Holt, retired at the end of March 2004 after nearly 18 years of service. Ernest developed the laboratories and provided an excellent analytical service for foliar, water and soil samples for FR, FC and the forest industry, greatly helping towards the application for UKAS accreditation. June Bell retired after 16 years with Forest Research. In addition to her work in Typing Services and Mensuration, June always supported staff events and took a leading role in Alice Holt Christmas productions.

New appointments to the Agency included: Dr Stuart A’Hara to work in Tree Improvement at NRS on molecular mapping/microsatellite markers; Carol Knight to work in Finance and Planning; Stephan Berthier from INRA, Bordeaux on a two-year Marie Curie fellowship, to work on the EU Ecoslopes project; Dr Elena Vanguelova to work as a biogeochemist at Alice Holt; Jane Poole to work as a statistician at Alice Holt; Stephen Bathgate to work at NRS as an analyst/programmer; Joe Hope who has joined Woodland Ecology at NRS as a research assistant; Dr Geoffrey Sellers to work on the EPSRC funded SUBR:IM project on urban greening and land reclamation; Dafydd Huw Thomas to work at Talybont as a forest hydrologist; Benjamin Griffin and Sam Catchpole to work with TSU at Talybont; Rene van Herwijnen to work on the use of novel composts in land remediation as part of the SUBR: IM project; Gary Ashdown as Head of Chemical Analysis at Alice Holt; Rory Cobb as field station manager at Alice Holt.

Visitors and events

Forestry Commissioners, including Tim Rollinson, newly confirmed as FC Director General, visited NRS in March 2004. At the start of their visit, I welcomed them with an outline of the organisational changes being introduced in FR, then followed a series of presentations on Tourism and forestry, Timber quality research, Biodiversity in forests, Genetic conservation of native species. Staff from BBSRC's Rothamsted Research visited Alice Holt to progress ideas for collaboration and developing partnerships with research council partners. The BBC filmed work being done on *Phytophthora ramorum* by Pathology at Alice Holt, as part of their Countryfile programme on 'Sudden Oak Death'.

A wide range of seminars, conferences and workshops were held at the research stations and forest sites. These included: FR/BBSRC Partnership workshop; Taking to the trees in West Argyle - a weekend of events showcasing treasures of the local forest; Innovations in restocking in Hafren Forest; History of southern Scottish woodlands; 'ROOTS': decision support system software for specifying new woodland on disturbed land; Small scale harvesting demonstrations in Shropshire, Herefordshire and Llanfylliu, Wales; Modeller's forum - an overview of FR modellers' projects; Forest Pathologists Group Meeting in Thetford: attended by UK/EU members.

FR was well represented at many UK and international conferences and meetings. These included: the All-party Parliamentary Group on Forestry in the House of Commons to review *Phytophthora ramorum*; the International Forestry Quarantine Research Group in Rome; Annual Contaminated Land Meeting; International Cleanup Exhibition; FRCC: Woodland birds in the UK; Sixth Regional Biodiversity and International Conference; The Royal Show at Stoneleigh, Warwickshire; Genetic conservation and management of British native trees; the South West Woodland Show.

'Woodfuel meets the Challenge' at the South West Woodland Show.

FR's short Research Update Seminars, held regularly at NRS and AH, have continued to be very popular and informative.

The Agency maintained its links nationally and internationally by hosting a variety of groups and individual visitors.

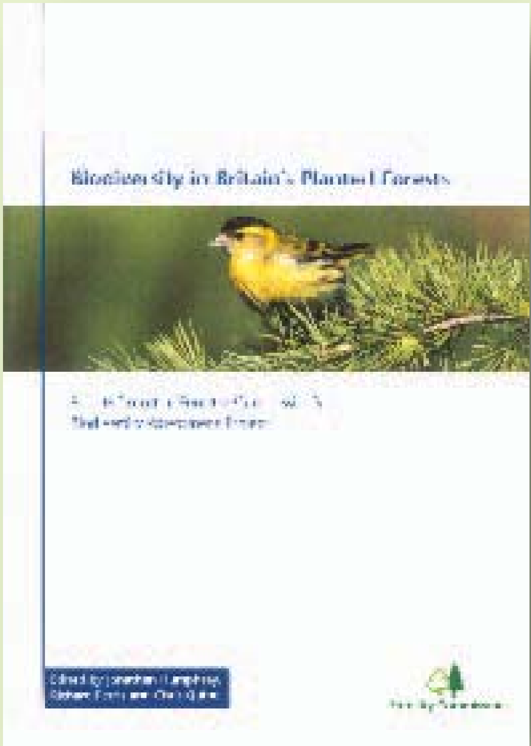
Our most valuable resource in Forest Research is our staff; I thank them sincerely for all the support they have given me during the year in delivering our mission and showing flexibility to the evolution of our structure. This is aided by the good internal relationships we have within FC and with the Forestry Commissioners. Similarly, our network of external relationships both at home and abroad is developing rapidly. Together we have massive scope to demonstrate the value of forestry research in developing sustainable land use and producing optimum economic returns for the industry that we support.

Professor Jim Lynch
Chief Executive

Woodland biodiversity and ecology

Chris Quine

Conserving biodiversity has become one of the most important objectives of sustainable forest management.



Biodiversity assessment in planted forests

Publication of the results of the Biodiversity Assessment programme: *Biodiversity in Britain's planted forests* was a major achievement. Twelve chapters summarise the context, methods and findings of this ambitious programme that investigated 54 plots of one hectare in 16 forests to capture a picture of the biodiversity of Britain's planted forests. The key message to emerge was that these planted forests, even those of non-native tree species, are not 'ecological deserts' as had previously been feared. Much of the biodiversity has benefited from aspects of the habitat that have occurred by chance, but considerable benefits could be obtained if more attention is given to biodiversity during the planning and layout of forests and their subsequent management.

Herbivores as an aid to woodland management

Herbivore impacts are frequently perceived to be negative for forest and woodland development, and as such have been the focus of work on deer populations. However, there has been growing interest in the targeted use of herbivore activity and, in particular, the use of cattle as a way of manipulating vegetation structure. During the year, a survey of cattle-grazing in British woodlands was completed. A database of known sites (over 400 records) was constructed, and a report published summarising the key lessons for managers; a supporting field survey provided insights into relative palatability of elements of the ground layer. In collaboration with local Forest Enterprise staff, work has begun to monitor a trial of cattle-grazing in forests in Glen Garry. The objective is to modify the vegetation composition and encourage regeneration of the native pinewood. Finally on this theme, a trial of a vegetation monitoring method, suitable for use should the European beaver be re-introduced into West Scotland, was developed on contract to Scottish Natural Heritage.

Supporting strategic decision making: whole forest, whole region and whole country

Last year's report highlighted the growing interest in landscape-scale decision-making. In the current year the prototype landscape ecology tool BEETLE was further developed by extending the focal species-based approach to incorporate 'generic species profiles'. These profiles represent the functional characteristics of species groups and allow the impacts of broad-scale decision making to be considered even though the ecological knowledge for individual species is inadequate. We have used the BEETLE model and related analysis to consider options for forest design planning in Clocaenog Forest, for the development of forest habitat networks for West Lothian region, and in the strategic planning of woodland habitat networks for the whole of Wales. In each case, the application of the scientific model has been accompanied by substantial discussion with 'stakeholders' before, during and after the results are obtained.

Ecological studies of Glen Affric

Two PhDs focusing on aspects of the ecology of Glen Affric were successfully completed, one of the case study areas of the landscape ecology project and an important national reserve renowned for its extensive native pinewood. The first developed a challenging dynamic landscape ecology model in the SELES programming language, and demonstrated the integration of a variety of sub-models to consider the expansion and cycling of the pine and birch forests within the Glen over timescales of hundreds of years. Important lessons were learnt over the technical integration of models, and interesting insights gained into potential ecological bottlenecks due to stand dynamics and expansion. The second was a study of the process of broadleaf tree species establishment within the native pinewoods, a component of the stand composition frequently overlooked. The link was examined between inherent shade tolerance and other limiting factors such as soil nutrition and vegetation competition. Strategies of accelerated natural regeneration and enrichment planting were recommended as a result of the findings.

Supporting publications	
Biodiversity assessment	Humphrey, J. W., Ferris, R. and Quine, C. P., eds. (2003). *Biodiversity in Britain's planted forests.* Forestry Commission, Edinburgh.
Herbivores and woodland management	Armstrong, H. M., Gill, R. M. A., Mayle, B. and Trout, R. C. (2002). Protecting trees from deer: an overview of current knowledge and future work. In: *Forest Research annual report and accounts.* The Stationery Office, Edinburgh, 28–39. Armstrong, H. M., Poulsom, E., Connolly, T. and Peace, A. J. (2003). *A survey of cattle-grazed woodlands in Britain.* Internet published report. Forestry Commission, Edinburgh.
Supporting strategic decision making	Quine, C. P. (2004). Woodland biodiversity: research highlight. *Forest Research annual report and accounts 2002–2003.* The Stationery Office, Edinburgh, 16–17.
Glen Affric	Hope, J. C. E. (2003). Modelling forest landscape dynamics in Glen Affric, northern Scotland. PhD, University of Stirling. Ogilvy, T. (2003). Regeneration ecology of broadleaved trees in Caledonian forest. PhD, University of Edinburgh.

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Sustainable forest and woodland management

Bill Mason, Alan Harrison and Bill Jones

The current emphasis on continuous cover forestry, native woodland and natural regeneration have called for new approaches to woodland establishment and management.

Direct seeding by scarifier fitted with New Forest Oy 'Seedgun', identified by the grey box and yellow feed pipes at rear.

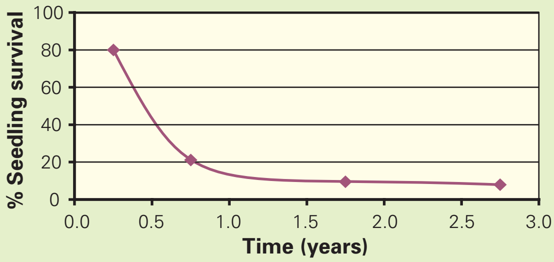
Direct seeding of upland restocking sites

Direct seeding is a potential alternative to the conventional practice of restocking clearfelled sites through planting. Theoretically it is around 50% of the cost of replanting, provided that losses due to poor germination, frost heave, insect and animal browsing, and weed competition can be overcome. The technique is likely to be most applicable on nutritionally poorer, upland sites with limited vegetation competition and where a reduction in establishment costs can offset lower timber values. The method has been successfully used on poorer site types in Scandinavia, which is the source of the sowing technology under trial in the UK.

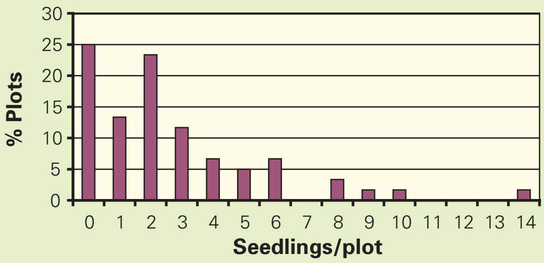
For the past three years, FR has been working in conjunction with FE Wales on the development of direct seeding with Sitka spruce. The site types targeted have been those where Sitka spruce is not expected to exceed YC14 productivity. These are generally above 350 metres elevation with peat or peaty-gley soils, soil nutrient regime (SNR) poor/very poor and soil moisture regime (SMR) moist or wetter, with the vegetation type including one or more of *Calluna, Vaccinium, Molinia, Juncus* or *Eriophorum.*

Experiments were set up in 2001 and 2002 to test the efficacy of ground preparation method, sowing method and sowing density on seedling survival and growth. Mechanical mounding, screefing and scarifying were the cultivation types tested. Concurrently with cultivation, seed was sown onto these prepared areas, either by hand or by one of two types of mechanical seeders, at predetermined rates of between 50 000 and 100 000 seeds per hectare.

Mechanical scarification or screefing has been found to be the best method of seedbed preparation, with sowing by a pneumatically powered seed-gun mounted on the ground preparation machine. A sowing rate of 50 000 seeds per hectare has been found to be the minimum necessary to ensure a sufficient number of surviving germinants (3500 ha^{-1}) three years after sowing. However, since 1 kg of Sitka spruce seed (about 300 000 seeds) costs around £40, sowing at this rate still costs significantly less than conventional planting stock at around £100 per 1000.



Sitka spruce seedling survival on scarified ground following direct sowing of seed with a tested viability of 80%.



Variation in number of seedlings per 1 m^2 experiment plot (mean of combined scarified and screef plots).

Most initial seedling loss is thought to be caused by frost heave and wash-out of weakly developed root systems, though seed predation and pine weevil *(Hylobius abietus)* damage are also factors. Weed competition has been slow to develop on these nutritionally poor sites and so far has not been a factor in seedling survival. After three years, average seedling height is >20 cm. A current stocking of around 7000 seedlings per hectare following the highest sowing rate shows the approach to have potential. However, the distribution of seedlings is erratic, indicating that final stocking is likely to be uneven which will have implications for future timber quality. This may necessitate re-spacing or enrichment planting to reach satisfactory tree density.

This year, three new experiments have been established in Wales to check the efficacy of direct seeding on different site types and the success of 300 ha direct sown in 2003–04 will be evaluated. There is increasing interest in this technique in England and Scotland, particularly with pine and birch. Small-scale trials are currently under way in North Scotland and Kielder.

Overall, direct seeding is a promising restocking method but a better understanding of the interactions between site factors, germination and early seedling growth is needed before it can be said to be reliable.

Operational aspects

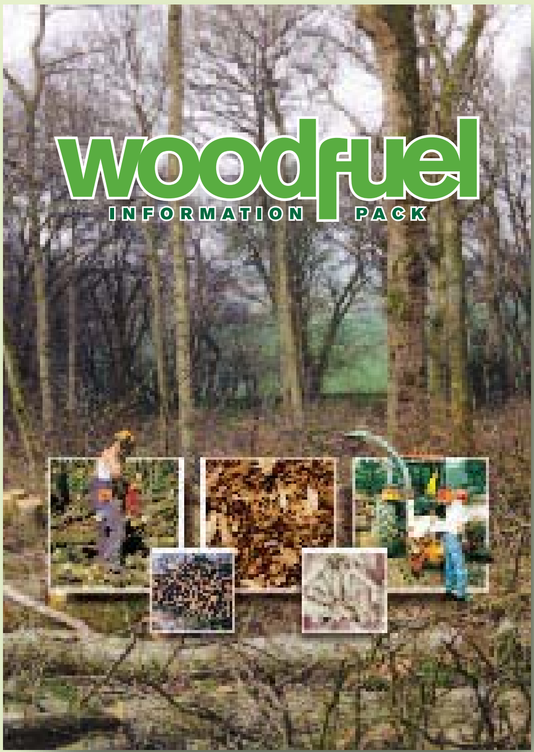
Following completion of work on developing and evaluating methods of excavator mounding, a Technical Note: *Excavator mound spacing on restocking sites* was published during 2004 giving the results of research, which will assist in the improvement of standards to achieve more consistent and uniform stocking. The results focus specifically on methods of dealing with brash, reducing the amount of spoil required (and therefore the width of the trench) and techniques, which enable better judgement of spacing between mounds. These results have also been disseminated via seminars to forest managers and operators and these will be ongoing during 2004–05. Successful trials have also been completed on a new bucket design, which resolves the problem of clays and peats sticking in the bucket. This problem had slowed the operation and caused extra vibration for the operator. The new design can achieve significant time and cost savings in these particularly difficult soils.

New bucket design shown at left.

Other related work, which will be reported in another Technical Note, is on the construction of brash mats during harvesting. This work identifies the method to achieve best flotation, reduce brash mat repair time and reduce operator vibration when travelling. It also improves subsequent ground preparation.

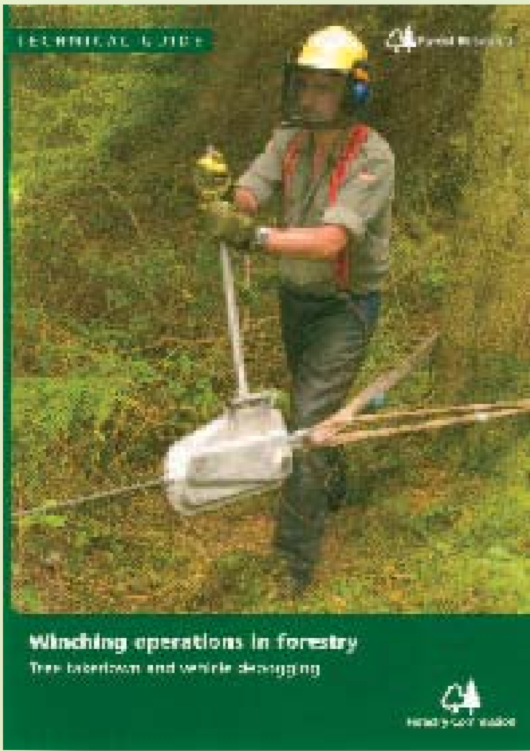
Woodfuel

There is generally a low level of knowledge in the forestry industry about supplying the new and developing woodfuel market. We have produced a *Woodfuel information pack* with foresters and managers in mind. The pack is a good starting point for all those who need to know more about converting wood into energy. It provides key, basic information about the many aspects of using wood for fuel, including: background on benefits; renewable energy targets and policy; sources; conversion; end users and systems. There are four main sections, starting with background information on the developing industry: the other three cover the types of processes or categories of operations, namely: biomass sources, biomass conversion and biomass users.



Hand winching

A new Technical Guide: *Winching operations in forestry* was published during 2004, giving definitive guidance on the safe use of hand winches for tree takedown and the debogging of forest machinery. The forces developed during winching operations can be considerable and difficult to calculate particularly when pulleys are introduced to multiply pulling forces and/or to deflect the pulling angles. Full understanding of the need for appropriate equipment selection and safe operation is essential. The guide covers four subject areas: Advantages of hand winches, Winching safety, Operational aspects, and Equipment selection.



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Evaluating woodland resources and potentials

Alan Harrison and Graham Bull

There is a wide range of ways in which research, particularly in partnership with the forest industry, can increase the competitiveness of British-grown forest products and their contribution to wealth creation.

A 12-year-old Scots pine, at 450 m asl (DAMS 17), showing needle loss and branch death.

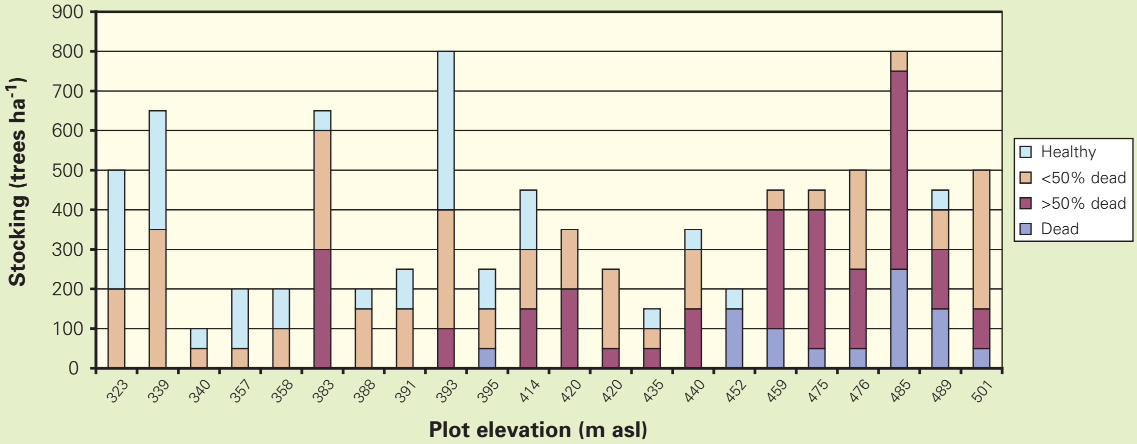
New native woodland establishment update

Last year we reported the results of a pilot survey of new native woodland (NNW) schemes in Scotland where low survival and poor establishment appeared to be linked to poor silvicultural practice on exposed sites of very poor nutrient status. In September 2003 the opportunity arose to investigate a 'problem' site in more detail. The 300 ha site in Perthshire is a typical NVC W18 pine-birch site with *Calluna* dominated vegetation, growing on freely draining podzols and podzolic brown earth soils. Exposure ranged from DAMS 13 at 300 m asl to DAMS 17 at 480 m asl. It was planted in 1992 with roughly equal amounts of native Scots pine *(Pinus sylvestris)* and downy birch *(Betula pubescens)*. The pine and birch were planted at 1500 and 1100 stems ha^{-1} in line with grant scheme prescriptions. The trees had initially appeared to be establishing well but there had been a recent serious decline in tree health and stocking. We examined site factors in relation to the growth and health (above and below ground) of the trees.

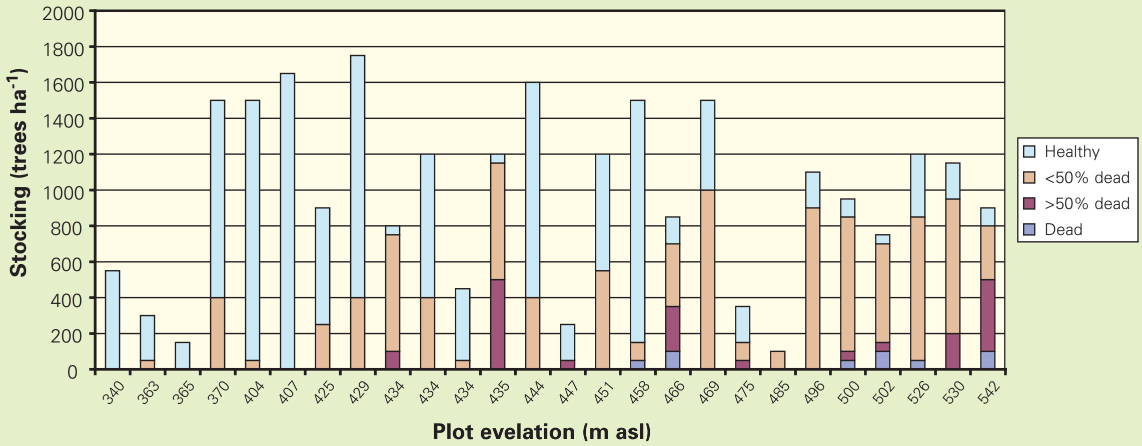
Overall survival was about 60% for the site as a whole with lower survival and poorer health at higher elevations. Mean stocking density for birch was lower than for Scots pine (357 compared to 958 trees ha^{-1}) and thus well below target densities. Exposure appeared to be the major factor affecting tree health, particularly birch, and this effect was exacerbated by poor root growth.

Root investigations showed that many of the live trees were suffering root constriction due to poor planting. This was compounded by the incipient ironpan soil not having been adequately disturbed by the rip cultivation used. Though not statistically linked to exposure due to the small sample size, trees with symptoms of poor health invariably had poor root systems. Approximately 25% of the living trees were likely to become unstable in the near future because of poor root architecture; compare the excellent and poor quality birch root structures.

The poor state of this site is not uncommon since it is thought that up to 30% of NNW schemes are in an unsatisfactory state. This problem seems to be due to establishment prescriptions that ignored or diluted basic silvicultural practices for exposed infertile sites. A programme of joint FR-FCS seminars with associated publications is under way to advise woodland owners and foresters of these issues.



Downy birch: distribution of stocking density and health score by elevation.



Scots pine: distribution of stocking density and health score by elevation.

Excellent quality birch root structure, showing a high number of structural roots with good radial symmetry. Indicative of good initial planting practice.

Poor quality birch root structure, linear, one-sided and inherently unstable. Indicative of poor planting, i.e. plant was swept into the planting slit with no attempt to arrange the roots more evenly.

Woodland and tree surveys

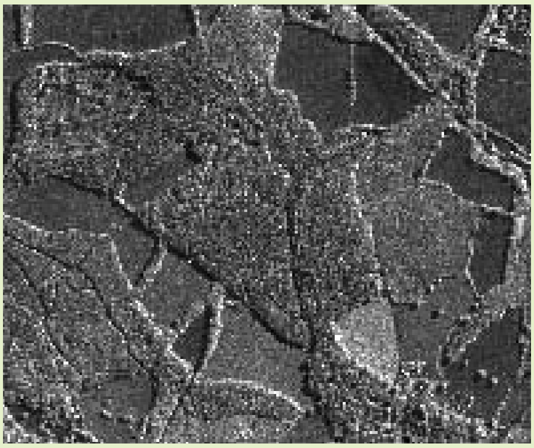
A key requirement for the formulation and monitoring of forestry policies, forestry standards and forest management strategies is to know the extent and condition of woodland and trees.

The national woodland inventory, and information derived from it, has been recognised as a major factor in our ability to monitor sustainable forest management and forests. It provides much of the basic data necessary to monitor progress in, and report on, the published UK criteria and indicators, some of which also operate at country level. The next woodland inventory, National Inventory of Woodland and Trees 2 (NIWT2) is scheduled to start in 2005.

During 2003–04, Woodland Surveys with Technical Services Unit carried out field tests in fifty 1 ha sample squares in FE woodland in England, Scotland and Wales in order to establish field methods and information for consultation with the three countries on their requirements to devise the new field data protocol.

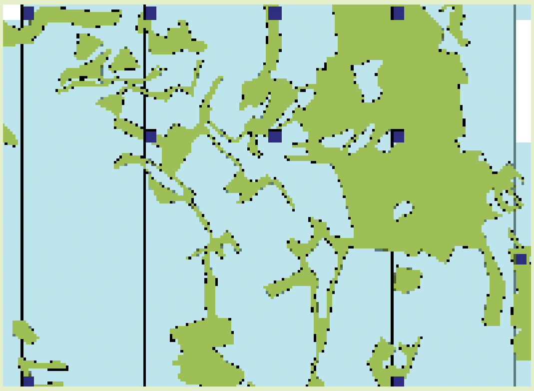
During 2004, we also tested production of a new NIWT2 updated digital woodland map for woodland of 0.5 ha and over using colour orthorectified aerial imagery and Intermap Technologies NextMap ORI (Orthorectified Radar Imagery) product within a 20 x 20 km tile in Southeast England.

Example of coloured aerial imagery used to create woodland map.



Example of NextMap ORI product.

Once the digital woodland map has been created Woodland Surveys Unit will be able to combine it with an Ordnance Survey 1x1 km grid and select out the 1 ha samples for the field survey. The current estimate is between 40 000 and 45 000 1 ha samples throughout GB, with approximately 20 000 in England, 18 000 in Scotland and 5000 in Wales.



1 ha samples generated over woodland map.

The overall NIWT2 programme is to be made up of two, complementary surveys: the Woodland survey (woodland of 0.5 ha and over) and the Survey of tree features (to include all tree features less than 0.5 ha, i.e. small woodland, groups of trees, linear features and single trees). The Survey of tree features will be a sampling exercise, and will use the same set of approximately 2400 1 km^2 sample squares selected for NIWT1. Using the same digital imagery as for the Woodland survey map, an API exercise will identify the features required and map and record digitally within each 1 km^2 sample square.

The aim of the NIWT2 is to provide up to date information on the extent, size and composition of our woodlands. In particular the aim is to provide an accurate assessment of woodland location, area and composition, and to provide estimates of a set of woodland parameters. The survey data will provide information for:

- decisions on land use and woodland expansion
- forecasting wood production
- targeting advice and grant aid
- assessing woodlands as a wildlife and conservation resource
- studies on biomass production and carbon storage
- monitoring the sustainability of forest management, and contributing to the monitoring of sustainable development of land use
- other more specialised woodland surveys.

Forest Research will be working closely with FC Scotland making use of the NIWT2 woodland map to assist selection of sample woodlands for the Scottish Native Woodland Survey (SNWS) which is scheduled to start in summer 2005.

NIWT2 field survey test sites in Scotland.

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People, trees and woods

Paul Tabbush and Liz O'Brien

Links between trees and woodland and the environmental, economic and social aspects of our lives are wide-ranging. Woods can contribute to human well-being by providing natural restorative spaces.

Forest School at Whitestone Woods in the Wye Valley.

During 2003, social researchers became involved in a number of EC funded projects. This reflected international will to include social issues in research aimed at defining good practice in sustainable forest management.

Project work included 'Leisure landscapes', and a final report on 'Social and cultural values of woodlands and trees in northwest and southeast England'. In addition, a number of projects were undertaken working with external contractors. Some key examples are described below.

Forest School evaluation

The New Economics Foundation (NEF) was contracted to evaluate two Forest School projects in Wales as phase one of a two-phase project. The Forest School idea is attracting a great deal of excitement among education professionals and there is anecdotal evidence from teachers and others that it has a profound positive effect on the way children relate to each other and the world around them. NEF applied a qualitative approach to evaluation, including participatory appraisal, and the development of a self-appraisal toolkit was a major product of the research. The report identifies and describes the development of major positive outcomes from the forest school process. These outcomes include increased self-confidence and self-esteem in the children who get involved, as well as a better understanding of the environment and a sense of ownership of the woodland they visit on a regular basis.

Phase two of the project involves NEF working in partnership with Forest Research to evaluate Forest School in England. The self-appraisal toolkit developed in phase one will be used to track changes for a small group of children over a seven-month period. A final report is due in August 2005.

The phase one report is available at:
http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-5Z3JVZ

Woodland owner's attitudes

The Social Research Group (with sponsorship from Forestry Commission England) contracted the University of Brighton to research ownership patterns and woodland owners' attitudes and perceptions of public access provision in the southeast of England. The findings of the report distinguished a typology of three distinct views. 'Dutyists' who feel they have a duty to supply public access, often because they have received management and planting grants from the Forestry Commission. 'Marketeers' who will provide access if the incentive is right; these are generally private woodland owners who view access as a market phenomenon and many are not interesting in permitting public access if it interferes with current market and non-market benefits obtained from the woodland. Finally, 'Reluctants', who are unlikely to be attracted by incentives to provide access. The work led to a recommendation for a menu-driven approach to providing incentives, so that woodland officers can tailor incentives for access to the wider management objectives of woodland owners.

Social enterprise and community woodland

The Social Research Group undertook work for Forestry Commission England to explore a case study of a woodland social enterprise in Lincolnshire called Hill Holt Wood. The work explored and described how the woodland has developed to provide vocational training for young people excluded from school and for young unemployed people. Interviews with staff, members of the local community and key staff from organisations contracting work to Hill Holt Wood explored Hill Holt's role as a social enterprise, the community involvement and control of what takes place in the wood and its delivery of education and vocational training to young people. The woodland habitat provided a number of advantages:

- Ability to absorb activity without seeming crowded.
- Calming and therapeutic effects of trees and woodlands on the young people being trained, some of whom have emotional and behavioural difficulties.
- Opportunities for a variety of different training activities such as coppicing and making wood products as well as recreational activities.

Young person carrying out a demonstration at Hill Holt Wood in Lincolnshire.

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Woodlands and the environment: hydrology, archaeology and environmental change

Andy Moffat

Climate change, pollutant depositions and other anthropogenic factors can have a major influence on forest condition and thus on terrestrial and aquatic ecosystems. The merits of effective co-ordinated monitoring and research have become clear.

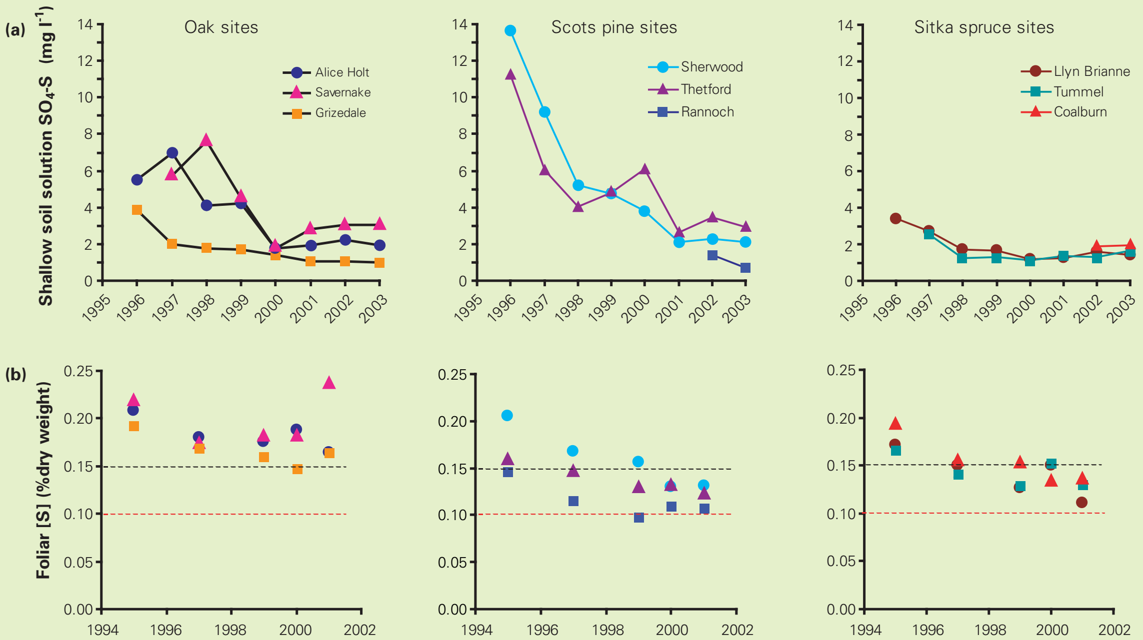
Hydraulic models are being used to assess the ability of trees and woody debris to slow down flood flows.

Forest hydrology

The role of forestry in flooding is an issue of increasing interest, and work on this subject was strengthened with the appointment of a new forest hydrologist at the Research Field Station at Talybont in Wales. The work will focus on modelling the hydraulic impact of floodplain woodland. A significant output in 2003–04 was the completion of a study examining opportunities for planting floodplain woodland for flood alleviation in the River Parrett catchment in SW England. Staff were closely involved with the publication of the 4th edition of the Forestry Commission's *Forests and Water Guidelines*, and the final conference and report on the EU LIFE Demonstration Project: Sustainable Forestry to Protect Aquatic Biodiversity. Forest Research has joined the National Board of Forestry in Sweden and the Office National des Forêts in France as partners in a new EU LIFE project: Forests for Water.

Remote sensing for archaeological surveys of woodlands

A review of remote sensing methods showed that with large image resolutions and the application of multispectral and thermal analysis, some archaeological features can be detected below the canopy. Developments in canopy penetrating methods such as Light Detection and Ranging (LiDAR) and Radio Detection and Ranging (RADAR), and the computer processing of their data, allow earthworks to be mapped with considerable accuracy and precision. The potential of LiDAR led to a commissioned survey specifically designed to assess the ability of the method to model earthwork topography below forest canopy cover. Preliminary results are very encouraging and suggest a large potential for this form of survey.



Trends in (a) soil solution sulphate sulphur and (b) foliar sulphur at UK Level II sites.

Environmental change

The use of Ecological Site Classification (ESC) to predict the likely effects of climate change on species suitability for timber production has been extended to include a wider range of tree species and to assess suitability of NVC woodland types for semi-natural woodland regeneration. These assessments provide a basis for climate change adaptation strategies for woodland management. The role of seed origin in climate change adaptation has also been addressed through the re-interpretation of existing provenance trials, together with an analysis matching current climates in Europe with those predicted for the UK over the coming century.

A national ozone visible injury monitoring scheme was established in 2003, making a significant contribution to the derivation and adoption of new Critical Levels for ozone for forest trees within the Gothenburg Protocol. The summer of 2003 saw the highest ozone levels for over a decade and visible injury was reported at two of the 13 assessment sites. An experiment investigating the interacting effects of elevated carbon dioxide and ozone levels on tree growth and function in the open top chambers at Headley Nursery has been completed. The data will be analysed to develop the flux-based approach to critical load assessments for ozone.

A protocol for preparing a carbon inventory for UK woodland is being implemented in two pilot areas. The carbon inventory is based on a range of FC monitoring networks, together with a modelling component and an assessment of inter-annual variation in carbon fluxes derived from CO_2 flux stations.

Analysis of the macro-moth data collected at the Environmental Change Network (ECN) site at Alice Holt since 1966 has shown a decline in the number and diversity of moths. Vegetation data have been used to produce chronosequenced plots, and changes to understorey related to age of stand have been examined. The environmental status of ground flora in different woodland types has been studied using Ellenberg indicator values. Provisional results show a significant difference between the young, mid rotation and mature woodland nutrient status of the ground flora.

Some recovery from high pollution loading in the past and the successful implementation of emission control policies is evident in some Level II plots. There is a general downward trend in foliar sulphur concentrations at most sites, and sulphur deficiency may become more widespread if the downward trend continues. Recovery from soil acidification at previously polluted sites is also evident, with reduction in foliar aluminium levels.

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Land regeneration and urban greening

Tony Hutchings and Danielle Sinnett

Woodland and other greenspace can provide a wide range of socio-economic, health and environmental benefits, including amenity, recreation and economic regeneration of deprived areas.

Recent work incorporates:

- Integrating site remediation and greening
- Utilising wastes in greenspace establishment
- Assessing site fitness for greening
- Testing new cultivation technologies

Example of community woodland following brownfield restoration in a residential area.

Integrating site remediation and greening

Existing sites where integrated remediation and greening solutions have been employed provide a vital vehicle for investigating the sustainability of remediation and greening systems, and for securing the development of robust, reliable, cost-effective and sustainable design methods for the future.

Experimental research is also necessary to test the interaction of different types of vegetation with engineered systems, the ability of materials remediated *in situ* to support vegetation, and the re-use of materials within the creation of green landscapes. In 2003 we began conducting a project through the Engineering and Physical Sciences Research Council SUBR:IM (Sustainable Urban Brownfield Regeneration: Integrated Management) consortium. This project is designed to review existing information on integrated remediation and greening systems; to assess the sustainability of a number of greening systems and their design methods; to develop environmental, economic and social sustainability criteria for greening; and to develop improved and new integrated remediation and greening solutions designed to meet the existing sustainability criteria.

Utilising wastes in greenspace establishment

Also within the SUBR:IM consortium, we began a project examining how the remedial capabilities of composts derived from wastes could be enhanced through amendment with naturally occurring minerals. Soil remediation using compost is an emerging technology that is gaining considerable acceptance due to its success for the treatment of various contaminants and its environmentally friendly principles. The relatively high success of this technique strongly suggests that particular activities of compost can be enhanced, thereby increasing its effectiveness. We are particularly interested in the improvement of contaminant

binding capacity of composts by the addition of inorganic materials. Research indicates that some naturally occurring minerals such as clays and zeolites interact with metals to form a matrix in which the bioavailability of the metals is remarkably decreased. This attribute, coupled with the biodegradation capability of the compost, could provide a unique and novel remediation technique. It is thought that novel composts could facilitate plant growth, providing soil conditioning and nutrients to a wide variety of vegetation, as well as reducing contaminant availability.

Assessing site fitness for greening

Currently no technique exists to determine the ecotoxicological impact of soil-borne contaminants to trees or landscape flora. This means that a significant proportion of expenditure from a reclamation budget is used to clean up contamination to generic levels. This is often unnecessary, environmentally and financially costly, and may lead to a reduced quality of the final landscape. In addition, traditional methods of assessing the phytoavailability of potentially toxic elements in soils are difficult to interpret and are often contradictory. Forest Research, in collaboration with ARUP, began a research programme in 2003 which aims to develop a biological indicator methodology for assessing the feasibility and risk-benefit of direct vegetation establishment on contaminated land. The project is being supported by CL:AIRE (Contaminated Land: Applications In Real Environments) and the Forestry Commission.

Although still in its preliminary stages, early results have already yielded significant findings. For example, we have found that Field Portable X-Ray Fluorescence (FPXRF) technology can give a good indication of total metal contaminants in soils. We have also found that the biological indicators tested are responsive to metal contaminant levels. We have yet to gather all of the data necessary to determine whether the indicators are responsive enough to ascertain how other landscaping trees and shrub species will perform. Our continuing work on this project aims to develop such links over the coming three years.

Testing new cultivation technologies

Tree roots are frequently unable to penetrate highly compact, restored substrates. Current cultivation treatments are either considered to be too expensive by developers or are not effective in the long term. We have been conducting research on methods of achieving deep cultivation of compacted soils that is both sustainable and cost effective. The research focus has been: to examine the effectiveness of different deep cultivation methods in creating a uniform and loose soil condition; to assess the longevity of the treatments and their impact on long-term tree growth and rooting; and to provide indicative costs and output rates for all cultivation methods.

Treatments included total cultivation, industrial ripping and the 'Maxilift' prototype ripper which were tested against uncultivated controls. A long-term tree growth and rooting trial is ongoing at a former sand and gravel quarry site near Reading. Results so far indicate that both the Maxilift prototype ripper and the total cultivation methods achieve full 1 metre profile loosening. The loosening effects of both methods have been retained for at least three years following the cultivations. The ‘Maxilift’ has the advantage that it can be operated at a quarter of the cost and a quarter of the time input of the total cultivation system. The ‘Maxilift’ has since been used to successfully establish new community woodlands in The National Forest on a wide range of sites over the past two years. With the continued support of the Forestry Commission, we aim to monitor the longer term effects of the different cultivation treatments on tree performance.

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Protection of trees, woodlands and forests

Hugh Evans and Joan Webber

The management of woodlands to provide a wide range of public benefits places even greater priority on their protection. Risks to trees and woodlands need to be properly understood; in many instances new threats need to be excluded or established pests and pathogens managed.

Longhorn beetle *Monochamus galloprovincialis*, native to Portugal.

Plant health

Research has started under the new EU Framework Programme 5 topic PHRAME (Plant Health Risk and Monitoring Evaluation) on improved Pest Risk Analysis of the threat posed by pinewood nematode, *Bursaphelenchus xylophilus*, in Portugal as a model system. This programme involves Entomology and Mensuration, includes partners from Austria, France, Germany, Portugal and Spain. Significant progress has already been made by the consortium, particularly in providing new information on the interactions of the nematode and vector insects, which in this case are *Monochamus galloprovincialis*, longhorn beetles native to Portugal. Forest Research scientists are concentrating on development of improved PRA models by integrating new biological and eco-climatic information gathered by the consortium with existing tree growth models that have been produced by FR staff. This phase of the work will have increasing impact as new data are gathered during the course of the programme. Meetings have been held in Portugal, Germany and UK in order to exchange information and plan new work. The Consortium website can be accessed through the Forestry Commission website at http://www.forestry.gov.uk/forestry/ggae-5rhgfr.

Insect impacts

An unusual problem requiring attention during 2003 was the reported death of young poplar trees caused by the stem aphid *Pterocomma populeum* at a site in Cornwall. The poplars had been planted in early 2001, and following initial reports of *P. populeum* in the second year, large numbers of the aphids were present in 2003 and were associated with shoot dieback and the death of several hundred trees. Field surveys during the summer revealed that most of the aphids and damage was restricted to the poplar varieties 'Gibecq', 'Gaver' and 'Ghoy', especially the former which appeared generally less suited to the site, and was growing poorly even where the aphid was not present.

Horse chestnut leafminer, *Cameraria ohridella*, a small leafmining moth, was first reported in Britain in 2002, when it was discovered attacking horse chestnut trees in the Wimbledon area of London *(Forest Research Annual Report and Accounts 2002–03)*. During 2003 FR Entomology scientists began a programme to monitor the spread and impact of the moth, which had already established in several London Boroughs, and had spread to Ashstead, Leatherhead, Weybridge, Tonbridge, Sevenoaks, Medenham in Buckinghamshire, and Oxford. This pattern of spread is similar to the two-phase process of dispersal seen on the continent, with movement away from the centre of infestation on a broad front, presumably by adult flight assisted by the wind, and the separate, sudden appearance of the moth in towns and cities some distance from the known area of infestation, apparently because of transport inside or on cars or other vehicles. The expectation is that *C. ohridella* will colonise most of the UK during the next few years.

Pathogens

Phytophthora ramorum

The new pathogen *Phytophthora* ramorum which causes sudden oak death in the USA, was first found in the UK in 2002. For eighteen months infected plants were mainly limited to nurseries and consisted of ornamental species such as *Rhododendron* and *Viburnum*. However, in October 2003 Forest Research pathologists found *P. ramorum* infecting mature trees in the south of England. The groundwork of host susceptibility tests had predicted that tree species such as red oak and beech would be the most susceptible to *P. ramorum*, and the field findings confirmed this. The first infected tree, a *Quercus falacata* (southern red oak), had extensive bleeding and bark necrosis around the trunk; similar symptoms were then found on beech trees (*Fagus sylvaticata*). Around ten *P. ramorum* infected trees have now been found at a total of three sites, with all but one of the infected trees located in Cornwall.

Extensive bleeding on the root flares of a mature beech caused by *Phytophthora ramorum*.

Foliage of holm oak (*Quercus ilex*) infected by *Phytophthora ramorum.*

It has also become clear that while some tree species are susceptible to lethal trunk infections caused by *P. ramorum*, other species (holm oak and sweet chestnut) suffer only foliar infection. These foliar infections are not lethal to the tree but do give the pathogen the opportunity to sporulate, and the spores may then go on to infect other plants.

To discover how widespread *P. ramorum* was beyond known outbreaks, the Forestry Commission tasked Forest Research Technical Support Units to carry out a survey in areas of the UK considered to be at high risk from the disease. These were regions with a climate that was predicted to favour infection and symptom expression by *P. ramorum*, and where woodlands with susceptible tree hosts where mixed with rhododendron. Following training in disease recognition on trees and ornamental plants such as rhododendron, a total of 1217 sites were surveyed in the high risk area. As a result, 335 samples were collected from rhododendrons that had symptoms that could indicate infection with *P. ramorum*. However, all proved negative. On this basis, the distribution of *P. ramorum* is considered to be very limited: further details of the survey are available at www.forestry.gov/pramorum.

Concerns about the potential impact of sudden oak death has generated intense interest from many sectors: the public, tree wardens, arboriculturists, local councils and the media. Forest Research pathologists, working with Defra scientists, have participated in five stakeholder meetings with interested parties to provide information about *P. ramorum* and the extent of disease development in the UK compared with the parts of the USA where the disease is extremely damaging. In addition, a number of television programmes and publications (Country File, BBC news, *New Scientist* and *Tree News*) have featured the potential threat posed by *P. ramorum* and the work of Forest Research.

In January 2004, a new EU funded project started on 'Risk Analysis of *Phytophthora ramorum*'. Involving six countries and nine research institutes, the project consortium is led by Forest Research pathologists and the aim is to develop a European Pest Risk Analysis (PRA) for American and European isolates of *P. ramorum* (see http://rapra.csl.gov.uk). It will assess the potential for pathogen establishment, the environmental and socio-economic impacts, and also develop risk management strategies and contingency plans for areas where the pathogen is found. The PRA will draw on information and data that is already available, but a major part of the project will consist of research to provide data for PRA.

Dothistroma pini

Red band needle blight caused by the fungus *Dothistroma pini*, another quarantine listed pathogen, is also a matter of concern in the UK particularly in commercial forestry plantations. Corsican pine *(Pinus nigra* var. *laricicola)* is highly susceptible to this pathogen, and the incidence of the disease has increased markedly over the past five years. We know that *D. pini* is active in a number of locations in England, Scotland and Wales but the disease is particularly severe in East Anglia.

Corsican pine shoot showing typical symptoms caused by red band needle blight (*Dothistroma pini*).

A survey of pine in the East Anglia Forest District has indicated that 75% of the compartments of Corsican pine (covering around 10,500ha) have *D. pini* infected trees. On average about a third of the crown displays symptoms on infected trees, but in some stands up to 95% of the crown of each affected tree has symptoms of needle loss and discoloured needles. All age classes of trees can suffer from the disease, but the most seriously affected tend to be in the 10-30 year age class. When the past three years growth (2000–03) were compared with previously ten years (1990–2000) in severely affected stands, the annual height and diameter increments were halved, with serious implications for productivity.

So far only the asexual stage of the fungus has been found, so we conclude from this that only low levels of variation occur in pathogen population. Work planned for the immediate future includes a comparison of *D. pini* populations from the UK with those from France and Germany where the disease has also become much more severe in recent years.

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Enhancing economic value

Barry Gardiner and Sam Samuel

There is a wide range of ways in which research, particularly in partnership with the forest industry, can increase the competitiveness of British-grown forest products and their contribution to wealth creation.

Off loading pine logs at a sawmill in Aboyne, Aberdeenshire.

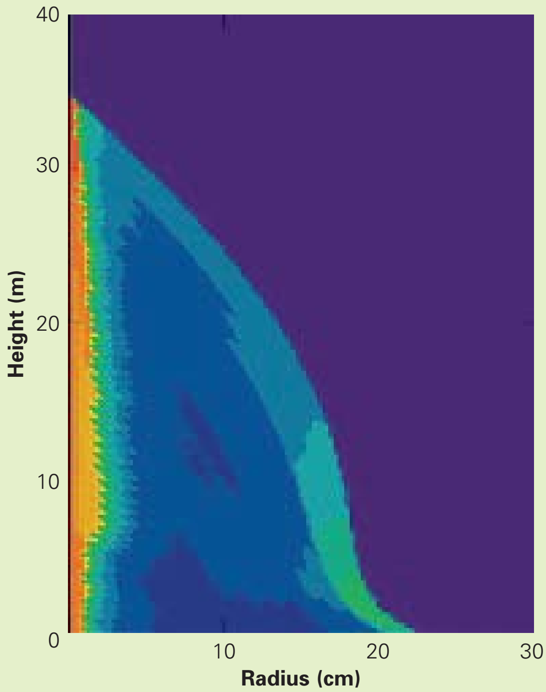
Modelling the effects of site factors and silviculture on Sitka spruce timber properties

A model predicting Sitka spruce wood properties is being developed with three main aims:

- To predict the timber properties of the existing Sitka spruce resource, on the basis of inventory data.
- To quantify the interaction between timber quality, site factors and silvicultural regime, which will enable forest managers to evaluate the effects of different management options.
- To estimate the impact on timber utilisation of changes in wood properties brought about by selection and breeding programmes.

During 2003 Dr Jean-Michel Leban of INRA (Institut National de la Recherche Agronomique), Nancy in France was awarded a John Eadie fellowship by the Scottish Forestry Trust to adapt an existing Norway spruce timber quality model to Sitka spruce. Data collected by staff of Forest Research and Bangor University from a range of Sitka spruce stands throughout Britain were used to develop models predicting wood density and branching characteristics on the basis of tree height, diameter and age.

A prototype computer software programme was developed which integrates the density and branching model relationships with growth models for Sitka spruce to enable simulations to be run for a range of scenarios. The yield class, thinning treatment, initial spacing and age of the stand to be modelled can be selected from drop-down lists. The model then gives estimates of ring widths up the entire stem, i.e. taper on an annual basis, wood density distribution within the stem and number, size and insertion angle of branches at different heights up the tree.



Predicted wood density distribution in the stem of an 80-year-old Sitka spruce growing at Yield Class 20, after planting at 2.6 m spacing and with no thinning. In relative terms green is the highest wood density with dark blue lowest and other shades intermediate. Note the comparatively large area of low density timber towards the base of the stem as a consequence of having been grown at wide spacing on a fertile site.

At present the growth models available enable predictions to be made for the average tree in an even-aged stand. As more complex growth models are developed, these will be incorporated to allow for the different diameter classes present in a stand. This will enable a more realistic assessment of the wood properties of various types of potential products, such as sawlogs and pulpwood, and will facilitate the modelling of uneven-aged stands. Plans are also in place to extend the model to include predictions of grain angle and compression wood. The next important step will be to link the timber quality model with sawing simulation software and batten performance models developed by the Building Research Establishment. This will allow estimates of batten mechanical properties and drying behaviour to be made for different silvicultural scenarios.

Planting stock derived from family mixtures and seed orchards can give gains of 20 to 30% in final volume

Analysis of 38-year-old volume data collected from one of the first Sitka spruce progeny tests ever planted has confirmed that significant volume gains can be obtained by planting selected stock. The test, growing in Clocaenog forest, involved the measurement of diameter and top-height amongst open-pollinated Sitka spruce families collected from highly-selected plus trees growing in forests around the country. Some individual families had 35 to 42% additional standing volume relative to the control plots of direct import material from the Queen Charlotte Islands. Conifer breeders have used these data to predict likely final-rotation volume gains from currently available tested clonal seed orchards and family mixtures as around 20 to 30%. Further economic gains from the selected planting stock can be expected due to additional improvements in stem straightness and branching quality which will be the subject of another study in 2004–05.

Family forestry - the promise of improved crop uniformity

Mass vegetative propagation by cuttings now makes a major contribution to the flow of genetically improved Sitka spruce into commercial planting, combining advantageous gains across a range of selection traits. To date, this has been based on superior half-sib families in which a number of plus trees are used to provide a pollen mixture for the male parent. The number of parents involved in such pollinations means that despite often high predictions of gain, the resultant crop is very variable in stem size and quality. However, the testing of families deriving from two specific parents (full-sib families) has indicated that further enhancements, particularly to quality characteristics, can be achieved. Artificial pollination work to re-create such families is now proceeding. The resultant seed will provide full-sib families with enhanced gain and advantageous combinations of selection traits for propagation by cuttings. Deployment of this material can be in family mixtures or individual family blocks, which will provide a more homogenous and uniform product.

Selections completed for the hybrid larch breeding population

Ten-year height and stem straightness data collected from over 43 progeny tests were brought together and analysed during the year. As a result of this, the very best European (EL) and Japanese larch (JL) plus trees selected over the last 30-years will be re-selected to form the Hybrid Larch breeding programme. The genetic testing of JL and EL plus trees selected in forests around Britain proved to be time-consuming due to incompatible flowering times across the two species, early spring flowering leading to many losses from frost damage, low viability of stored pollen and low numbers of seed per cone. True hybrid families involving the best parents from each species should result in genetic gains of between 15 to 20% for 10-year height and 20 to 25% for stem straightness relative to a JL seed stand. Grafted copies of re-selected EL and JL plus trees will now be retained in two geographically separate clone banks.

Understanding the genetic structure of native black poplar in Britain

More detailed knowledge of the genetic structure of black poplar *(Populus nigra var. betulifolia)*, one of Britain's rarest native trees is emerging. This is contributing to the development of a conservation policy for the species. As a result of cooperation under EUROPOP, an EU funded Europe-wide partnership, analysis of molecular data has revealed that genetic diversity was greatest in countries from southern Europe (France, Italy and Spain) and lowest in Britain. The results confirmed a contrasting situation in the British population which contained widespread duplication of genotypes as a result of extensive vegetative propagation. There is also a serious imbalance in Britain between male and female trees, males outnumbering females to a large extent.

A specimen of a black poplar growing in an urban setting. Black poplars were commonly used in amenity plantings because of their attractive form.

The project also addressed the question of introgression of introduced *Populus x* euramericana hybrids into the native black poplar gene pool. Results from several different sites showed that where a female black poplar was within pollinating distance of both hybrid and non-hybrid male trees there was no introgression. However, introgression did occur in situations in which there were no male non-hybrid trees within pollinating distance of a female tree which was surrounded by male hybrids. It appears therefore that female black poplars preferentially breed with non-hybrid males if they are available but in situations where non-hybrid males are not available the females can breed with hybrid males. It becomes clear, therefore, that new planting of the species should aim for a balance of male and female trees.

Results based on chloroplast DNA demonstrated that there were both eastern and western refugia of black poplar in Europe during the last glacial period. The majority of British samples originated from an eastern refugium, which is in contrast to results obtained in an earlier project showing that oak in Britain originated from Spanish refugia. Some British samples of black poplar showed cpDNA variation typical of material originating from Spain, but this may have reached Britain through human mediated movement.

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Continuous cover forestry in British conifer forests

Bill Mason, Gary Kerr, Arne Pommerening[1], Colin Edwards, Sophie Hale, Duncan Ireland and Roger Moore

Introduction

From the beginning of the 1990s a number of factors, such as the Rio-Helsinki process, the requirements of certification and an international movement favouring more natural forest management, all began to change thinking about appropriate silvicultural systems for plantation forests in Britain. This has resulted in a move away from the predominant silvicultural practice where even-aged stands of a few species are managed using the clearcutting system (Matthews, 1989) and the clearfelled areas are often 5-20 ha or more in size. The new silvicultural approach, generically known as continuous cover forestry (CCF), is based upon certain key principles such as a presumption against clearfelling, the use of natural regeneration and the creation of a varied stand structure containing a range of species (Mason *et al.*, 1999; Pommerening and Murphy, 2004).

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Further impetus to these changes was provided by the Scottish and Welsh forestry strategies (Anon., 2000; Anon., 2001) which both contain aspirations to increase the area under CCF management. The Welsh Woodland Strategy contains the strongest commitment, aiming for 50 per cent of public forests to be transformed to CCF by 2020, where feasible.

Achieving these aspirations represents a major challenge for forest managers in Britain, given that there were probably less than 5000 ha of forest under CCF management at the beginning of the 1990s. As a consequence, there is little experience of appropriate stand management strategies to favour CCF (Hart, 1995) and of a range of operational aspects (e.g. harvesting techniques, modelling growth of stands) which could affect the outturn. Research programmes were started in the late 1990s at Forest Research and the School of Agricultural and Forest Sciences (SAFS) of the University of Wales, Bangor to provide knowledge that would help overcome these difficulties. For example SAFS and Forestry Commission Wales started the 'Tyfiant Coed' project in September 2001; the Welsh phrase means forest or tree growth: see more details at http://tyfcoed.bangor.ac.uk

The following sections provide a brief overview of findings from our research. An earlier report (Kerr, 2001) discussed alternative methods of developing irregular structures in broadleaved and conifer stands in lowland Britain. The focus here is on the use of CCF in conifer plantation forests in upland Britain since this is where the challenge of transformation to irregular stand structures is the greatest.

Management demonstration sites

A number of trial areas have been established in different forests in Britain to support this research (see Table 1). It is critical to install demonstration sites relevant to CCF to illustrate best practice and to convey an impression of what particular forest types on particular sites could look like (Gadow, 2001). The sites can also provide data for modelling transformation to CCF (Pommerening, 2002), since the growth information from mixed uneven-aged stands subjected to modern CCF management complements existing knowledge. Besides standard mensuration procedures, the data are also spatially explicit which means that all trees are mapped and can be identified by their three-dimensional coordinates, enabling a wide range of follow-up research involving spatial statistics. Subsequent re-measurement every five years will establish an excellent database of forests in transition from even-aged management.

A mixed 34-year-old Sitka spruce–birch stand at Coed y Brenin (see Figure 1) at an elevation of 210 m asl on a site formerly dominated by oak may serve as an example. The parent rock is Cambrian sandstone and the predominant soil types are brown earths; the yield class of Sitka spruce ranges between 16 and 18. Although birch readily seeds itself on Sitka spruce restock sites (Humphrey *et al.*, 1998) it is eventually outcompeted by the spruce and is shaded out, which in Wales generally occurs at a stand age of about 30 years. Maintaining the birch in mixture for longer would enhance the diversification of coniferous plantations. In this plot the competitors of 75 birch and 66 Sitka spruce 'frame' trees (per hectare) were removed in a crown thinning in May 2003. Most competitors were Sitka spruces; birches were only removed when accidentally damaged by falling trees.

Table 1

Main experimental sites, species and aspects for the investigation of CCF in Great Britain.

Forest	Main species	Approximate age (years)	Main aspects under investigation
Aberfoyle[a]	European larch	70	Thinning, seed fall, light regime
Glasfynydd	Sitka spruce	50	Thinning, light regime, *Hylobius* damage
Wykeham[a]	Scots pine/others	70/50	Thinning, stand development
Gwydyr	Douglas fir/others	80	Thinning, stand development
Gwydyr	Scots pine/others	80/70	Natural succession, mycorrhizal ecology
Clocaenog[a]	Sitka spruce	50	Thinning, natural regeneration, stand stability
Clocaenog[a]	Japanese larch and Norway spruce/others	75	Natural succession
Mortimer	Douglas fir	35	Thinning
Glen More	Scots pine	75	Thinning, light regime, seed fall
Coed y Brenin	Sitka spruce/birch	30/20	Stand development
Cardrona[a]	Scots pine	65	Natural regeneration, cultivation
Trawllm[a]	Sitka spruce	40	Thinning, operational aspects

[a] Denotes that the experiment is located within a national CCF demonstration site.

Figure 1 gives a visual impression of the spatial impact of the intervention. As a consequence of the crown thinning the proportion of birch trees per hectare (ha) increased from 40% to 43% while the Sitka spruce trees decreased from 41% to 38%. The SG ratio, an index to assess thinning types (Gadow and Hui, 1999), shows that the intervention clearly fell into the crown thinning category.

Figure 2 depicts the so-called mark connection function (Pommerening *et al.*, 2000; Stoyan and Penttinen, 2000) applied to the main two tree species and the situation before and after thinning. In this case a particular tree species is given a discrete mark.

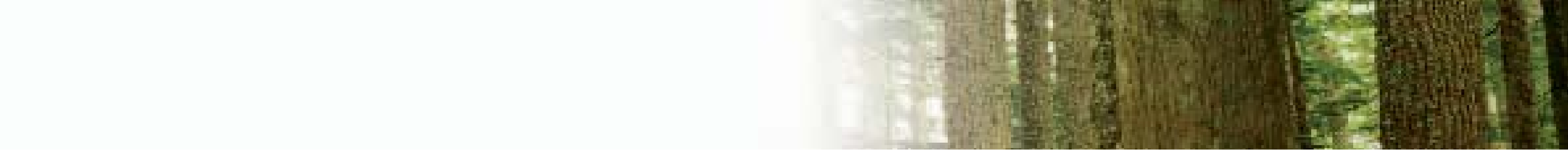
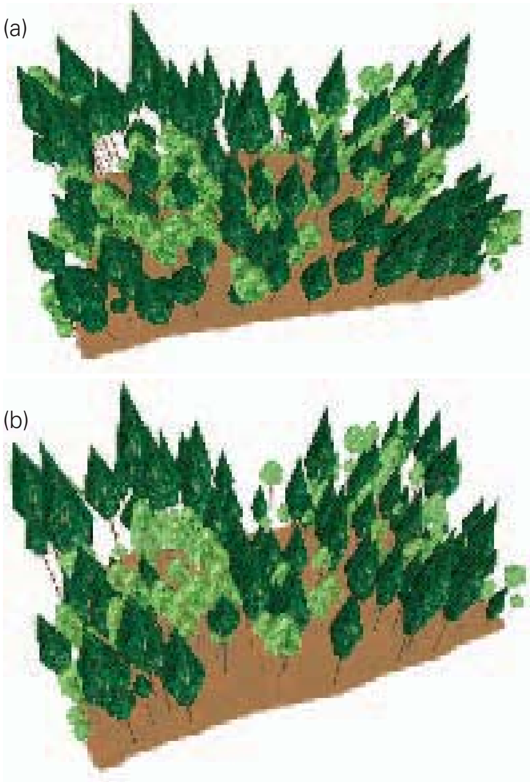


Figure 1

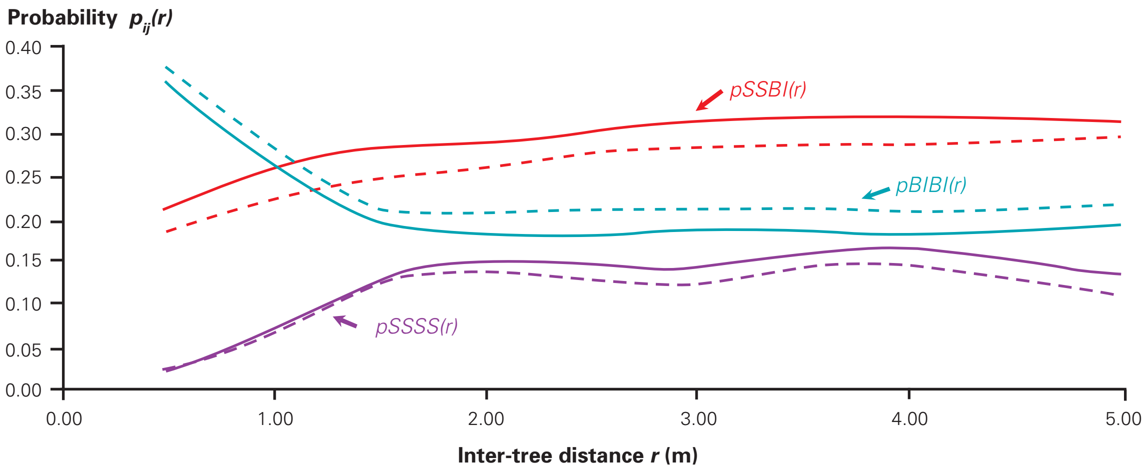
Computer visualitions of a 34-year-old mixed Sitka spruce and birch stand at Coed y Brenin Forest: (a) pre-thinning, (b) post-thinning. Dark green: Sitka spruce, light green: birch.

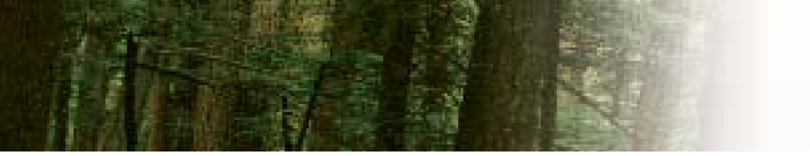


The value $p_{ij}(r)$ of this function is the conditional probability that one of two trees considered has mark *i* (e.g. Sitka spruce) and the other has mark *j* (e.g. birch). On average the combination Sitka spruce–birch is the most likely pairing. However, at distances of less than 1.0 m, there is a high probability of birch–birch combinations occurring.

Also, when considering tree distances from 0.5 m to 1.5 m it becomes clear that the probability of Sitka spruce–birch pairings occurring has been reduced following the thinning. The probability of Sitka spruces having Sitka spruce neighbours at these distances remained virtually the same and the probability of birch trees having birch trees in their immediate vicinity has slightly increased. The results show that the thinning has released birch trees from Sitka spruce competition by consolidating birch clusters and reducing mixed species pairs of nearest neighbours. However the general character of a mixed Sitka spruce–birch woodland has remained unchanged.

The mark connection functions showing the probability of different species combinations occurring (solid curves: pre-thinning, dashed curves: post-thinning) when applied to the Sitka spruce–birch stand at Coed y Brenin (see Figure 1).





Natural regeneration

The promotion of natural regeneration is generally a precondition for wider use of CCF. To encourage the establishment and growth of natural regeneration, five fundamental requirements, outlined in Box 1, must be met (see also Nixon and Worrell, 1999).

Box 1

Fundamental requirements for natural regeneration.

There must be:

- a sufficient seed supply
- a suitable seedbed for germination
- an adequate light environment for seedling growth
- protection from browsing damage
- freedom from vegetation competition.

Seed supply

There is considerable year-to-year variation in seed production in conifers, with good seed years occurring at intervals of several years (Malcolm *et al.*, 2001). This is exemplified by 5-year results from the larch plots at Aberfoyle (Table 1) where monthly seed fall has been compared in two plots thinned to different intensities and on an adjacent clearfell (Figure 3). In the one very good seed year (2001) the seedfall under the more heavily thinned plot was almost twice as high (16.3 million ha^{-1}) as on the plot given standard thinning (9.0 million ha^{-1}), with even fewer seeds on the clearfell area. These results indicate the potential interaction between thinning and seed production as well as the limited potential for colonisation of relatively small (1.0 ha) clearfelled coupes.

Seedling growth and light environment

Tree species vary in their ability to survive and grow at different light levels. Thus species which are considered 'shade tolerant' such as western hemlock and beech can survive at low light levels where 'light demanding' species such as Scots pine or birch would die. Implementing CCF requires an understanding of the critical levels of below canopy light for the survival and growth of different conifer species which, in turn, influences the choice of silvicultural system and the desired stand structure (Mason and Kerr, 2004).

In 1999 seedlings of European larch, Scots pine, Sitka spruce, Douglas fir and western hemlock were planted in a Sitka spruce spacing trial, which provided a range of light environments. After 4 years, there were clear differences in survival between species according to light intensity (Table 2). The highest survival of all species was found at the highest light intensity and declined with decreasing light. However, the more light demanding species such as larch and Scots pine were unable to survive at the lowest light intensity unlike more shade tolerant Douglas fir and western hemlock. Thus, everything else being equal, managers can manipulate the light environment within a stand to favour the growth of one species at the expense of another.

There are two main methods of increasing light levels to allow seedling growth: gap creation and thinning of the overstorey. Creating gaps within a forest stand will create areas which receive greatly increased light levels compared to the intact stand, with systematic variation in light across the gap. Seedling growth is likely to be uneven across the gap, and the greatly increased light levels may result in rapid colonisation by vegetation competing with seedling growth. The microclimate will be relatively harsh, with high daytime and low night-time temperatures causing risk of desiccation and frost damage, respectively.

Thinning a stand creates a light environment which is more variable at a small scale than in a gap. Increased light levels are not concentrated in any single location, allowing better control of vegetation competition. Microclimate is less severe than in gaps, with lower diurnal fluctuations. Measurements showed that even a

Figure 3

Cumulative seeds per hectare in three European larch plots at Aberfoyle; opening of the canopy in the thinned plot occurred in December 1998.

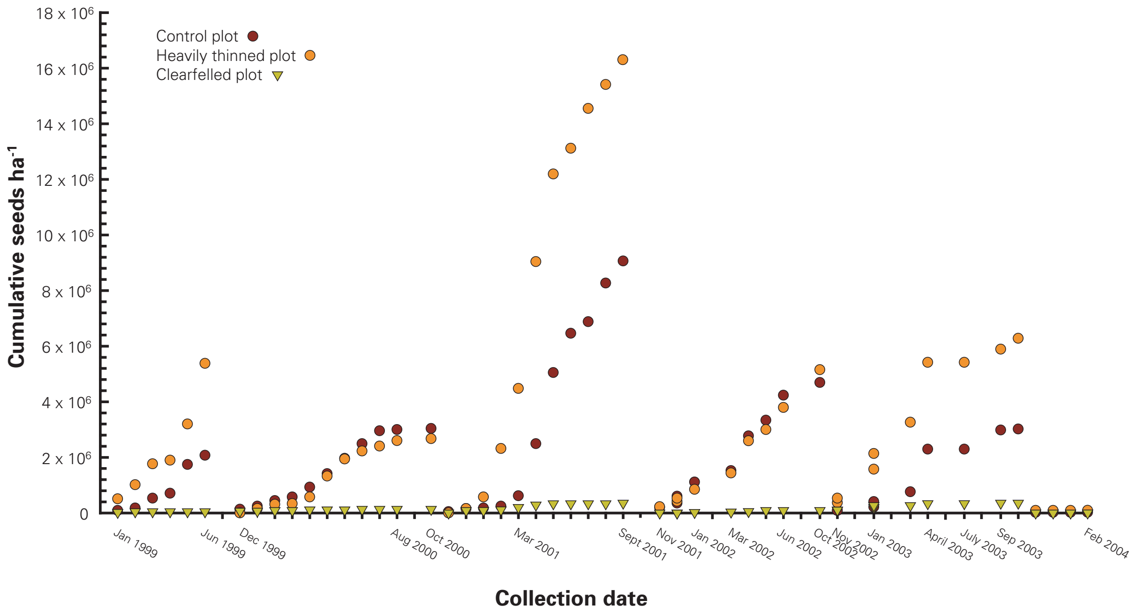


Table 2

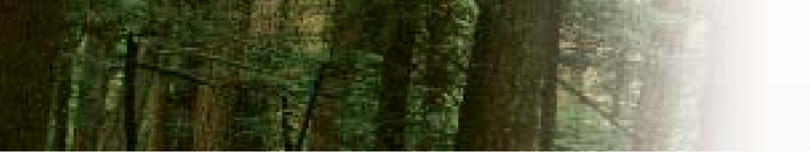
Survival (% : transformed) of seedlings of five conifer species 4 years after planting in a Sitka spruce spacing trial with different light environments (adapted from Mason *et al.*, 2004).

Species	**Spacing: 8 x 8 m**	**6 x 6 m**	**4 x 4 m**
Light intensity:	**61%**	**16%**	**3%**
European larch	78.1	39.9	-
Scots pine	90.0	34.2	-
Sitka spruce	78.3	53.7	-
Douglas fir	70.3	68.5	11.9
Western hemlock	79.2	60.9	25.6
Significance	**	*	**
5% LSD	10.1	21.7	9.9

*$p < 0.05$, ** $p < 0.01$.

relatively sparse tree canopy (trees at 8 m spacing) caused the night-time temperature to be up to 7 ˚C warmer than in adjacent open ground on a cold calm night (Sellars, 2004).

Figure 4 shows canopy transmittance (the proportion of incident radiation passing through the canopy) plotted against basal area for a range of Sitka spruce and Scots pine stands in Britain. These data are derived from hemispherical photographs and show excellent correlation with estimates of light transmittance from direct measurements (Hale, 2003). We have combined these results with studies of seedling survival and growth in different light regimes to produce guidelines for the critical basal area which should provide sufficient light for seedling growth beneath a canopy (Table 3). These critical basal area values tend to be lower than those recommended in management yield tables (Edwards and Christie, 1981), particularly for the more light demanding species, suggesting that heavier thinning should be employed to promote growth of advance regeneration.



Note that although basal area can be used as general guidance (Hale, 2001), light levels will also vary with stand structure: a more mature stand with fewer, larger trees will transmit more radiation than a less mature stand with many small stems, because there are larger gaps between the crowns and crowns themselves are sparser. Ongoing work to collect data from very open stands of Sitka spruce and other species should allow species-specific relationships to be developed to predict light regime from stand-level parameters such as basal area, stocking and top height.

Canopy transmittance plotted against basal area for stands of Sitka spruce and Scots pine in Britain.

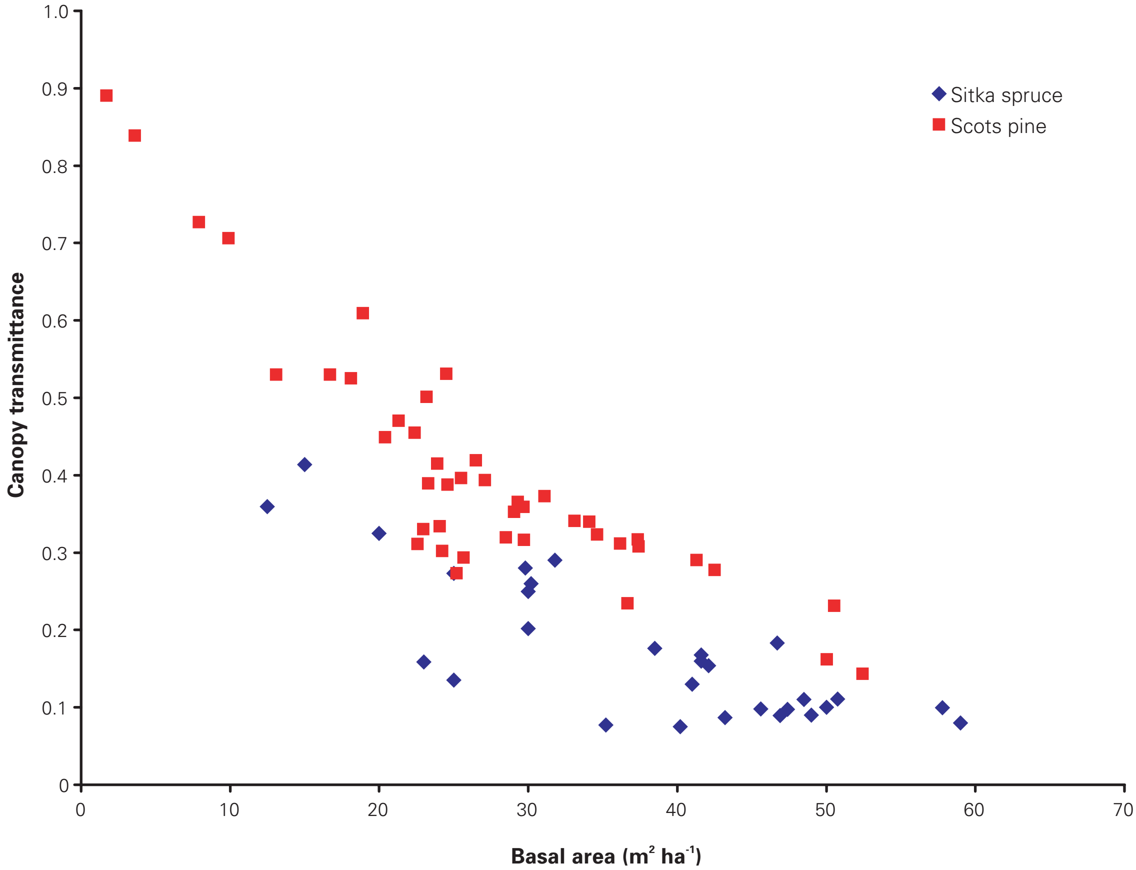


Table 3

Minimum percentage of incident light (transmittance) required for seedlings to achieve 50 % of the growth that would be achieved in full light, and the critical basal area required to achieve these light levels beneath an overstorey of the same species.

Species	Percentage light	Critical basal area (m^2 ha^{-1})
Larch	Light-demanding > 40 %	~20
Scots pine	~35 %	~25
Sitka spruce	~20 %	~30
Douglas fir	~15 %	~35
Western hemlock	Shade-tolerant ~10 %	~40

Hylobius damage

In 2002, an experiment was started at the Glasfynydd site (see Table 1) to investigate the effect of differential thinning in three Sitka spruce CCF stands upon *Hylobius* populations, and the damage to planted Sitka spruce seedlings. Comparison with a nearby clearfelled site was included. Description of the stands at the beginning of the experiment is given in Table 4.

Until July 2002, *Hylobius* population numbers were broadly similar in all treatments. Thereafter they were substantially higher on the clearfelled site than on any of the CCF stands, particularly during the autumn (Table 5). However, past experience suggests that the population density on the CCF sites in July and August would have been sufficient to have caused appreciable damage on a clearfelled site. At the end of 2002 mortality due to Hylobius exceeded 60% on the clearfelled site (Figure 5) but was negligible in the CCF treatments. These trends were also apparent in 2003 (data not shown) by which time mortality on the clearfelled plot exceeded 90%.

These early results are encouraging since they suggest that a possible benefit of a move to CCF could be a reduction in the risk of Hylobius damage to planted or regenerating seedlings. This might also result in a reduction in pesticide inputs to the forest ecosystem in line with UKWAS requirements.

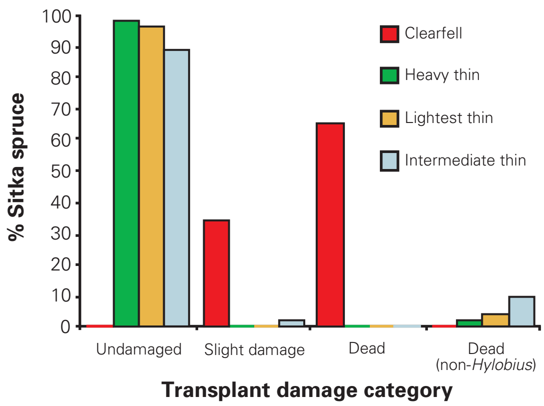
Details of the 3 CCF Sitka spruce stands in Glasfynydd in 2002 at the beginning of the study of *Hylobius* damage.

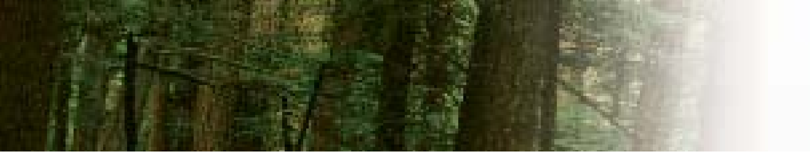
Treatment	Trees ha^{-1}	Top height (m)	Basal area (m^2 ha^{-1})	GYC	% Light transmittance
GNT	519	23.8	40.9	16	15
GLT	348	28.3	41.3	20	14
GHT	287	29.0	38.1	22	14

The total numbers of *Hylobius abietis* that were caught at billets on 1.0 ha plots at Glasfynydd between 29 May and 30 October 2002.

Treatment	Total *H.abietis* captured
Clearfell (CF)	1230
Heavy thin (GHT)	355
Intermediate thin (GLT)	277
Lightest thin (GNT)	190

Levels of damage to Sitka spruce transplants on a clearfelled site and in three Sitka spruce CCF stands due to *Hylobius abietis* feeding.





Stability of CCF stands

As the discussion of critical basal area makes clear, thinning is critical in developing a stand structure and microclimate favourable for promotion of natural regeneration and achievement of CCF. When carrying out such a thinning, care must be taken not to increase the risk of wind damage to a stand in order to achieve light levels required for seedling growth. In general, previously unthinned stands will be less suitable for heavy thinning than those where previous thinnings have resulted in increased tree stability (Hale *et al*., 2004).

Preliminary evaluation using the wind risk model ForestGALES suggests that sites of wind exposure of greater than DAMS 17 should not be considered for CCF management (Mason, 2003). The timing of early thinnings may be critical in ensuring that the trees within a stand develop more stable (i.e. lower) height:diameter ratios and root architectures to withstand the increased wind loading experienced by the dominant trees in CCF stands. Since the interaction between thinning, stand structure and wind risk will largely determine the extent of use of CCF in upland Britain, a new research project starts in 2004 to investigate wind forces upon trees in irregular stands using the Clocaenog site as a test bed.

Modelling CCF scenarios

Silviculturists have recognised the need to compensate for the lack of practical experience with scientific tools, producing management guidelines and corresponding financial scenarios (for example, see O'Hara and Valappil, 1999; Twery *et al.*, 2000; Lexer *et al.*, 2000). Therefore part of the Tyfiant Coed project is the modelling of CCF scenarios. According to Pretzsch (1992) existing yield models based on even-aged management are inadequate for use with CCF for at least three reasons:

1. The development of mixed stands cannot be predicted reliability from models of single species stands.
2. The transition to new thinning and harvesting strategies based on the selection of individual trees requires more flexibility and better quality of information from growth models. The demand for information has shifted from mean stand values to individual tree dimensions of specific parts of a forest stand.
3. Since the 1970s it has been realised that, for example, steadily increasing uptake of carbon dioxide and nitrogen results in a better and faster growth than is indicated by the yield models currently in use.

Research is under way at SAFS to develop a spatially explicit individual tree model capable of simulating different management scenarios for CCF (Pommerening and Wenk, 2002; Pommerening, 2002). The results can then be assessed in the light of management, ecological and other objectives. Forest managers should be able to use this model to compare and identify suitable silvicultural options without relying on lengthy experiments. Figure 6 gives the visual impression of such a simulation which shows the transformation of a Scots pine plantation to a mixed uneven-aged Scots pine–oak forest. The simulation assumes a planted stand with no thinning before year 40. Phase 1, beginning at year 40, involves a selective crown thinning to favour 'future' trees at about 6 m centres. In phase 2 there is light thinning from below, complemented by pine regeneration and some underplanting of oak. Finally, in phase 3, the majority of the overstorey trees are removed in target diameter fellings. The simulation also demonstrates the length of time required to achieve transformation from regular stands to CCF.

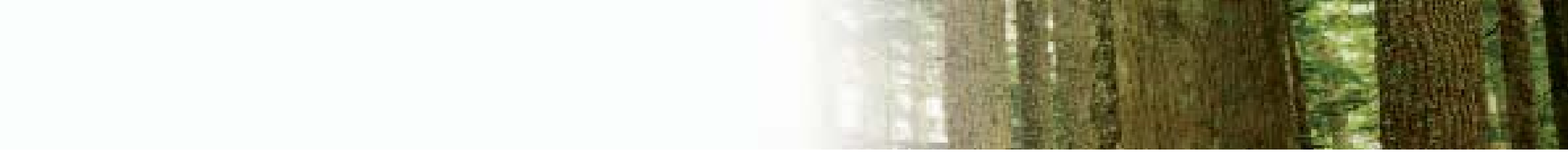
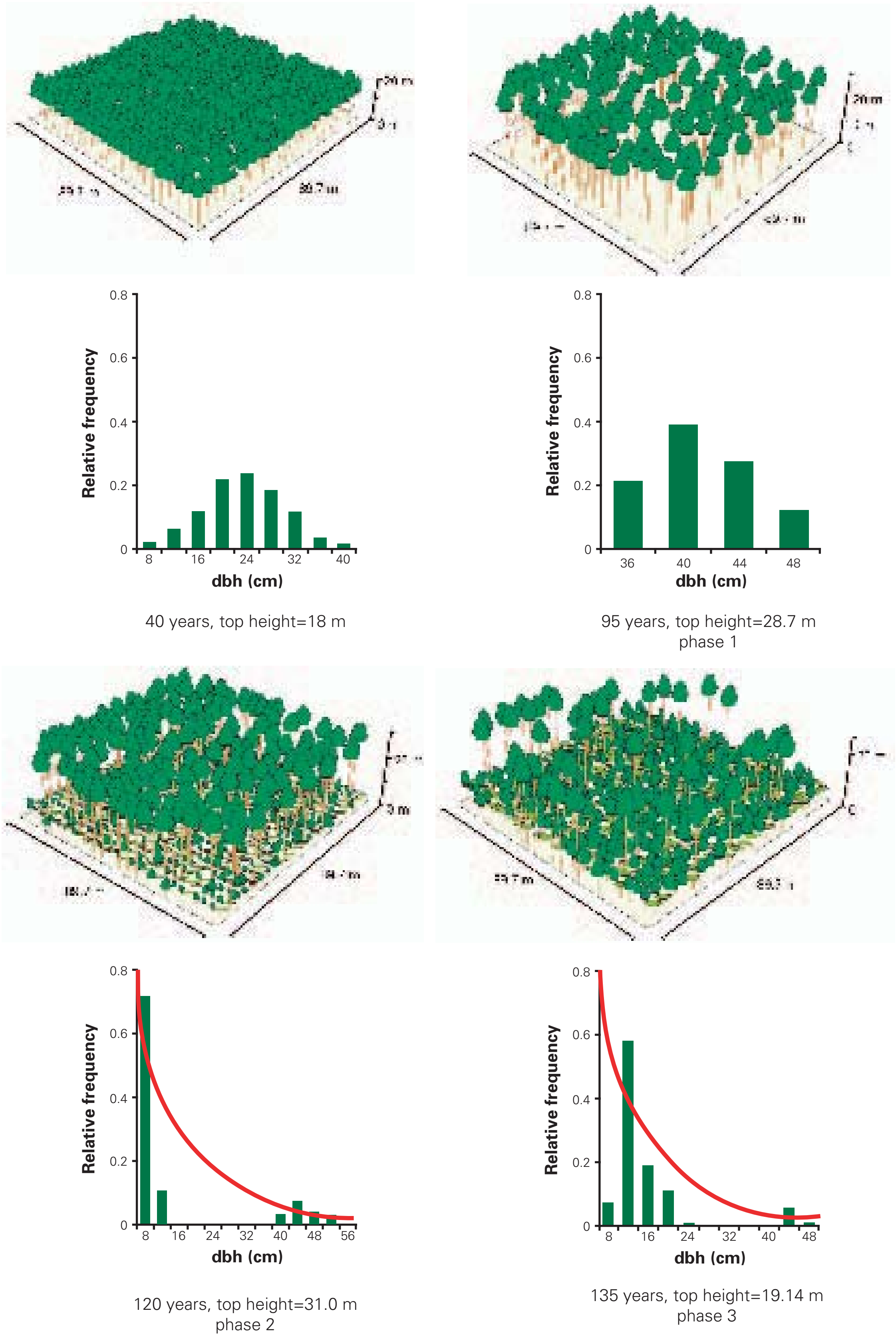
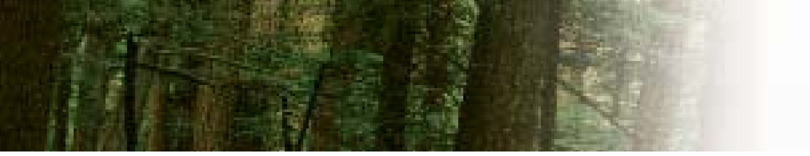


Figure 6

Visualisation of a sample simulation run for the transformation of a Scots pine plantation from a 40-year-old even-aged stand to a 135-year-old irregular stand. Upper graph shows the spatial pattern while the lower graph illustrates diameter distribution over time.





Harvesting requirements and access tracks

With an increasing number of foresters attempting to transform even-aged stands to CCF there is a need for guidance on operational aspects including methods of timber extraction and appropriate provision of forest access tracks.

Selection of extraction system and machinery

A decision support system has been developed to identify the most appropriate selection of timber extraction methods and machinery for a given site (Ireland and Jones, 2004). This starts by carrying out a preliminary site assessment to identify the site and crop constraints on extraction systems and machinery. Significant variation in site and crop will require stratification of the site into homogeneous management blocks. A decision matrix (Figure 7) is used to guide the user through the criteria influencing the choice of extraction machinery, and suggests a range of appropriate extraction methods, given the specific site constraints. These criteria include slope, terrain, extraction distances and environmental site constraints as well as crop factors such as the size and end use of the felled timber.

For example, if a transformation thinning is to be carried out on a site with a gradient in excess of 30˚, and extraction distances more than 250 m, then the only feasible extraction options will be cable crane or helicopter. Given the prohibitive cost of helicopter hire for forestry operations, it is likely that cable crane extraction will be the most practical option in this example. Examination of Figure 7 indicates that the harvesting systems suited to cable crane extraction are: *pole-length* where felled, snedded poles are extracted; *part pole-length* which is a variation where the sawlog component of the pole is removed at stump and extracted separately allowing for easier product sorting; and *whole-tree* where all the above ground parts of the tree including crown and branch wood are extracted. The selection of appropriate timber extraction equipment and machinery is important to ensure cost-effective timber extraction. Additionally, equipment and methods of extraction should be appropriate to the site conditions, so as not to cause excessive disturbance to the site or standing crop.

Suitability of extraction machines for different harvesting systems.

Suitable harvesting system	Extraction machine option: Forwarder/ mini-forwarder	Skidder	Portable winch	Log chute	Cablecrane/ highlead	Horse	Wire loader	Specialised terrain chipper	Helicopter	Fell to waste/ chemical thin
Terrain chipping								■		Alternatives to extraction
Shortwood	■	■	■	■		■	■		■	
Pole-length	■	■	■		■	■			■	
Part pole-length	■	■	■		■	■	■		■	
Whole-tree		■	■		■	■			■	

■ Harvesting system is suitable for the given extraction machine option.

Access track planning

Appropriate planning and construction of access tracks and racks is essential to allow sustainable timber harvesting and extraction (Ireland, 2004). Appropriately specified tracks can reduce harvesting and extraction costs and enable all weather access through the stand, with minimal environmental and landscape impacts. As well as allowing for sustainable timber harvesting, tracks also provide for a range of additional benefits including access for forest management, conservation and recreation.

CCF management requires ongoing access to the stand for thinning both during the transformation phase and the subsequent implementation of the chosen silvicultural system. The need to establish natural regeneration within a stand is likely to restrict location of machinery access routes. One option is to construct a permanent track infrastructure. Alternatively, a network of permanent access routes may be supplemented by temporary or semi-permanent access tracks that will allow the same level of machine access as permanent tracks but at a lower construction cost and offer increased flexibility in relocating tracks in the future. Racks (i.e. unsurfaced corridors through the standing crop) are likely to require some level of brash cover to achieve machine flotation and avoid excessive compaction and soil disturbance when harvesting. The amount required will depend upon soil type. The appropriate specification and location of access through the forest must be carefully planned to enable sustainable long-term use to an appropriate standard.

Monitoring

One way of increasing success in transformation to CCF is to practise 'adaptive management', i.e. to base silvicultural interventions on stand level information (Mason and Kerr, 2004). A system of monitoring has been designed to collect useful stand data at low cost. This procedure aims to (1) quantify changes in the diameter distribution and species composition of a stand over time and (2) ensure that regeneration fulfills stocking requirements.

The first step is to stratify the area into blocks with common site factors that are to be managed as a single unit (for more information see Kerr *et al.,* 2002, 2003). Within each block, data are collected from fixed-area plots where the plot area is selected to assess a minimum number of trees. To avoid the problem of clustering associated with random sampling, plots are located on a systematic grid covering the whole area (Figure 8); this has the added benefit that systematic sampling is easier to implement. The plots can be permanent or temporary depending on the data required by the forest manager and the resources available. The main assessments are: species, number and diameter of trees; species and number of saplings; species and number of seedlings; and vegetation type and cover.

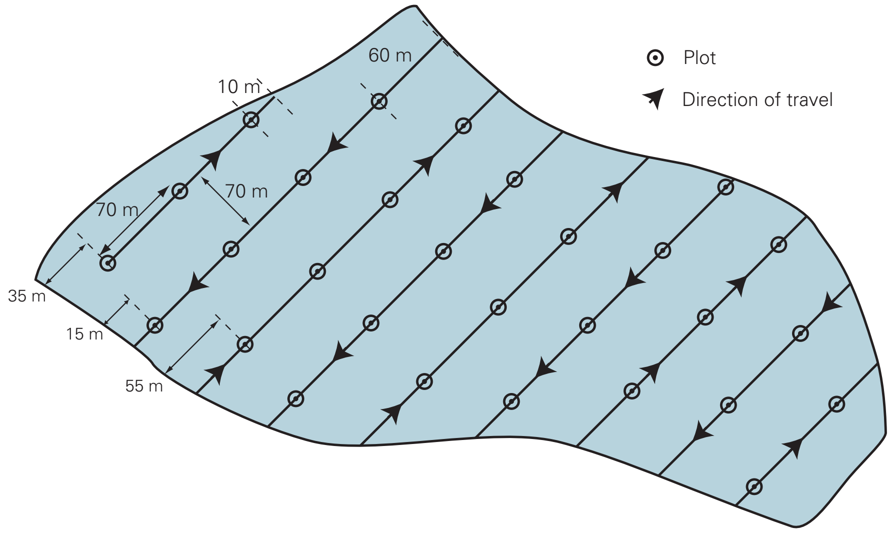
To help forest managers, we have developed software that processes the data into a useful format. The opportunity has also been taken to allow other information about the transformation of an area to be recorded alongside the monitoring data. Hence the system allows storage of the transformation plan, diary notes, fixed-point photographs and information on stand location. The following information is displayed:

- Species, number and size of trees
- Basal area per species
- Diameter distribution
- Sapling and seedling regeneration
- Vegetation type and cover.

The software was released in 2004 (contact gary.kerr@forestry.gsi.gov.uk).

Figure 8

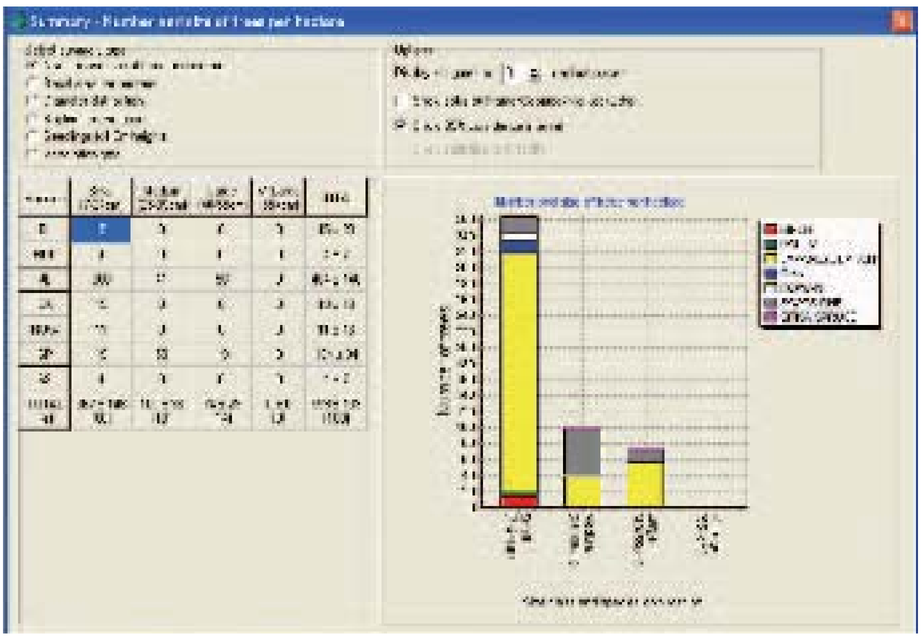
Plots are located on a systematic grid to ensure data is collected from the whole stand.



Examples of the way the software presents data are shown in Figures 9 and 10, using data from a mixed stand dominated by Scots pine and Japanese larch in Wykeham Forest, Yorkshire. Figure 9 shows the number and size of trees presented by species; Figure 10 shows the diameter distribution of the stand. A statistical test can be performed on the diameter distributions to determine if the distribution is 'symmetric' (similar to a normal distribution) or 'skewed'.A skewed distribution would have a large number of small trees, a moderate number of medium trees and a low number of large trees, and is similar to the 'reverse-j' distribution much discussed as an option for managing continuous cover forests (O' Hara, 1996 and 1998). This information can be used when thinning the stand, especially if the aim is to develop a complex structure, i.e. one with three or more canopy strata and a skewed diameter distribution.

Figure 9

Number and size of trees per hectare presented by species.



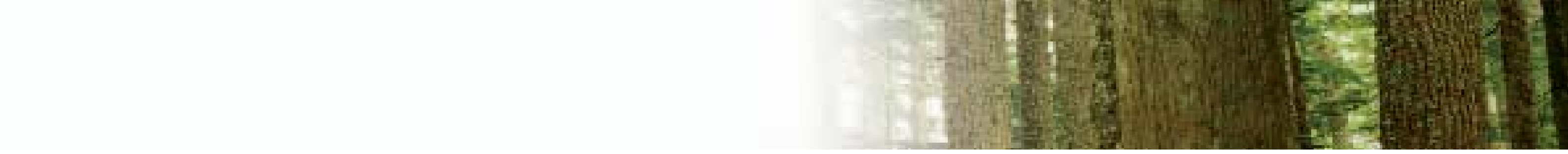
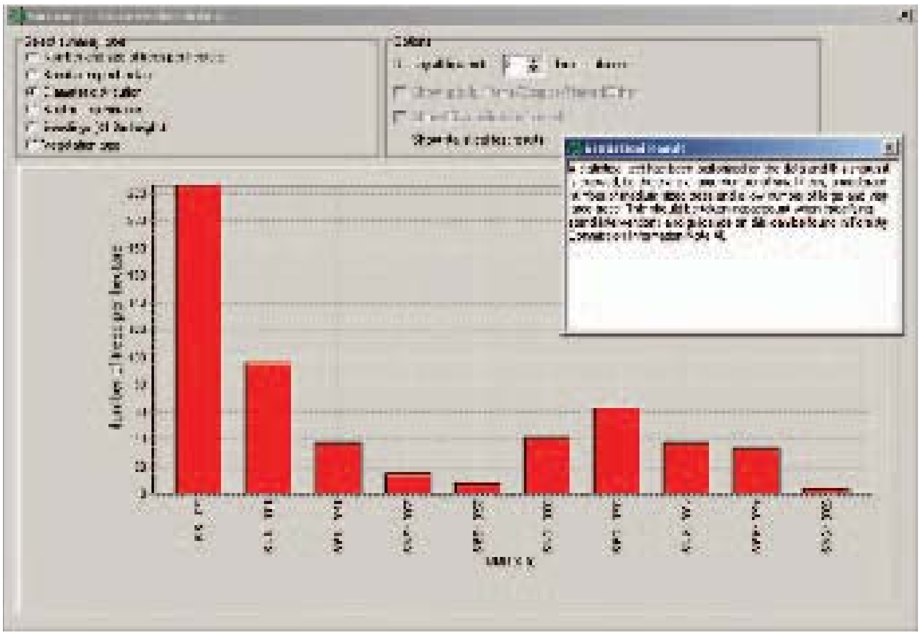


Figure 10

Diameter distribution of the stand.



Data on sapling numbers can also be examined, including testing whether the distribution of saplings is even, clustered or distinctly clustered. The quantity and spatial distribution of sapling regeneration is one of the factors to consider when transforming a stand to continuous cover (Mason and Kerr, 2004).

Conclusion

The breadth of research activity outlined above indicates how widespread adoption of CCF could affect a wide range of conventional forestry practices and outputs. Other aspects that may need to be considered include effects upon wood properties (where a preliminary study is being sponsored by the Scottish Forestry Trust), on biodiversity, on amenity and recreational benefits, and upon soil properties and quality. Given that transformation to irregular forest structures can take 50-100 years, successful implementation of these desired changes will only be achieved through an 'adaptive management' approach involving shared experience between field foresters, forest scientists, policymakers and other stakeholders.

Acknowledgements

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Leisure landscapes: understanding the role of forests and woodlands in the tourism sector

Suzanne Martin

Background

While the use of forests and woodlands for tourism is not new, their utilisation for leisure purposes is receiving new impetus. This is strongly driven by the growing demand from a diverse range of groups within society for opportunities to take part in leisure activities. The increasing interest in tourism is also a response to the recognition among policymakers of the ability of tourism and broader leisure activities to address a range of economic and social dilemmas facing contemporary society, for example the diversification of rural economies, social exclusion and obesity. There is also a mounting awareness that it can work to support, and even act as, a key driver, for the protection and enhancement of the environment. As a result tourism has moved from being a peripheral aspect to a central focus of sustainable forest management.

Figure 1

Tourism is seen as being central to sustainable forest management due to the economic, social and environmental benefits it can deliver.

With the newly emerging emphasis on tourism comes a need for forest managers to explicitly focus more on leisure uses within decision making and a related demand to develop knowledge and understanding of issues relating to these uses. Indeed, as the impacts and lessons learned from the outbreak of foot and mouth disease in spring of 2001 began to be assessed, it became clear that values of forests and woodlands for tourism were far greater and diverse than had been previously recognised (Figure 1). However, it also led to a realisation of the lack of knowledge of both the current and potential role of forestry in the tourism sector and the need for research to understand how those relationships might be developed to their full potential.

While some research had sought to understand how tourists use forests and woodlands (for example Forest Enterprise agencies' visitor monitoring programmes), there had been little, if any, research which had attempted to work directly with tourism providers to understand (a) how they value and use forests and woodlands and (b) how the relationship between the forestry and tourism sectors might be developed to deliver benefits more effectively. The Leisure Landscapes research project was developed to address such questions.

The project worked with tourism providers in three case study areas in England (Suffolk Coasts and Heaths), Scotland (The Great Glen) and Wales (Dyfi Valley) during 2003 (Figure 2). Each study area was selected in order to obtain a diversity of situations in terms of natural environment, including forest and woodland type, socio-economic structure of local communities and the stage of development of the tourism sector and its relationship to forestry. The project sought to understand how tourism providers perceive and use forests and woodlands and to explore the issues they saw as being important to enabling the forestry sector to support and benefit from the work of the tourism sector. Tourism providers were split into two key groups.

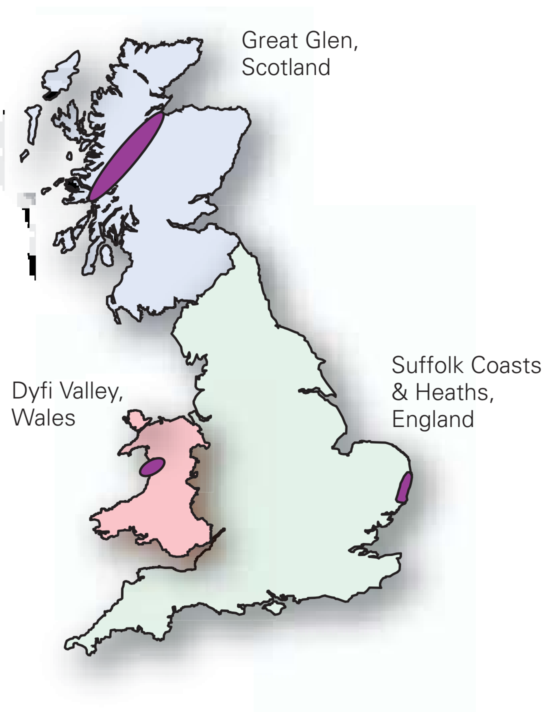
Strategic organisations: generally those with a policy remit, currently linked or which might link with tourism, and selected to represent a broad range of sectors such as those relating to environmental protection, economic development, health and education.

Tourism enterprises: mainly businesses but also organisations, particularly in the arts sector, falling into three broad categories:
(a) accommodation providers, pubs and shops, (b) activity providers, (c) arts providers and tourist attractions.

This article reports on some of the key findings from interviews with the strategic organisations and focus groups with tourism enterprises, and discusses their possible implications for forest and woodland management.

Figure 2

Map of study areas.



Values and uses of forests and woodlands for tourism

Strategic organisations saw forests and woodlands as having a number of key qualities which make them suitable and sometimes favoured spaces for tourism activities. These were identified as:

- Visual screening abilities
- Noise absorption abilities
- Extensiveness (especially in the case of publicly owned forests)
- Physical robustness (especially in the case of coniferous plantations)
- Ability for year-round use
- Ability for all-weather use.

Consequently it was argued that forests and woodlands are well suited to accommodate tourism uses, as they can:

- Absorb relatively large numbers of people
- Accommodate a wide diversity of uses
- Accommodate physically destructive, noisy and/or visually intrusive uses (particularly coniferous woodlands)
- Promote year-round tourism
- Attract visitors regardless of the weather.

Interviewees suggested that opportunities exist to utilise these values so that, where appropriate, forests and woodlands are more explicitly used as tools for tourism management in the wider areas in which they are located. For example, to enable tourism destinations to absorb visitors and a wide range of uses in more socially and environmentally acceptable ways than they would otherwise. Given the relatively 'robust' nature of coniferous plantations and their consequent ability to accommodate physically destructive, noisy and visually intrusive uses (Figure 3), there is a strong case to argue for further modification and promotion of these areas for outdoor recreation and tourism.

In contrast to strategic organisations, tourism enterprises identified forests and woodlands as being valuable in terms of:

- Motivating people to take visits
- Extending the length of time people stay in local tourism areas
- Extending the length of the tourist season.

For example, an activity business described how they ran guided horse-riding tours and the way in which the woodlands in the area enabled them to take visitors somewhere peaceful, attractive and where they could see wildlife, where they could feel they had 'got away from it all'. They described how the alternative to using woodlands was to ride through agricultural fields and on roads. This however was not seen to offer the quality of experience sought by visitors. As such forests and woodlands were critical in enabling the company to motivate people to visit their business.

An accommodation provider in the Great Glen also spoke about value of woodlands for tourism but this time in relation to their role in extending the length of stay of visitors to his business:

> ...we tell them about which woodland they can walk in and suddenly they decide they are not going to stay one night, they are going to stay two or three nights and from my point of view it's essential to have a good woodland around, because the business is quality effective by the fact that we do have it.
>
> Accommodation business, Great Glen

Another business spoke of the way in which forests and woodlands extend the tourist season:

> There is a lot of photography that goes on and I think with all the different colours, just ordinary touring people who would never get out of the car, sort of older people, you know, they are all taken on the colours and I think that it is selling an extended season as far as we are concerned.
>
> Accommodation business, Great Glen

Figure 3

Forests and woodlands were valued due to their potential ability to raise the social and environmental acceptability of tourism by absorbing a wide diversity of people and uses, including physically destructive uses.

These values were seen to be related to three key three features of forests and woodlands – their imagery, the access they provide to the 'natural' environment and their man-made facilities and services. These are discussed in more detail below.

Imagery

Forests and woodlands were seen to have an important role in determining the identity of local tourism destinations (Figure 4). It was felt they provided the image of a 'green' and 'rural' tourism destination. In the Dyfi Valley it was the sheer extent of forestry which was seen to promote 'green' imagery:

> Some people have never seen that expanse of green and trees and it is useful for that benefit, and certainly the views straight out of my accommodation, I get people just stood hour after hour…just looking at it, it could be much better, but it is certainly better than without them.
>
> Accommodation provider, Dyfi Valley

In the Great Glen it was the way in which the forests contrasted with the mountains, lochs and waterways which was seen as important in creating the area's tourism identity. In the Suffolk Coasts and Heaths it was the contrast and blending of woodland with lowland coastal heath which was seen as critical in creating an image which attracted visitors to the area. The changing colour of woodlands and their strong association with spring and autumn, were seen to extend the length of the tourist season by attracting visitors at times of the year traditionally regarded as 'shoulder' seasons in the tourism industry.

Access to the natural environment

Forests and woodlands were also felt to provide access to the 'natural' environment in which the biological materials (for example plants and animals), sights, sounds, smells and over all aesthetics and ambience could be used by tourism enterprises to stimulate a range of beneficial experiences for their visitors (Figure 5):

> You wouldn't believe the number of visitors who say, the best thing about this place is the smell, the older generation, 'this reminds me of my childhood', which for them was great, the smell, the whole building has that wood smell through it.
>
> Accommodation provider, Dyfi Valley

It was highlighted that the forest and woodland environment contrasted with the everyday settings of many people, particularly urban dwellers, and that these experiences might not otherwise be available to them. The ability to explore away from trails into the 'wild' resource and the related sense of excitement and adventure were seen as being important, especially for activity providers.

Facilities and services

It was also discussed that forests and woodlands contain a range of man-made tourism facilities such as trails, visitor centres, interpretation boards, car parks and toilets which can be used by tourism businesses and their visitors.

Services such as guided walks and activities were available in the Great Glen and Suffolk Coasts and Heaths, and these too were also felt to be part of the product sold by tourism enterprises to visitors (although they appeared to be currently under-utilised). It was felt that high standards of facility and service provision were critical if tourism areas were to maintain or develop a reputation for quality but that this was partly related to the condition of the natural environment in which they were located. Developing and maintaining the appropriate balance between 'natural heritage infrastructure' (Scottish Natural Heritage, 2001), for example plants and wildlife, and man-made infrastructure, for example trails and car parks, for different tourists and tourism areas was seen as being critical.

Uses of forests and woodlands by tourism providers

Having developed an understanding of the values associated with forests and woodlands by tourism enterprises, it was important to explore and understand how they utilise those values. As discussions developed, it became clear that tourism enterprises use forests and woodlands in a diverse range of ways but that these uses fall into two broad categories:

Figure 4

Forests and woodlands can be an important part of an area's tourism identity.

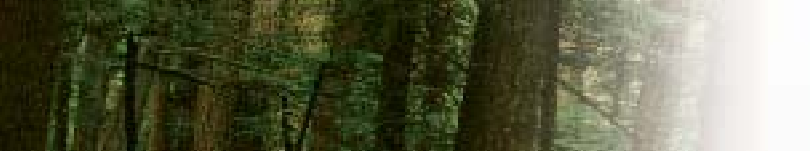
Figure 5

The access provided by forests and woodlands to the natural environment enables tourism enterprises to provide a range of beneficial experiences to visitors.

- **Direct uses:** which take place in forests and woodlands.
- **Indirect uses:** which utilise forest and woodland characteristics, biological materials and infrastructure, but do not take place within forests and woodlands.

These uses are explained in more detail in Table 1.

As enterprises explained their uses, it became evident that it is not possible to make assumptions about the nature of use according to the core activity of an enterprise (for example, accommodation provision or activity provision). The increasing competitiveness of the global tourism industry has created the need for high quality and distinctive tourism products which are more complex and grounded in local and regional contexts to a greater extent than they have been in the past. One approach from enterprises has been to add quality and value to their core service through diversification and an emphasis on local and regional experience, so, for example, accommodation providers may also offer guided tours and activities, evening meals as well as use and sell local products.



As such the use of forests and woodlands by tourism businesses reflects the wider tourism services and activities which constitute their overall product. This is illustrated in the following extract from a discussion with an accommodation provider in the Great Glen, Scotland:

> We were talking about the berries, we utilise the sloes for sloe gin and brambles and that sort of thing. Again we kind of use these and tell people about them and they buy into it, the kind of being out in the nature.
>
> Accommodation business, Great Glen

Given this situation it is more accurate to refer to direct and indirect uses rather than direct and indirect users, as it is generally the nature of the activity rather than the provider which determines the way in which tourism providers utilise forests and woodlands. This has important implications for the way in which forest managers consider and deal with the needs and concerns of tourism enterprises, stressing the need to be flexible and open-minded with regard to accommodating the needs of different businesses.

Relationship between the Forestry Commission and the tourism sector

Both strategic organisations and tourism enterprises discussed the need for the development of a stronger relationship between forests, woodlands and tourism, and in particular, partnership working, to share a broader range of resources than at present (Figure 6).

Indirect and direct tourism uses of forests and woodlands.

Indirect uses **Images, text and verbal references to:**	**Direct uses** **Physical uses of:**
■ **Forests and woodlands (imagery)** in marketing literature, e.g. websites, leaflets, brochures, guide books, CD roms, and in conversations with guests and potential visitors.	■ **'Natural' space and biological materials and their related ambience and acoustics** for activities, e.g. forest theatre and adventure activities, which do not specifically focus on the use of built facilities such as trails and visitor centres.
■ **Facilities and services**, e.g. trails, visitor centres, car parks and guided walk services, in forests and woodlands.	■ **Man-made facilities** such as trails, interpretation, visitor centres, toilets and car parks for activities, e.g. guided walking and horse riding tours.
■ **Biological products (plants and animals)** found in forests and woodlands. Also physical use of biological materials gathered in forests and woodlands by others to provide products for visitors, e.g. food and drink, furniture and textiles.	■ **Biological materials** (viewing and gathering) to make products such as food and drink, arts and crafts, or as a means of providing enjoyment education and learning.

Figure 6 (a) - (d)

Partnership working to integrate different aspects of forest and woodland tourism will be important to its success in delivering sustainable development. (a) Furniture made from British hardwoods. (b) Blackthorn berries (used to make sloe gin). (c) Cafe at Coed Y Brenin Forest. (d) Visitors enjoying a forest walk.

Strategic organisations stressed the importance of the Forestry Commission and forestry sector understanding more fully the resources it has available for tourism and utilising those wide ranging resources to their full potential. They identified the ‘tourism resources’ shown in Box 1 which they felt the Forestry Commission possessed.

In particular it was felt that there was a tendency to focus on the physical land and infrastructure resource of the Commission, and that a wider range of resources could be more actively utilised to add value to current tourism work. Knowledge and skills for tourism land management were felt to be particularly underappreciated and underutilised.

Box 1

Forestry Commission 'tourism resources'.

- Trees
- Land
- Other natural and biological materials
- Man-made infrastructure and information materials
- Services such as guided walks
- Expertise (knowledge and skills) to manage for leisure uses
- Funding/access to funding
- Human resources

Partnership working was seen to be important in terms of:

- The planning, delivery and maintenance of tourism products and services
- The marketing and provision of information to tourism providers and visitors
- The transfer knowledge and skills for tourism land management.

For example, it was suggested that with greater involvement of tourism enterprises in forest planning it might be possible to better link facilities and services in forests and woodlands with those of surrounding tourism providers. For example, trails could be planned so that they linked to local attractions, shops, pubs and accommodation. This approach was seen not only to support local economies but also to potentially provide visitors with a higher quality of experience. Similarly, in relation to marketing and information provision, it was suggested that, given the positive imagery associated with woodlands, there was potential to link many small and diverse forest and woodland tourism providers (e.g. landowners and managers, activity providers and crafts people) and projects into a more integrated and thus powerful 'woodland tourism' concept (Figure 6).

For example, a craftsman in one of the study areas discussed the potential value in being able to connect the wooden furniture he made to places where people could find out more about the management of woodlands and where they could go to experience that environment.

At the same time, the potential in working with enterprises to market and deliver information on Forestry Commission tourism products and services was also highlighted. As a shop owner in the Suffolk Coasts and Heaths commented: 'we talk to customers, we act as a tourist information service, we tell them places to go'. Indeed, some enterprises were already promoting forest and woodlands through word of mouth, leaflets and websites. It can be seen therefore that through partnership working, it was felt that much could be done to add value to the tourism sector by increasing the diversity (breadth), meaningfulness (depth) and accessibility of tourism products and services.

It was clear, however, that the precise nature of involvement needs careful consideration of the local contexts within which development is being considered. For example, issues of competition and commercialism were key concerns in some areas. Where this was the case, there was strong support for the Forestry Commission to fill gaps in the market left by the private sector and to provide non-market goods and services.

A number of barriers to joint working between the Forestry Commission and the tourism sector were identified by tourism enterprises; these are shown in Box 2.

These barriers suggest there is a need for forest management to more explicitly consider the needs of tourism providers, particularly enterprises, and ways in which the availability and accountability of resources and processes surrounding forest and woodland management, including those relating to information provision, might be increased. At the same time it is critical that forest and woodland owners and managers also consider their own marketing and

Box 2

Perceived barriers to joint working between the Forestry Commission and tourism enterprises.

A lack of:

- Understanding that Forestry Commission is a tourism provider
- Understanding that forests and woodlands are tourism products
- Knowledge of products and services offered by the Commission, including tourism sites and facilities, leaflets and the website and lack of processes to gain information on those opportunities
- Information on forest planning and management and opportunities to get involved in those activities
- Resources available within the Commission to provide recreation facilities and to support and train enterprises in the provision of recreation infrastructure
- Reliability in the availability and quality of the infrastructure e.g. if forest trails are closed for timber felling or if infrastructure is left to deteriorate after an initial period of capital funding

information requirements in relation to tourism providers; for example in order to market their recreation resources as tourism products what information do they need from local accommodation providers and activity providers?

Conclusions

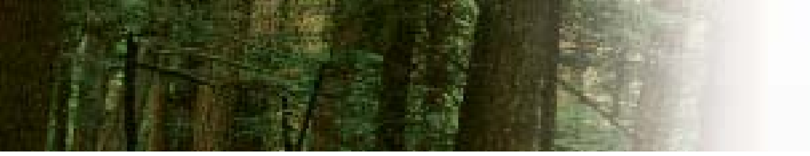
This research has highlighted the considerable value and wide-ranging resources that tourism providers feel the forestry sector has for tourism as well as the vast potential that they feel exists for the further development of forests and woodlands as tourism resources.

In particular, it proposed that given the relatively 'robust' nature of coniferous plantations and their consequent ability to accommodate physically destructive, noisy and visually intrusive uses, there is a strong case to argue for further modification and promotion of these areas for tourism. More broadly it was proposed that forests and woodlands, where appropriate, could be used to increase the social and environmental acceptability of tourism activities. These management potentials might be especially pertinent with the passing of new access legislation in Scotland, England and Wales where there may be a need to accommodate increased leisure use of open space land and to more actively manage the way in which people use that land.

The work also revealed that tourism providers have a diverse and complex range of relationships with forests and woodlands, which as well as them taking part in and promoting activities which might typically be associated with woodland recreation, such as walking, cycling and horse-riding, also involves them using and promoting natural and locally sourced materials and products as well as man-made infrastructure.

The potential for the development of a closer working relationship between the forestry and tourism sectors was identified and explored. The potential for greater partnership working is especially significant given that tourism and recreation management is split amongst a wide range of strategic players, for example those involved with sports development, environmental protection, tourism promotion and land management.

It was stressed that in order for joint working to be developed more effectively, there is a need for the Forestry Commission and forestry sector to more fully understand the resources available for tourism and the ways in which these might support the work of the tourism sector and, in particular, how they can be made more accessible to tourism providers.



As well as focusing on the delivery of new products and services, the work highlighted the importance of forestry providing added value to the tourism sector, for example by strengthening the connections between forest and woodland tourism products and the wider tourism sector, including other landowners and managers.

In particular, the work suggested that in order to get the full potential out of its wide-ranging resources available for tourism, the Forestry Commission needs to consider more proactive and effective communication with tourism providers to deliver strong and focused messages about its role in tourism and information on its related products and services as well as day-to-day forest management. It has also highlighted a need to develop more open and transparent approaches to forest planning.

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Monitoring of forest health in Britain: The Forest Condition Survey and Level I networks

Steven Hendry

Introduction

Every year, Forest Research undertakes an extensive survey of the condition of Britain's forest trees. The Forest Condition Survey has been carried out since 1984 and, in addition to providing comprehensive information on tree health in Britain, it contributes to an EU programme monitoring the health of a forest area of over 150 million hectares. As well as detecting, quantifying and determining the causes of short-term damage to trees, the presence of long-term trends in the condition of particular tree species can also be detected by the survey. The Forest Condition Survey therefore plays an important role not only in the immediate identification of particular tree health problems but provides information of relevance to studies of pollution effects, climate change and sustainable forest management. This article provides an overview of the history, structure and function of the survey and details its relationship to the ICP-Forests Level I network.

Background

In the mid-1970s, reports of declining forest health began to emanate from Central Europe. Initially, these reports did not cause undue concern since they mainly related to the condition of European silver fir *(Abies alba)*, a species which was known to have suffered periodic declines for at least the previous 100 years (Wachter, 1978). However, by the early 1980s accounts of new and widespread damage to Norway spruce and a number of broadleaved species were being received from Germany and other central European countries. The scale and development of the forest damage which was apparently occurring in Europe prompted many countries to establish national surveys in order to assess the condition of their own forests.

The Forestry Commission initiated the first survey of forest health in Britain in 1984, assessing the condition of Sitka spruce, Norway spruce and Scots pine (Binns *et al*., 1985). By 1987, the programme had been expanded to include oak and beech and the age range of the trees assessed in the survey had been widened to incorporate older crops of the coniferous species. Plots were also established on private land to increase the survey's geographical coverage and to provide a more representative sample of British forests (Innes and Boswell, 1987).

Forest decline was linked with air pollution by certain scientists and foresters during the 1980s. Concern over atmospheric pollution had already given rise to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) in 1979 and, under its auspices, an International Co-operative Programme on Assessment and Monitoring of Air-Pollution Effects on Forests (ICP-Forests) was set up in 1985. In co-operation with the European Commission (EC), which introduced legislation requiring member states to undertake forest health monitoring programmes in 1986 (Regulation EEC No. 3528/86), an extensive network of forest monitoring plots (the Level I network) was established. By 2002, 17 countries from outwith the EU and 15 EU member states including the United Kingdom were contributing to an ICP-Forests Level I network consisting of approximately 132 000 trees located in 5900 plots and representing a forest area of over 150 million hectares (Lorenz *et al.*, 2003).

The Level I survey was designed to provide accurate information on changes in the extent, distribution and symptoms of forest damage occurring at a European scale. However, to obtain sufficient data to allow the identification of trends in forest condition at a national level many countries, including Britain, established and retained networks of plots at a higher density than that required for the Level I survey. The survey protocols followed by individual countries, although sharing many of the assessments laid out in the ICP-Forests manual (Anon., 1998), also differed according to national requirements (Innes, 1990). This article provides a detailed account of the structure and function of the annual Forest Condition Survey (FCS) carried out in Britain and details its relationship to the ICP-Forests Level I network.

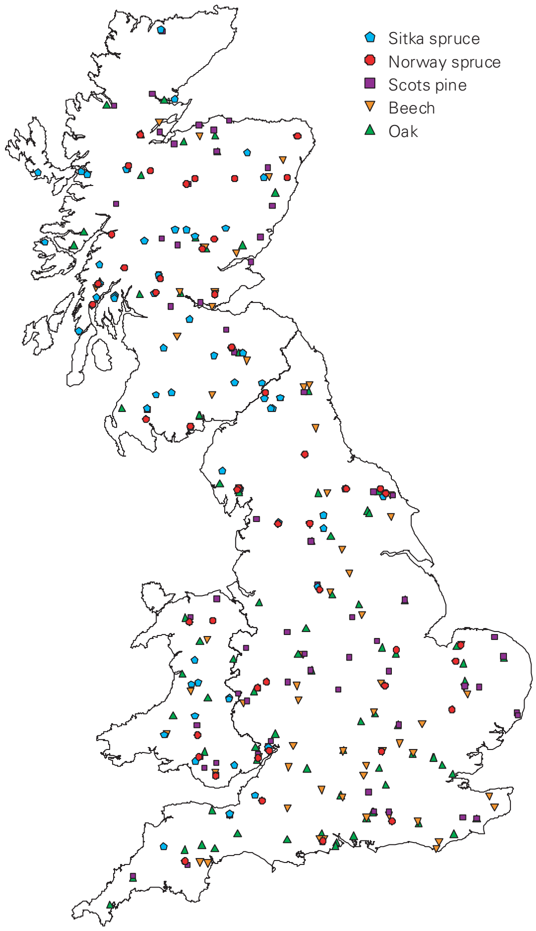
Overview of the Forest Condition Survey

The current Forest Condition Survey is based upon the assessment of five tree species: Norway spruce, Sitka spruce, Scots pine, oak and beech. Each year, between late June and September, the condition of approximately 8400 trees distributed across a network of 350 permanent monitoring plots is determined (Figure 1). Plots consist of 24 trees located in four sub-plots of six trees and, depending upon the species assessed, between 29 and 33 features indicative of condition are scored for each tree. The feature of greatest interest is an assessment of crown density: an estimate of the degree of transparency of the crown which is used as an index of tree condition. Reductions in crown density are estimated in 5% classes by reference either to a standard set of photographs of 'ideal' trees (Innes, 1990) or to 'instant' photographs of individual local reference trees (Anon., 1998). Data are collected on hand-held computers and are checked for consistency and departures from expected values both in the field and before analysis.

The assessments are carried out by between 15 and 20 regionally based surveyors (Figure 2). Although all of the surveyors participating in the programme receive a week of training prior to the start of each year's survey, between a quarter and a third of all plots are reassessed by one experienced supervisor to check the consistency of assessments. At the conclusion of the survey, the data from both the main and check survey are verified and loaded onto a dedicated Oracle database containing the results of all of the surveys conducted since 1987. Following analysis, the data are reported both nationally and internationally (Hendry *et al.*, 2003; Lorenz *et al.*, 2003).

Figure 1

Distribution of Forest Condition Survey plots in Britain: 2003.



Surveyors record FCS assessments using hand-held computers which provide context-sensitive help and carry out data consistency checks in the field.

Box 1

Two sampling strategies for the assessment of forest condition.

Systematic sampling involves the establishment of monitoring plots at the intersection points of a regularly spaced grid overlaid on the area of interest. Given an appropriate sampling intensity the design benefits from:

- Reflecting the relative abundance and geographical distribution of the surveyed tree species.
- Reflecting the age structure of the wider populations of the surveyed species.

But the design suffers from the disadvantages that:

- Plot numbers will be low for particular species and the condition of plot trees may therefore be unrepresentative of condition at a wider scale.
- The statistical sensitivity of the survey for under-represented species will be poor.
- Geographical coverage may be patchy, negating the possibility of spatial analysis of condition.
- It may not be possible to analyse condition data for the effects of potentially significant co-variables such as pollution deposition or soil moisture deficit.

Stratified sampling involves the identification of a limited number of particular (usually site-related) variables of importance and establishing plots at locations where differences in these variables exist. The design benefits from:

- Allowing the effects of the stratified variables (e.g. pollution deposition, soil moisture deficit) to be tested.
- Ensuring geographical coverage for the species which are assessed and therefore allowing spatial analysis of condition.
- Ensuring that appropriate numbers of plots are present to attain the required statistical sensitivity for all of the species included in the survey.

But the design suffers from the disadvantages that:

- The number of species which can be incorporated into the survey is limited.
- The distribution of plots may not reflect the locations in which the species are numerically important, or the age structure of the wider populations of the surveyed species.

Survey and plot design

The majority of forest condition monitoring programmes in Europe employ survey designs which are based upon either systematic or stratified sampling. Each of these strategies has attendant strengths and weaknesses (see Box 1), and the choice between them depends both upon the key aims of the survey and the nature and distribution of the forests to be assessed.

The Forest Condition Survey was established to a stratified sampling design (Binns *et al.*, 1985; Innes and Boswell, 1989; Mather *et al.*, 1995) with two levels (high and low) of three variables: altitude, rainfall and sulphur deposition. The country was divided into six different regions and, within each of these, plots displaying all possible combinations of level and variable (eight combinations in total) were established for each of the assessed species. Contrastingly, the Level I survey to which the UK contributes, is based upon systematic sampling from a 16 x 16 km grid covering the British Isles and Continental Europe (Regulation EEC No. 1696/87). The differing requirements of these two sampling strategies were reconciled by establishing a specific subset of Level I plots in the UK in 1987 (Innes and Boswell, 1987).

Table 1

Numbers of Forest Condition Survey (FCS) plots by type and species in 2003.

Species	Number of plots		
	FCS + Level I	FCS only	FCS total
Beech	12	53	65
Norway spruce	12	42	54
Oak	18	68	86
Scots pine	15	66	81
Sitka spruce	23	37	60
Mixed (Sitka spruce & Scots pine)	3	0	3
Total	86	266	349

By their inclusion in the Forest Condition Survey, the Level I plots have blurred the original stratification of the sampling design but this effect is limited since they constitute less than 25% of plots which are assessed each year (Table 1).

The non-systematic design of the FCS allows the condition of a limited number of key species to be assessed efficiently across their entire range in Britain. Although less-common tree species are not represented, the quantity of data gathered for those species which are included in the survey increases its statistical sensitivity to any changes in their condition. The range of locations at which plots have been established, and the associated variety of site conditions which are sampled, also allows sufficient flexibility for unforeseen stratification of the survey data to be carried out (Mather *et al.*,1995). This not only makes the analysis of existing data in the light of new findings possible but also demonstrates that the survey is capable of responding to unforeseen circumstances – a key requirement for any long-term monitoring programme (Skalski, 1990).

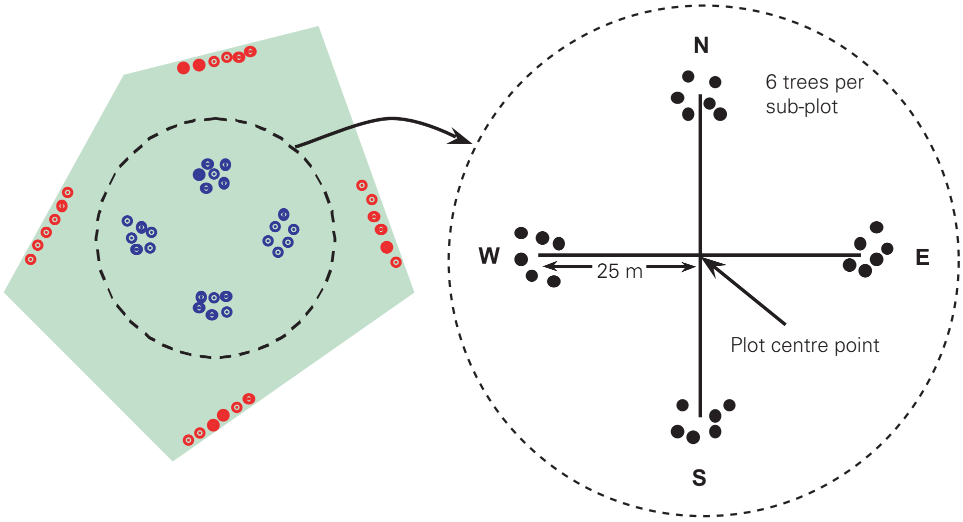
Plot design

All Forest Condition Survey plots, barring three which have been established in mixed crops, are located in even-aged stands of a single tree species. The plot design employed in the FCS follows the recommendations for the Level I survey (Anon., 1998) and consists of 24 dominant or co-dominant trees located in four sub-plots of six trees. Adaptation of the standard cross-cluster design for survey plots is, however, frequently required in Britain (Binns *et al.*, 1985). In dense crops, where the crowns of trees located within the stand are not clearly visible from the ground, sub-plots are established in openings within the crop or on the stand margins closest to the plot centre (Figure 3). Although previous work from the Republic of Ireland and elsewhere has suggested that there may be differences in crown density between edge trees and those within stands (Moffat and Durrant, 1998), the edge trees assessed in the FCS are located along internal boundaries within forests and are unlikely to be exposed to the weather, pollution levels and light conditions experienced by trees at forest margins. A recent study conducted on FCS plots found no significant difference in crown density between plots of trees located on stand edges and plots established inside the same crops (Durrant and Boswell, 2002).

To ensure that the survey plots are truly representative of normal forest crops, no management restrictions are placed upon the stands which contain them, and both sample trees and entire plots can therefore be lost as a result of thinning or clearfelling operations.

Figure 3

Forest Condition Survey plot designs for dense crops (red circles) and open crops (blue circles).



Lost trees are replaced by selecting suitable replacements located as close to any remaining sub-plot trees as possible, whilst plot losses are generally made good by the establishment of new plots in similar crops nearby.

Forest Condition Survey assessments

A record of site history and physical characteristics, including soil type, is maintained and updated annually for each FCS plot. Assessments carried out on individual trees vary according to species, with the number of variables recorded currently ranging from 29 for oak and beech to 33 for Sitka and Norway spruces (Table 2). Basic mensurational data are also collected via an assessment of diameter at breast height for each tree. Tree heights are measured when plots are first established but are only recorded at irregular intervals thereafter. In addition, all assessors are trained to identify common types of biotic and abiotic damage and these are recorded as comments which qualify certain damage scores (Figure 4).

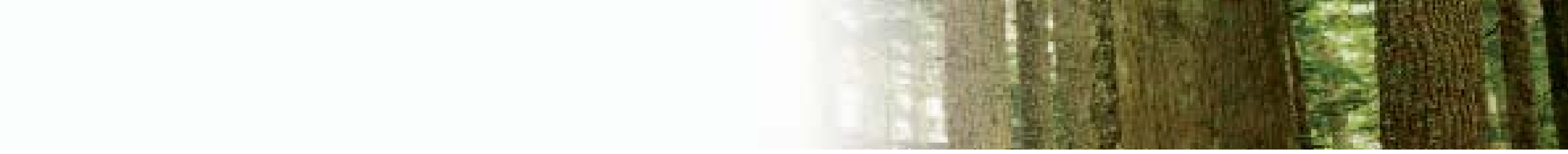
The assessment which is most widely reported from both the FCS and Level I surveys is that of crown density. This is an indirect assessment of defoliation which compares the opacity of the crown of the subject tree with that of a standard reference tree bearing full foliage. Two estimates of crown density are possible: absolute crown density which compares the subject tree with an ideal reference tree with a totally opaque crown, and local crown density which compares the subject tree with a local reference tree (the most densely foliated tree of the same species and age as the subject tree growing under local conditions). Under most circumstances, and particularly in exposed

Mining by larvae of the weevil *Rhynchaenus fagi* results in damage and discoloration of beech leaves.

Table 2

Variables assessed for FCS sample trees by species.

Variables	Sitka spruce	Norway spruce	Scots pine	Beech	Oak
1 Diameter at breast height	✔	✔	✔	✔	✔
2 Height	✔	✔	✔	✔	✔
3 Dominance	✔	✔	✔	✔	✔
4 Canopy closure	✔	✔	✔	✔	✔
5 Crown density – local	✔	✔	✔	✔	✔
6 Crown density – absolute	✔	✔	✔	✔	✔
7 Branch pattern	✔	✔			
8 Crown form			✔		✔
9 Defoliation type	✔	✔	✔	✔	✔
10 Shoot death (crown)	✔	✔	✔		
11 Shoot death (branches)	✔	✔	✔		
12 Shoot death extent	✔	✔	✔		
13 Dieback type				✔	✔
14 Dieback location				✔	✔
15 Dieback extent				✔	✔
16 Location of secondary shoots	✔	✔			
17 Abundance of secondary shoots	✔	✔			
18 Epicormics					✔
19 Flowering			✔		
20 Fruiting	✔	✔	✔	✔	✔
21 Needle retention	✔	✔	✔		
22 Browning – current	✔	✔	✔	✔	✔
23 Browning – current type				✔	✔
24 Browning – old	✔	✔	✔		
25 Yellowing – current	✔	✔	✔	✔	✔
26 Yellowing – current type	✔	✔	✔	✔	✔
27 Yellowing – old	✔	✔	✔		
28 Yellowing – old type	✔	✔	✔		
29 Overall discoloration	✔	✔	✔	✔	✔
30 Leaf rolling				✔	
31 Premature leaf loss				✔	
32 Mechanical damage type 1	✔	✔	✔	✔	✔
33 Extent of mechanical damage type 1	✔	✔	✔	✔	✔
34 Mechanical damage type 2	✔	✔	✔	✔	✔
35 Extent of mechanical damage type 2	✔	✔	✔	✔	✔
36 Butt and stem damage	✔	✔	✔	✔	✔
37 Game damage	✔	✔	✔	✔	✔
38 Insect damage	✔	✔	✔	✔	✔
39 Fungal damage	✔	✔	✔	✔	✔
40 Abiotic damage	✔	✔	✔	✔	✔
41 Anthropogenic damage	✔	✔	✔	✔	✔
42 Fire damage	✔	✔	✔	✔	✔
43 Pollution damage	✔	✔	✔	✔	✔
44 Other damage	✔	✔	✔	✔	✔
45 Comments	✔	✔	✔	✔	✔



areas, the local reference tree does not possess a totally opaque crown and therefore represents a less stringent standard for comparison than an ideal reference tree. Between 1984 and 1992 only absolute crown density was assessed as part of the Forest Condition Survey but since 1993 local crown density has also been determined to harmonise with the survey protocols employed by most other countries contributing to the Level I monitoring programme.

A local crown density assessment might be seen as providing a more realistic impression of a tree's condition because it takes into account factors such as tree age and exposure which will affect the crown condition of even the healthiest trees in a particular locality. However, because trees in different areas of the country are being compared with reference trees in different states of defoliation, direct comparisons of local crown density scores between plots can be misleading. The relative condition of trees in different localities can only be determined if the condition of the local reference trees for each plot are known (Redfern and Boswell, 2004). Absolute crown density scores do not suffer from similar problems of interpretation because all trees are assessed with reference to a common standard. The condition of trees in different locations or at different times can therefore be directly compared.

The function of many of the FCS assessments is to qualify the crown density scores which are obtained for each tree. In some cases, low crown density scores can be directly attributed to certain causes, e.g. to mechanical damage such as breakage of branches by wind or snow, resulting in gaps within the tree's crown. In many instances, however, it is necessary to examine the change in crown density of a species, plot or individual tree and to relate this to changes in other attributes in order to identify potential cause(s) of defoliation. For example, a decrease in the mean crown density of a species between one year and the next may be related to an increase in damage from defoliating insects (Box 2).

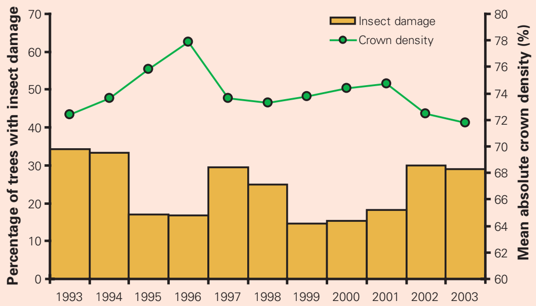
Box 2

Crown density and insect damage in Sitka spruce.

In Britain, Sitka spruce is occasionally subject to severe defoliation by the green spruce aphid *Elatobium abietinum*. In winter, spring and early summer the aphid feeds on mature needles which become discoloured and quickly fall. In certain years, outbreaks of the insect are widespread and Sitka spruce is defoliated over large areas of the country. The Forest Condition Survey results for the period 1993–2003 clearly show two occasions on which the crown density of Sitka spruce has deteriorated markedly: between 1996 and 1997, and between 2001 and 2002 (Figure 5). On both of these occasions, the proportion of trees in the sample population which was recorded as being damaged by insects increased notably. With few exceptions, the insect damage which occurred in 1997 and 2002 was identified by the FCS surveyors as being caused by *Elatobium abietinum* (Redfern *et al.*, 1998; Hendry *et al.*, 2003).

Figure 5

Mean absolute crown density and percentage of trees recorded as insect-damaged for Sitka spruce in the period 1993–2003.



The connectivity survey

The assessments which are made during forest condition monitoring exercises are subject to human error. Appropriate checking of the quality of survey assessments is therefore essential if recorded differences in crown density and other variables are to be ascribed to differences in the condition of the assessed trees rather than differences in the accuracy and consistency of the assessments themselves.

The importance of quality assurance was recognised at the inception of the FCS (Binns *et al.*, 1985) and the first check or 'connectivity' survey to determine the nature and extent of any assessor bias was implemented in 1985 (Binns *et al.*, 1986). Considerable differences were initially detected between the scores which different surveyors allocated to the same trees and improvements in both survey procedures and surveyor training were instigated to address this problem (Innes, 1993). Greater accuracy was also introduced into the connectivity survey by comparing the surveyors' results with those of a single experienced assessor rather than relying upon the inter-comparison of scores obtained by the surveyors themselves (Innes and Boswell, 1987).

Since 1995, the FCS connectivity survey has involved the re-assessment of between a quarter and a third of all survey plots by a single experienced assessor (the standard observer). Individual plots are assessed simultaneously but independently by both the standard observer and the surveyor being tested, thus ensuring that the appearance of the trees and the conditions under which they are viewed are the same for both assessors. Differences in the scores obtained by the standard observer and the surveyor therefore reflect differences only in their respective assessments of the condition of the trees.

For crown density assessments, surveyor bias is detected by calculating the average difference between the scores of the assessor and the standard observer (Figure 6). For comparisons conducted on a single plot of 24 trees, a difference of 5% or more has been found to provide a reliable indication of the presence of statistically significant bias (Redfern and Boswell, 2004). While a small number of comparisons usually reveal differences of this magnitude each year, e.g. in 4 of the 47 combinations of surveyor and species shown in Figure 6, consistent bias (i.e. bias affecting several species for an individual surveyor) has only been detected on two occasions during the past 10 years of the survey (Redfern *et al.,* 1996; 1998).

Survey results

Detailed data on the condition of each tree in the Level I subset of survey plots, and summary data for the entire Forest Condition Survey, are provided by Forest Research to ICP-Forests each year in fulfilment of the UK's obligations under EU regulations and CLRTAP. This information contributes to a joint EC/UNECE annual report on forest condition which informs policy decisions on forest health at a European scale (Anon., 2003a). Further dissemination of the Level I data also occurs through the Statistical Office of the European Communities (EUROSTAT, 2003) and the UNECE (Anon., 2003b).

At a national level, the results of each survey since 1984 have been published annually by the Forestry Commission (e.g. Binns *et al.*, 1985; Hendry *et al.*, 2003) in order to highlight any short-term or long-term changes in the condition of the surveyed species. Short-term changes in crown density, and geographical variations in the condition of the species in particular years, are attributed where appropriate to the action of particular damaging agents (see Box 2 and

Figure 6

Mean differences between the absolute crown density results obtained by the surveyors and the 'standard observer' on a sample of 88 plots in 1999. Differences are represented by bars for each surveyor/species combination tested. Assessor 12 was the 'standard' observer.

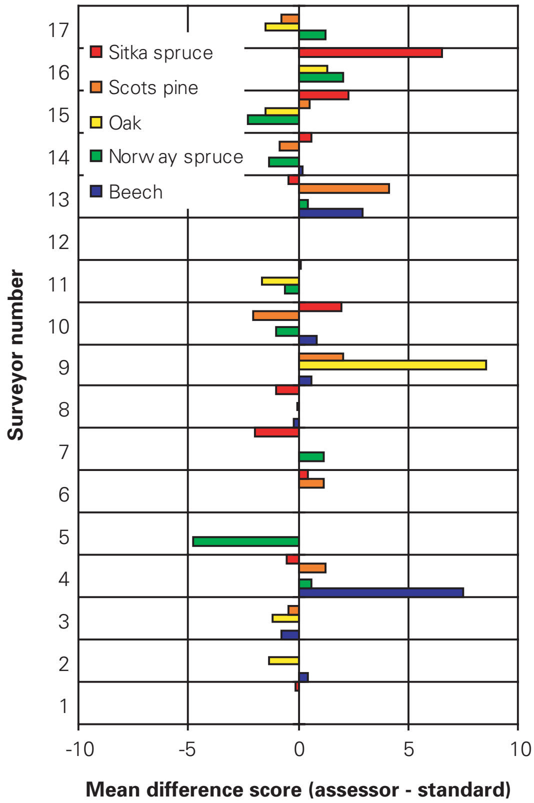


Figure 7

Bud blight of Norway spruce caused by the fungus *Cucurbitaria piceae* leads to death and distortion of shoots and can reduce the crown density of heavily infected tress.

Figure 7). Although statistically significant long-term trends in the crown density of particular species can also be detected, these are difficult to interpret since the time-series is of relatively short duration and the trends can be negated by relatively small changes in tree condition from year to year (Hendry *et al.*, 2002).

Analysis of the FCS dataset to identify correlations between tree condition and other factors has indicated that soil moisture deficit and potential evapotranspiration are significant explanatory variables with respect to changes in crown density for all of the surveyed species. Other indices recorded as part of the Forest Condition Survey which have been found to be strongly correlated with environmental variables include: masting in beech, flowering in Scots pine, shoot death in Scots pine, insect damage in all species except oak, and fungal damage in oak (Mather *et al.*, 1995).

It is important to note that correlations may suggest but do not establish the existence of causal links between variables. Environmental variables in particular display strong correlations with each other and, as a result, a significant relationship between crown condition and any particular environmental factor cannot be interpreted with certainty as demonstrating cause and effect. However, the assessments of tree condition obtained via the Forest Condition

Survey can provide compelling evidence that certain factors are not responsible for changes in tree condition and can indicate those variables which may be influencing long-term trends in forest health and which therefore require further study. In order to establish cause–effect relationships in such cases, a different and more intensive approach to forest monitoring is required. Such an approach is adopted in the EU Level II programme established in 1994 (EC Regulation 1091/94), which consists of a restricted network of plots across Europe, including 20 in Great Britain, at which detailed tree condition and environmental monitoring is conducted (Durrant, 2000). Thus, a complementary system of extensive monitoring via the Forest Condition Survey/Level I network and intensive monitoring via the Level II network ensures that changes in the condition of British forests are both detected and investigated at appropriate scales

Conclusions

The Forest Condition Survey, including its Level I component, provides a national overview of forest health in Great Britain. Focussing on a key selection of forest tree species over a wide geographical range, the survey continues to gather a unique time series of forest health data. This information not only fulfils the UK's international obligations to provide data on forest condition and indicators of sustainable forestry (Anon., 2001) but also supports national forestry policy, the UK Forestry Standard (Anon., 2004) and the UK Woodland Assurance Scheme (Anon., 2000). Whilst originally established to address the potential effects of air pollution on forests, the Forest Condition Survey remains responsive to changing requirements for data on tree health.

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Developments in the integrated management of pine weevil, a pest of restocking in conifer plantations

Hugh Evans, Roger Moore, Stuart Heritage and David Wainhouse

Introduction

Integrated Forest Management (IFM) as a concept parallels the Integrated Crop Management (ICM) approach being adopted increasingly in agriculture. It examines all aspects of the forest crop production system to determine which have most influence on total productivity and survival. Within the overall approach to management of commercial and recreational forests, the direct and indirect effects of existing management practices on the impacts of pests on trees are considered dynamically in order to provide options for longer term management. When pest populations lead to unacceptable damage or tree mortality, the approach adopted by Forest Research scientists is to utilise conventional Integrated Pest Management (IPM) as the core tool to reduce these populations to a level below economic injury level. This concept has been adopted within an IFM programme which initially addressed a wide range of topics and disciplines, including entomology, pathology and silviculture.

Figure 1

Adult pine weevil *Hylobius abietis* feeding on stem bark of conifer transplant.

After further evaluation of the IFM approach, work started on the most important insect pest of British forestry, namely the pine weevil *Hylobius abietis* (Figure 1), as a model system to develop IFM concepts towards a practical working system. As a result, existing projects on this pest were brought together. In developing a fuller understanding of the nature and dynamics of the *Hylobius* problem, it must be acknowledged that it is a man-made problem, which has been exacerbated by the introduction of efficient modern tree felling systems and replanting practices. The former have provided progressively more abundant breeding resources leading to greater *H. abietis* populations and the latter have led to greater damage by providing a preferred food supply for emerging adults within a clearfell area generally lacking in such resources. Conversely, the recognition that management practices are part of the primary cause of the problem also offers the potential to solve it, through changes in future management. Consequently, our approach to the challenge of developing a sustainable IFM system of management to counter the *H. abietis* threat includes the following key elements:

- Understanding and quantifying the links between felling dates and colonisation of the restock site by new populations of *H. abietis*.
- Quantifying the relationships between arrival of *H. abietis* colonising adults and subsequent breeding success and development in stumps, i.e. the net rate of population increase.
- Predicting the emergence periods of *H. abietis* populations on site, based on colonisation patterns relative to felling periods.
- Predicting the end-points of stump exploitation and *H. abietis* emergence to assess the magnitude and duration of risk over the period between felling and final restocking.
- Quantifying the links between *H. abietis* adult populations and damage to transplants to both determine risk and quantify the threshold population size for acceptable damage.
- Quantifying the impacts of insect parasitic nematodes on the survival of *H. abietis* in stumps treated with nematodes. This is the only strategy to directly reduce weevil populations towards the required threshold population size.
- Assessing and predicting the breeding success in stumps of different conifer species on a range of sites to aid the overall risk assessment model by quantifying the role of the previous crop on overall *H. abietis* dynamics on site.
- Assessing and predicting the relative resistance of transplants to *H. abietis* feeding pressure in relation to species, age, addition of fertilisers, etc. This is the final determinant of impact and links dynamically to threshold population size.

We are using acquired data and outputs of predictive models to develop options for management, with particular reference to reductions in the use of chemical insecticides. Currently, the emphasis is on spruce plantations, to reflect the importance of this genus in commercial forestry in Britain. While this places some constraints on the wider use of the particular models being developed, the general principles are also being adapted to upland and, more recently, lowland pine sites.

Key options that are being incorporated in the overall IFM strategy include:

- Use of chemical insecticides:
  - prediction of the need for pre-treatment
  - prediction of the need for top-up sprays.
- Guidance on the length of fallow period for delayed restocking (based on monitoring populations).
- Use of felling date information to predict exploitation and larval development in stumps to target nematode applications for maximum impact.
- Gradual reduction of *H. abietis* populations through use of nematodes in consecutive felling cycles within whole forest blocks. The key will be reduction in the source populations that constitute the pool of weevils for migration to new clearfells in the vicinity.
- Development of a Management Support System (MSS) based on known risk factors and, increasingly, predictive modelling supported by monitoring.

Biology, population dynamics and migration of *Hylobius abietis*

Initial studies on the biology of *H. abietis* have concentrated on quantifying the population dynamics and damage caused by the weevil from the time of clearfelling to 5 years post-fell in upland spruce sites. During this period, timing and amount of colonisation and emergence of *H. abietis* and its movement between mature 'source' clearfells and newly felled 'sink' clearfells have been shown to be critical to prediction of events on a given clearfell site. The aim is to use the data to develop decision support systems for the management of the restocking problem by developing models of *H. abietis* populations and their associated damage and movement between felling areas. The ultimate aim will be to achieve sustainable reductions of *H. abietis* populations towards levels known to lead to acceptable damage as predicted by population dynamics models. These models will be further refined to incorporate data from other projects within the IFM programme.

Results from studies carried out at Ae Forest, Dumfries, Scotland, over the period 1995 to 2002, indicate that there are consistent and predictable patterns of population development and damage following clearfelling and that timing of felling plays a key role in determining the magnitude and timing of the peaks of *H. abietis* density (Moore, 2004; Moore *et al.,* 2004). It has also shown that there is a strong relationship between populations and transplant damage and that the majority of damage occurs during periods of emergence of new generation adults from stumps. For the first time under British conditions, it is now possible to relate transplant damage to the size of *H. abietis* adult populations on site and to link these dynamically to the availability, temporally and spatially, of breeding material. Work is continuing to build predictive models that forecast population trajectories and transplant damage on a site-specific basis (see Management Support System, page 82).

Determining the length of the fallow period

Within the overall MSS concept, a number of 'tools' are being developed to provide managers with choices based on the improved information and predictability arising from the modelling approach. A low cost, low intervention approach is to predict the length of the fallow period which minimises the risk of *Hylobius* damage. This can lead to reductions in chemical treatments through minimising or eliminating the need for top-up sprays after restocking. This topic has been studied by assessing whether the patterns of population development found in Ae Forest (the length of the fallow period and size and dynamics of *H. abietis* populations) were similar to those at a range of sites across northern Britain. The work was carried out on 36 clearfell sites of known age since felling, in eight Forest Districts (FDs), and was also designed to determine our ability to predict damage (to treated and untreated transplants) from one year to the next, by monitoring *H. abietis* in the first year. On all sites, weevil densities and damage to transplants were monitored over a two-year period to determine the relationship between trap catches and damage (within and between years) as well as the length of the fallow period (i.e. the time taken post-fell before damage to transplants reduces to below 10%).

Initial results from the study showed that permethrin ED treated plants were well protected from damage on all sites in the first year after planting except on sites where the first emergence of *H. abietis* was occurring. The permethrin ED treated plants were not re-treated in the second year of the study and were badly damaged in that year, indicating little residual protection of the trees. This was the case for all sites except those that were aged from 4 to 5 or 5 to 6 years post-clearfell during the course of the work. In these cases little additional damage occurred, but this was as a result of general reductions in weevil populations associated with time since clearfell rather than continued insecticide protection. Damage to untreated trees was very high in sites of age 0, 1 and 2 (these being the year of colonisation, first and second emergence, respectively), intermediate on age 3 sites, but much lower and acceptable on sites of age 4 and 5. Damage levels varied in direct relation to catches of *H. abietis* at conifer billets and highly significant relationships were found between these variables 'within year'.

Models showed that it was possible to use billet captures in one year to predict damage in the following year ('between year' forecast). Precise knowledge of clearfell age significantly improved the ability to forecast from one year to the next. The highest *H. abietis* catches and damage occurred during late season (August/October) for the younger sites but during the early season (May/July) for older sites. These results were all consistent with those obtained in Ae Forest for the more detailed population dynamics work. It is likely that these models could be further improved by taking other site factors into account and this information is currently being collected. The data were analysed further and it was found to be possible to reduce the number of censuses and billets used to predict damage. This has made it possible to reduce monitoring costs for the *H. abietis* MSS.

Development and testing of a Management Support System for restocking conifer forests

The success of the population dynamics work and the forest-scale trials described has led to the development of a new 'Management Support System' (MSS). The MSS is currently being co-ordinated within this programme and trialled, through Technical Support Unit, in Kielder, Dornoch and Coed y Gororau FDs (one FD in each of the three countries) from 2003 onwards. The *H. abietis* population dynamics project and forest trials have enabled the development of models that can be used to predict population dynamics trajectories and subsequent damage following the pre-emptive collection of minimal site-specific data (Figure 2). These models will be used to predict the likely success (or otherwise) of using the various management options (shown in green in Figure 2) and to provide advice to FD staff on the *H. abietis* threat to transplants in different years following the completion of felling operations.

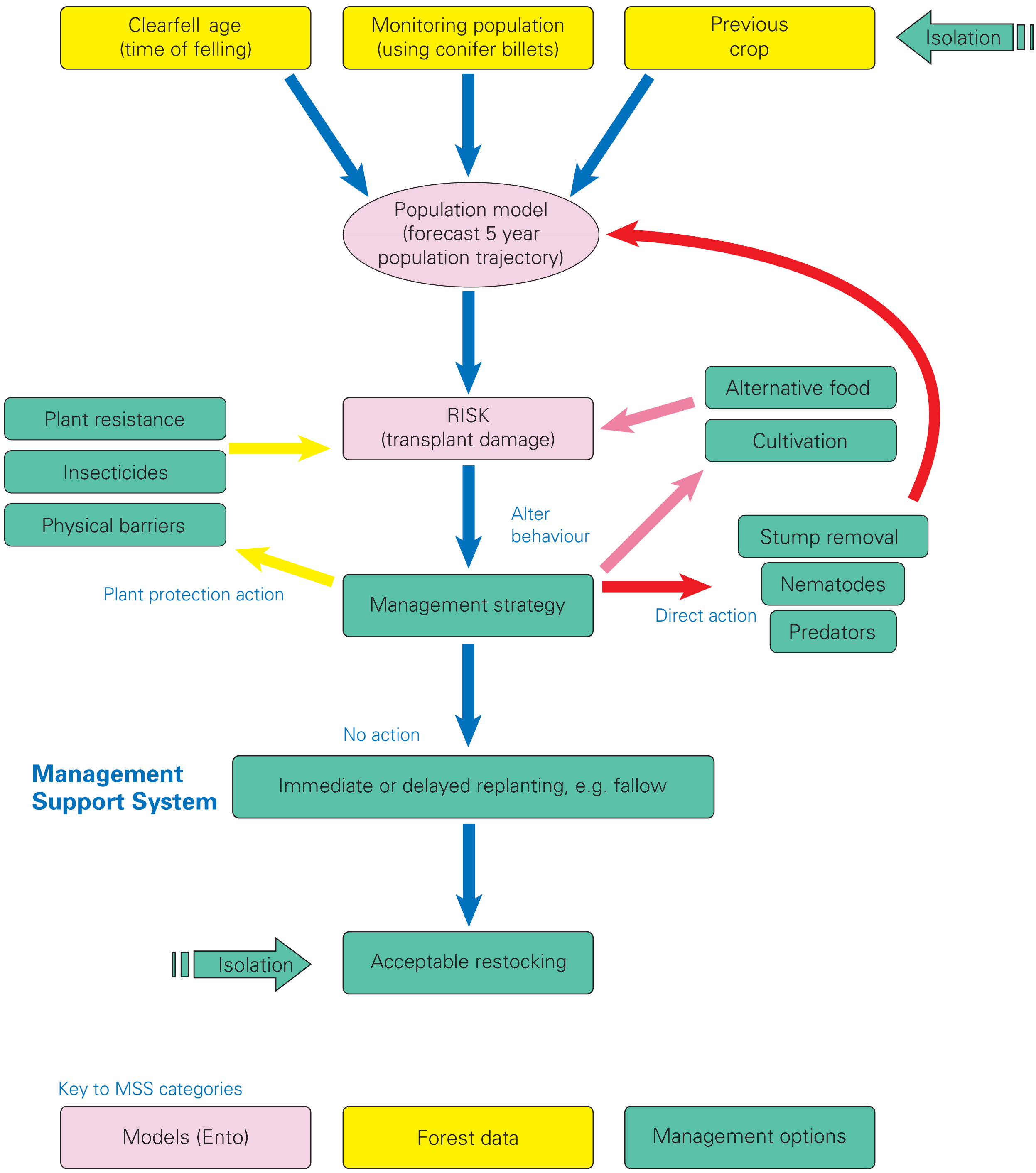
Protocols have now been developed for the site evaluation, data collection and temporal management of clearfell sites entering the MSS programme and initial *H. abietis* population monitoring started during two periods in the spring and autumn of 2003. The monitoring indicated that populations on individual clearfells were considerably different at these two times of year. However, when the 'independent' population data from these two time periods were analysed using the population model there was a very close agreement in damage levels forecast for subsequent years. The advice for each individual clearfell in the MSS will be presented to FDs during late 2003 for take up in 2004. At the end of 2004, the MSS recommendations made during 2003 will be evaluated by examining the variation in 2003 'predicted' and 2004 'observed' levels of tree damage.

Plant resistance as a factor in determining weevil population size and damage to transplants

The project on plant resistance has the aim of reducing susceptibility of plants to weevil attack and of increasing their survival after attack. Success will depend on understanding the nature of defensive mechanisms in young trees, the relative importance of genetic and environmental factors in resistance expression and the significance of feeding in the reproductive behaviour of adult weevils. A study is also being made of the effect of root-stump 'quality' on weevil survival and development rate and how this interacts with the silvicultural management of the forest. Results will have a direct bearing on the survival and breeding success of pine weevil and so this part of the project is closely integrated with the other main components of the IPM programme – population dynamics, control of larvae with nematodes and the MSS. Methods of monitoring pine weevil populations that are specific to lowland forestry are also being developed.

Figure 2

Developing a model to predict population dynamics trajectories and subsequent damage to conifer transplants.

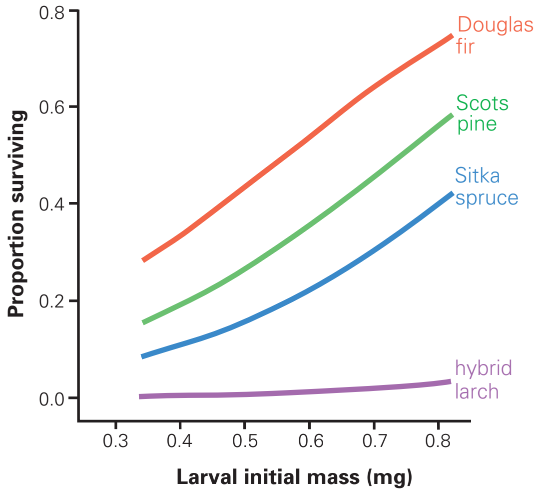


The influence of the breeding resource on *H. abietis* reproductive success

Emphasis on the quantitative aspects of root-stump availability as a determinant of weevil population size has tended to obscure possible qualitative variation, both within and between tree species, in their 'suitability' for larval development. In living trees, both preformed and induced defences are highly effective in preventing colonisation of conifer bark by bark beetles and weevils. In the intact root-stump left in the ground after felling, preformed defences and even induced responses could remain partially effective and reduce establishment success of pine weevil larvae for a period after felling.

Figure 3

Predicted survival of pine weevil larvae inoculated onto logs of four different conifer species.



We found significant variation in larval survival on different conifer species (Figure 3). In addition, 'maternal effects' determine egg size and therefore the size of larvae that attempt to establish galleries in the bark of different species. Larger larvae are more successful than smaller ones in establishing in 'fresh' bark (Figure 3; Wainhouse *et al.*, 2001) providing indirect evidence for the importance of 'residual' resistance mechanisms within the bark of roots and stumps after felling. Resin appeared to be an important cause of larval mortality in pine, whereas in Sitka spruce, physical defence in the form of lignified stone-cell masses reduced the growth rate of larvae and probably also affected establishment success. We predict that the number of weevils emerging from clearfell sites will be determined both by the quantity and 'quality' of root-stumps available and this information could be of value in developing and interpreting monitoring methods within a MSS.

Maturation feeding of adult *H. abietis* and damage to transplants

Adult female weevils emerge from root-stumps with undeveloped ovaries in which eggs develop only after a period of maturation feeding. In natural forest systems, these weevils will feed opportunistically on local food sources, especially the bark of branches and twigs within the crowns of mature conifers. At clearfell sites, initial feeding is likely to be on the bark of transplants although weevils also feed on the bark of logs and brash left at the site after felling operations as well as on standing trees in the vicinity. Adult weevils are large relative to transplants and because they feed on the bark of the main stem, relatively small amounts of damage can be lethal. As a result, significant damage to transplants is likely even at relatively low weevil population densities. Mass-produced conifer transplants (Figure 4) are, in general, highly susceptible to weevil attack and often require insecticidal treatment to ensure successful establishment. In addition, the use of highly susceptible plants makes the relationship between weevil population size and damage to transplants sensitive to relatively small changes in weevil abundance. This must be taken into account when using monitoring to predict potential damage to young transplants based on population size.

The aim of this part of the study has been to determine what factors influence the amount of feeding on transplants. To be of practical value,

Figure 4

Intensive production of young conifers in a forest nursery.

resistance in young conifers would need to be expressed through a reduction in the amount of feeding or an increase in the ability of the plants to tolerate and recover from a given level of feeding damage.

We have studied aspects of plant resistance by measuring weevil food consumption and rate of reproductive development when feeding on bark with differing nutritional and defensive characteristics. In order to understand the underlying processes, we have manipulated the growing conditions of young conifers to produce a range of phenotypes and, by analysing the main factors influencing the amount and distribution of feeding, identified likely resistance mechanisms (Wainhouse *et al*., 2005, in press).

The amount of feeding on young conifers was influenced by a wide range of factors including the sex and size of weevils, stem diameter and the nutritional and secondary chemical content of the bark. One of the most important factors influencing the pattern of feeding on three seedling conifers (Corsican and Scots pine and Sitka spruce) was the inherent variation in the size of resin ducts in the bark of the main stem. The flow of resin from ducts severed during feeding appears to provide the main defence against pine weevil. Factors that influence the size of resin ducts during plant development and the amount of resin produced are currently under investigation.

Direct intervention through reduction in *H. abietis* populations by application of insect parasitic nematodes

Building on several years' experimentation and field tests of the potential efficacy of entomopathogenic nematodes (EPNs) for biological control of *H. abietis* (Brixey, 1997), a programme of extended field trials and semi-operational use of nematodes commenced in 1999. Acknowledging that commercially available nematodes were significantly too expensive for operational use in forestry, a nematode production facility was constructed at Alice Holt during 1999, initially in collaboration with CABI Biosciences at Egham. Production was based primarily on techniques for the small-scale, low-technology production of nematodes developed by Australian scientists over the past few years. During this early phase of our work, a business model was prepared, demonstrating that nematodes may be produced at a cost considerably lower than those produced using commercial fermentation systems. During 2003, Forest Research embarked on development of its own variant of the Australian-based production technique.

One of the key constraints to such techniques has been separation of the nematodes from the sponge medium during harvesting. To address this we have collaborated with BHR Group, Cranfield, in the design and production of a prototype separation system to remove nematodes from diet. This uses cyclone technology to separate the nematodes and is fully automated, offering the potential for considerable cost savings compared with conventional zonal centrifugation. Despite these encouraging developments in nematode production in-house, we are keeping our options open and have developed an excellent working relationship with Becker Underwood, the principal producer of nematodes in the UK and have used their nematodes for field trials in 2002 and 2003.

Field trials have been carried out over the past four years in order to provide baseline data on population reductions following direct application of nematodes to late larval/pupal populations in stumps. For optimum impact on the *H. abietis* populations, the nematodes must be applied to individual stumps in relatively high quantities of water at the correct stage of weevil development. Techniques and equipment have been developed to handle and apply the EPNs and use of a purpose built spray rig allows nematodes to be applied at costs per hectare competitive with the costs of treatment with insecticides. In addition, EPNs also offer the prospect of considerable cost savings over the longer term as the accumulated impacts of consecutive nematode applications become apparent on a forest-wide scale.

Over 100 ha were treated with EPNs during 2003. The development of new equipment allowed significant increases in the efficiency of application enabling the team to treat up to 10 ha per day. Results indicate that the application of nematodes not only reduced the emerging population of weevils in the few weeks after treatment, but surviving nematodes have a significant impact on late developing weevils the following year. Combined with previous results in both small and medium scale trials (up to 85 ha), we are increasingly confident that EPNs will be a key tool in reducing populations of *Hylobius* towards the levels predicted to be economically acceptable in our IFM programme.

An improved business plan for the use of nematodes in the management of restocking areas has been developed together with a number of information leaflets, CDs and fact-sheets to support forest managers in their adoption of this system.

The next phase of the work is to model the within-year effects of population reduction within the overall MSS system and to assess how this affects the size of the incoming weevil population to 'sink' clearfells at different distances from the treated sites. An important element of using EPNs is to consider their impacts over the longer term and on a forest-wide scale so that the efficacy can be measured based on how well the treatment reduces migrant populations to new 'sinks'.

Conclusions

Taken together, the various elements of our work on sustainable management of *H. abietis* are now being integrated within the IFM approach so that, through monitoring and prediction, forest managers will be able to select options specific to local circumstances. Some of the tools will be low cost, but subject to temporal constraints, whereas others, such as use of nematodes to reduce pest populations and selection of transplants with improved ability to withstand attack, will directly affect overall damage levels. The current emphasis is on upland spruce areas but there is also encouraging progress on lowland pine sites indicating that the overall IFM concept is robust and likely to improve as our experience of the approach increases.

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Practical measures to encourage the use of woodfuel

Andy Hall and Bill Jones

Introduction

Woodfuel is not new, having been used as a source of heat for thousands of years. It is however going through a renaissance and is seen, in part, as a replacement for fossil fuels, both for use in heating and electricity generation and for its ability to reduce greenhouse gases and other emissions. The use of renewable resources is now stated Government policy and renewables are increasingly being considered as alternative energy sources by both the domestic and industrial markets.

It is Forestry Commission policy to help support the management of neglected or undermanaged woodland but the current low prices obtained for small roundwood, particularly arising from first and second thinning operations, often call into question the economic viability of harvesting. Consequently there is a tendency for some owners to avoid or delay thinning; this in turn can have a detrimental effect on the development of a more diverse woodland structure and a negative affect on the newly developing energy market. Harvesting for the production of woodfuel may make a thinning operation economically viable thus promoting active management of some small woodlands.

The industry in the UK

The United Kingdom (UK) forest industry is currently being swamped with requests for information and support from a new and exciting market about which practising foresters know very little. This lack of knowledge is understandable, as abundant supplies of fossil fuels have been available in the UK over the past two centuries. Although there has been a low level of woodfuel production, particularly logs, there is little established expertise with regard to new products, higher volume production and efficient, reliable supply chains. In order to avoid a barrier to future opportunities, we have to improve our knowledge of woodfuel production particularly in the areas of supply and storage.

The fledgling woodfuel industry in the UK is developing along two very distinct lines: the burning technology and the fuel supply chain. From the technology point of view there are optimum engineering solutions and these often take little account of what may be achievable in a practical sense when it comes to the supply chain (moisture content of wood, particle size and drying and storage). Although information is available on woodfuel harvesting and burner systems, there has been little effort on behalf of the producers/suppliers or the boiler/burner manufacturers to understand each other's requirements and both groups seem to have developed in parallel, with little or no technical integration. This lack of co-ordination between the two industry sectors has been responsible for the failure of installed schemes in some instances.

Identifying industry needs

Against this background Technical Development developed a strategy two years ago to direct and support future operational research into woodfuel production and supply. The strategy identified 13 areas of particular interest:

- Supply chain development
- Small-scale harvesting systems
- Short rotation forestry (SRF)
- Short rotation coppice (SRC)
- Residue harvesting
- Chipper/shredder/chunker technology review
- Transport
- Drying/storage
- Woodfuel standards
- Measurement systems
- Technology transfer (including the provision of advice)
- Calorific values
- Wood ash/waste ash.

The work recently undertaken by Technical Development has covered many of these areas.

Harvesting

Small-scale systems for harvesting woodfuel products from woodlands

The thousands of hectares of small woodlands in Great Britain are a potential source of woodfuel for local heating, but problems arise in identifying suitable and efficient harvesting systems see (Figure 1). The output from this work will be a Technical Note (2005, in press) which provides guidance on the selection of systems appropriate for small-scale harvesting operations. It considers four essential factors that influence the overall selection:

1. Woodland type, tree species and the woodfuel products present.
2. Site and management constraints affecting choice of harvesting system.
3. Options for harvesting system.
4. Specific machinery options.

The guidance is based on a comprehensive series of case studies, and provides outputs, costs and system descriptions for the sites studied, and recommendeds appropriate systems of work. A summary of the woodfuel production costs for the crop types studied and a comparative summary of harvesting options are also provided.

Key findings

The success and financial viability of any harvesting operation depends on the site, access and distance to roadside, methods used and the scale of the operation. Extraction machinery in particular will be a key influencing factor. Some systems may be inappropriate for small woods.

Costs vary widely according to the harvesting system used and are subject to the many factors already discussed. However, in simple terms, costs of extraction in thinning are higher than in clearfelling, with basic costs increasing between £1.00 and £2.00 per cubic metre (m^3) of wood for every additional 100 metres of extraction distance. Current indicative costs for extraction is shown in Box 1.

Large scale mechanised harvesting in a broadleaf crop.

Box 1

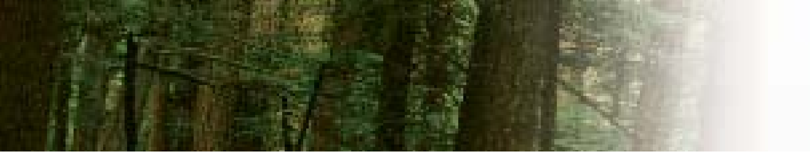
Current cost for extraction in thinning on different terrain types. The wide range of costs for each ground type is due to the combined impact of factors including terrain, crop type, and volumes per hectare, machine size and distance travelled.

Steep ground	Cable-crane systems: range £10–£25 per m^3
Moderate ground	Skidder (for example Ford County type): range £5–£12 per m^3
	Portable winch (short distance only): range £3–£6 per m^3
	Forwarder: range £3–£15 per m^3
Easy/flat ground	Forwarding systems (medium/large): range £3–£12 per m^3
	Skidder (for example Ford County type): range £5–£12 per m^3
	All terrain cycle equipment: range £13–£17 per m^3
	Small scale forwarder (mini): range £4–£15 per m^3

Comments applicable to all crop types

In broad terms the findings from the case studies are as follows:

- Forwarding tends to be more cost effective than skidding, which is considered to be inefficient for longer extraction distances, i.e. greater than 250 m.
- Where difficult sites require maximum man-oeuvrability and flotation, mini-forwarders should be considered for distances up to 250 m.
- Forwarding using the appropriate machine generally causes less ground disturbance on drier sites than skidders and terrain chippers, with small-scale forwarders causing significantly less site disturbance.
- Skyline operations tend to be the most expensive option, their use being dictated by site and set-up time constraints.
- System machine choice must take account of:
  - machine availability
  - machine flexibility
  - differing machine/labour costs within and between areas
  - site conditions.
- Unit costs vary according to the cost factors charged to the primary and or secondary operations, that is, if the primary operation is to fell, extract and convert, irrespective of fuelwood production, then the costs associated with those operational factors will already be incurred. Where this is the case, secondary operations such as fuelwood harvesting should be costed as such.
- In general terms harvesting costs increase when:
  - slopes increase
  - uphill extraction is used
  - lower volume and product densities are harvested
  - smaller product volumes or sizes are harvested
  - poor tree and product forms are worked and produced
  - access is poor or difficult
  - extraction is over longer distances.



Early broadleaved thinnings

- Lower volume returns, coupled with higher unit costs, make them the least profitable option.
- Pole length working is generally the cheapest system.
- On easy terrain a farm tractor-based forwarder is likely to be as cost effective as a larger purpose-built unit, for shorter extraction distance, i.e. up to 250 m.

Mixed broadleaved coppice

- Harvesting costs for machine/system combinations on each site were similar and choice is likely to be influenced by other factors such as availability, capital cost and site / environmental constraints.

Crownwood, scrub and residues

- Precommercial thinnings are often felled and left on site, however, there may be some cost benefit in utilising material as woodfuel.
- Crown wood can be a cost-effective fuel resource although the correct harvesting system needs to be adopted, that is, skidding, forwarding (to stump or roadside) or terrain chipping, subject to the correct machine choice.
- The only case study of terrain chipping showed it to be expensive and not cost effective. However the major factor influencing this was inappropriate machine choice, and the study demonstrated that there was significant room for improving outputs by using a suitable machine. Further research is required in this area.

Technology for burning woodfuel

Investigating methods for achieving woodfuel specifications

The aim of the new Technical Note (2004, in press) is to provide clear advice on the factors affecting quality when producing logwood or woodchip as fuel. It aims to clearly define the required fuel specification for the different generic types of wood burning appliances currently available in the UK.

Currently a wide range of woodfuel burning appliances is available. These vary from small domestic units suitable for installation in homes and other small properties (2–30 kW output range), medium sized units for community and business use (11–500 kW) and large industrial units capable of providing heat and energy for small factories or a cluster of small businesses (Figure 2).

Those interested in using woodfuel for heating and electricity generation need to consider and select the most appropriate wood burning appliances and, equally important, the supply of woodfuel. The need to ensure that it is the correct type and quality for optimum boiler/ burner efficiency cannot be overstressed.

The relationship between burner technology and fuel specification has been identified as one of the major areas requiring further investigation. The essential considerations in terms of burner requirements and achievable fuel specifications will be outlined in a new FC Technical Note due for publication in 2006.

Wood harvested and seasoned to a desired standard can be burnt efficiently. It is a safe, efficient and renewable fuel that can be economically competitive with some fossil fuels. (Currently in the UK mains gas is the most competitive and may be cheaper than woodfuel.) To help development in the industry a European-wide standard has been developed to describe the various types of woodfuel. Tables 1–3 show a synopsis of the Central European Norm draft standard CEN 335 Standardisation of Solid Biofuels.

Figure 2

Various types and scales of burning appliance.
(a) Domestic space heater, fuelled by wood pellets.
(b) Commercial scale wood chip fuelled boiler.
(c) Combined heat and power gasifier unit in Gussing, Austria.

Woodfuel is an internationally traded commodity, particularly within the European Union. In addition to producing a woodfuel that is consistent in quality it is important that the most efficient methods of processing, handling and transportation are used. The energy supply market remains very competitive and failure to produce and supply high quality woodfuel for energy production at an acceptable cost can result in prospective users considering alternative energy sources, thus weakening the development of a woodfuel market in the UK.

A major factor restricting the development of international trade in woodfuel is the absence of a common standard between countries. The European Union (EU) is currently preparing a European Standard (CEN/TC 335) for the various types of biofuels, which includes woodfuel in various forms. It is due to be released in mid 2005 and will be the accepted standard throughout Europe. The current draft can be viewed on the CEN web site, www.cenorm.be

Technical Development have looked at the factors that affect woodfuel quality and link woodfuel specifications to the range of wood burning appliances currently available in the UK. This concentrates on two types of woodfuel: log wood (firewood) and wood chips, both of which can be produced in the forest; however there is growing interest in wood pellet production as fuel for domestic appliances and as a replacement for fossil fuel in some larger sized boilers and burners.It was therefore considered appropriate to include the boiler/burner types suitable for wood pellets.

Wood chips and hog fuel: an example

High quality wood chips recommended for household usage should be sourced from stem wood with the following specification:

- Moisture content < 20 or < 30 %
- Dimensions P16, P45 or P63 (see Table 2)
- Energy density E 0.9 (net calorific value > 900 kWh/bulk m^3).

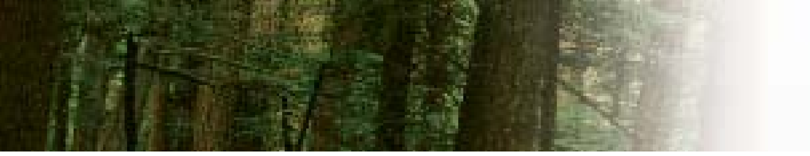


Table 1

Classification of origin and sources of woody biomass.

Wood origin	Wood source
Forest and plantation wood	Whole trees Stemwood Logging residues Stumps Bark (from forestry operations) Landscape management woody biomass
Wood processing industry by-products and residues	Chemically untreated wood residues Chemically treated wood residues Fibrous waste from the pulp and paper industry
Used wood	Chemically untreated wood Chemically treated wood
Blends and mixtures	Combination of any of the above

Particle size for wood chips and hog fuel.

Type of woodfuel	Main fraction (> 80%)	Fine fraction (<5%)	Coarse fraction, max. particle length (< 1%)
P16: Wood chips	3.15 ≤ particle ≥ 16 mm	< 1 mm	> 45 mm, all < 85 mm
P45: Wood chips and hog fuel	3.15 ≤ particle ≥ 45 mm	< 1 mm	> 63 mm
P65: Wood chips and hog fuel	3.15 ≤ particle ≥ 63 mm	< 1 mm	> 100 mm
P100: Hog fuel	3.15 ≤ particle ≥ 100 mm	< 1 mm	> 300 mm
P300: Hog fuel	3.15 ≤ particle ≥ 300 mm	< 1 mm	> 400 mm

P: equates to particle size in the chip and log size categories.

Dimensions for wood logs.

Wood logs	Diameter (D) and length (L)
P200	L < 200 mm and D < 20 mm ignition wood
P200	L = 200 ± 20 mm and 40 ≤ D ≥ 150 mm
P250	L = 250 ± 20 mm and 40 ≤ D ≥ 150 mm
P330	L = 330 ± 20 mm and 40 ≤ D ≥ 160 mm
P500	L = 500 ± 40 mm and 60 ≤ D ≥ 250 mm
P1000	L = 1000 ± 50 mm and 60 ≤ D ≥ 350 mm

P: equates to particle size in the chip and log size categories.

Key findings

The correct choice of raw material, harvesting system, comminution or processing machinery, storage, transport and burner will promote the continued development of a sustainable woodfuel market.

To achieve high quality woodfuel from green timber, moisture content (MC) should be reduced to 20-30 % (wet basis). This improves the calorific and monetary value; in addition the cost of handling and transporting is also reduced. It is important for both the producers and users of woodfuel that a consistent size and quality of woodfuel is achieved.

Transport

The essential features of fossil fuels are that they are readily available commodities and their supply is centralised and mostly in large units. The urban concentration of population in the UK offers scale economies in the supply and marketing of energy derived from fossil fuels, which gives a considerable economic advantage to the users of such forms of energy. This concentration is further encouraged by the transport costs factor, which can provide a marked constraint in the case of alternative energy sources. This contrasts sharply with many areas of widely dispersed woodland, far from developed markets, yielding a low-density, widely dispersed woodfuel resource, the production of which is in its early stages in the UK and almost entirely derived from relatively small-scale production.

In any woodfuel production chain the main cost factors are production (growing, some crops are specifically grown for energy), harvesting, comminution and transport. As production in the UK increases the need to transport material over longer distances is set to increase.

Transport of woodfuel products: development of guidance as a planning aid

This interim phase scoping project looks at the essential aspects influencing woodfuel transport in the UK, namely social influences, resource type, production systems, technology, transport logistics' distribution (physical distribution), woodfuel collection and storage, transport costs, overall energy balance considerations, current research (projects/case studies) and ongoing work.

Research can be marked according to tractability and timeliness as follows:

- Transport costs: fixed and variable costs associated with haulage
- Woodfuel collection and storage: the various methods available in relation to product type
- Distribution: new or existing networks
- Technology: machinery, equipment and computerisation of control systems
- Production system: in terms of standing tree to end use
- Resource type: e.g. virgin fibre, residue
- Infrastructure: the overall system in place to support production, distribution and use
- Social and political influences: political and fiscal considerations
- Transport logistics related to technology
- Overall energy balance considerations, i.e. does more energy go into producing woodfuel than it yields when burnt?

Our scoping studies indicate that joint research between FR, the Timber Transport Forum (TTF) and regional transport groups will be useful.

Drying

Small roundwood drying trials

Moisture content is critical in determining the value and combustion quality of wood. Consequently, there is a need to investigate the potential for in-wood drying, particularly of roundwood material. As part of an initial study into the subject of air-drying, a series of trials will be carried out in north Scotland. One specification of stacking and drying will be tested at two sites. The effects of all variables (e.g. local weather conditions, species, product variables) will be on a case study basis only. Considerably more trails and data would be required to develop accurate forecasts of drying regimes and definitive guidance of methods.

The project objectives include the development of methods to dry short rotation woodland material, and ways of controlling moisture content and the establishment of guidelines for stock management. The trials were laid down in April/May 2004; work is ongoing and there will be a series of data gathering exercises over the next eighteen months.

Technology transfer

Outdoor workshops, feasibility and case studies

As part of Technical Development's outreach commitment we have undertaken three outdoor workshops in the past year. One was specific to woodfuel production and marketing (Lake Vyrnwy, Powys, October 2003) and the other two (Woodland Enterprise centre, Flimwell, East Sussex, October 2003 and Cefn Llwyni Woods, Lanfyllin, Powys, February 2004) related to the management of ancient/small woodlands; both contained components relating to woodfuel. All three events were very well attended and received and we will continue to build on this success.

As part of our ongoing support service we have also undertaken a number of feasibility studies, which aim to help individuals through the initial consideration and selection process of installing a woodfuel burning system. Feasibility studies and case studies have been undertaken at:

- Capernwray Hall, Lancashire for Lancashire Rural Futures (local RDA)
- Forestry Commission Offices, Huntly, Aberdeenshire
- English Nature Area Offices, Wye, near Ashford, Kent
- The West Dean Case Study: an update of the main technical issues.

The West Dean woodfuel heating system has been in operation for the past 23 years and during this time has met all of the requirements placed on it. One of the greatest attributes has been the ability of the whole management team to work together successfully to develop and maintain the system. Additionally, a competently designed and installed woodfuel heating system and a readily available supply of woodfuel has provided an excellent foundation for success, as well as initial good planning by the estate to place the responsibilities for managing system specification and installation into the hands of a well-known UK engineering organisation.

Woodfuel information pack

In an attempt to address the wider information needs of the industry, Forest Research has produced an easy-to-use information pack (Hall *et al.*, 2004). This collection of fact sheets is a good starting point for all those who need to know more about converting wood into energy. It brings together key basic information about the many aspects of using wood for fuel, grouped into four themes: background information, biomass sources, biomass conversion, biomass user. New fact sheets can be added: additional topics are already in preparation.

The future

Technical Development will continue its work on woodfuel, as there is a need for clear, unambiguous information on all aspects of its production and use. The woodfuel industry in the UK is on a cusp. It is ready for considerable expansion, in terms of becoming commonplace alongside other types of energy provision, or it could completely fail to enthuse both industry and the public in general. In order to promote the former more research and support is required into the provision of reliable information, production streams and infrastructure development.

To that end, work for the coming year will include further workshops concentrating on woodfuel production, more feasibility studies and case studies, highlighting in particular good practice, and, as mentioned, additions to the Woodfuel information pack. Also planned is a series of chipper trials aimed at:

- Identifying suitable and readily available chippers
- Defining outputs and costs for the machines/methods/furnish trialled
- Defining optimum equipment settings.

References and further reading

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Recent advances in the mechanistic modelling of forest stands and catchments

Sam Evans, Tim Randle, Paul Henshall, Catia Arcangeli, Jennifer Pellenq[1], Sebastien Lafont[1] and Chris Vials

Introduction

Mechanistic approaches describing the complex processes that underpin forest system dynamics are increasingly required in order to manage forests from a multi-purpose perspective. When describing future forest dynamics the environmental implications of climate change on long-lived organisms such as trees also focus attention on the need to adopt a holistic perspective. In turn, any future perspective has to account for the interacting dynamics of the wider processes resulting from environmental, ecological and land-use change. Therefore considerable understanding of the biological, biophysical and physical processes influencing the life cycle of trees and the forest ecosystem is required to achieve full representation of the system and its dynamics.

[1]See Acknowledgments, page 110.

Modelling is increasingly used to complement and integrate the hypothetico-deductive approach to experimentation, as a means of encapsulating the current, mechanistic knowledge base on process dynamics. The large knowledge base on biophysical processes, coupled with the increased availability of detailed data availability for both parameterisation and validation, allows such an approach to be used and provides the basis for extrapolating beyond the range of observation.

In forests, growth dynamics are determined by the interactions between species and ecosystems with the terrestrial water, carbon and nitrogen cycles. Such interactions are modified by management, which in recent years has become more complex following the UK's adoption of multi-purpose forestry practice and the rural agenda (European Union, 1998, 1999; United Nations, 1992,1997). For example, management strategies now include methods for dealing with issues such as biodiversity, carbon sequestration and pollution uptake. Increasingly a landscape perspective is being adopted that requires integration of our understanding on forest systems with other land uses.

Given the complexity of options now facing the forest industry and land-use planners, forecasting systems that support decision-making are required at the research and operational levels. Such systems must accurately:

- describe the interactions between the forestry land use component and the terrestrial water, carbon and nitrogen cycles, as a function of soils, climate, species and management practice
- account for the forecasted impacts of climate change on growth conditions as they affect the environment at a range of spatial and temporal scales.

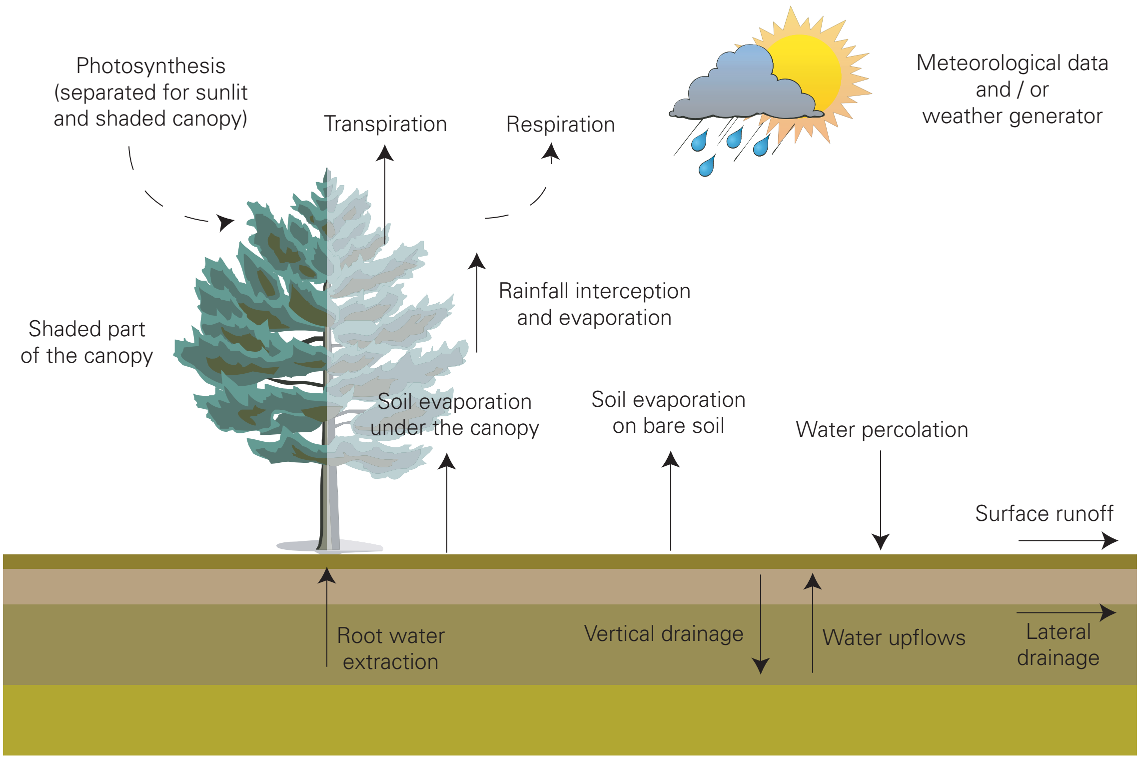
Over the past 5 years Forest Research has undertaken a major research programme that has developed mechanistic models describing forest stand growth dynamics. This programme complements ongoing work to characterise stand dynamics using an empirical approach. The observational approach relies on Forest Research's extensive and long-term tree growth monitoring network to propose the growth and yield curves widely adopted in British forestry. This article describes the initial outcomes of the mechanistic modelling programme, using a selection of results achieved to date.

The ForestETp model

ForestETp is a fully coupled, point scale and daily timestep soil–vegetation–atmosphere transfer (SVAT) model, which predicts vertical and lateral water movement through the soil–plant–atmosphere continuum and gross primary productivity (GPP). The model simulates relevant terrestrial hydrology processes (rainfall interception, vertical and lateral soil water movement, runoff, soil and canopy evaporation, and photosynthesis-coupled transpiration) for a forest stand of known structure, growing in locally determined soil and climate. Particular attention has been given to the parameterisation, kept as simple as possible and reliant on widely available relevant data. As an alternative to observational meteorological daily data, the model is coupled with a weather generator that generates daily time series from monthly summary data. The model structure is illustrated in Figure 1 and detailed in the following sections.

Figure 1

Schematic representation of water (solid lines) and carbon cycle (broken lines) processes simulated by ForestETp.



The climate module

ForestETp can accept either daily meteorological data or monthly mean climatic values. If daily values of air temperature, air pressure, wind speed, global solar radiation, air humidity and rainfall are available, the model uses these data as inputs. If total net radiation is not available, it is estimated using the weather generator, otherwise, the measured value is used. Solar radiation is also split into direct and diffuse radiation as explained later. Where only monthly input values are available, the model uses a stochastic-deterministic site-scale weather generator to downscale the monthly timestep input data to the daily scales and generates the other meteorological fields. Figure 2 shows the model structure.

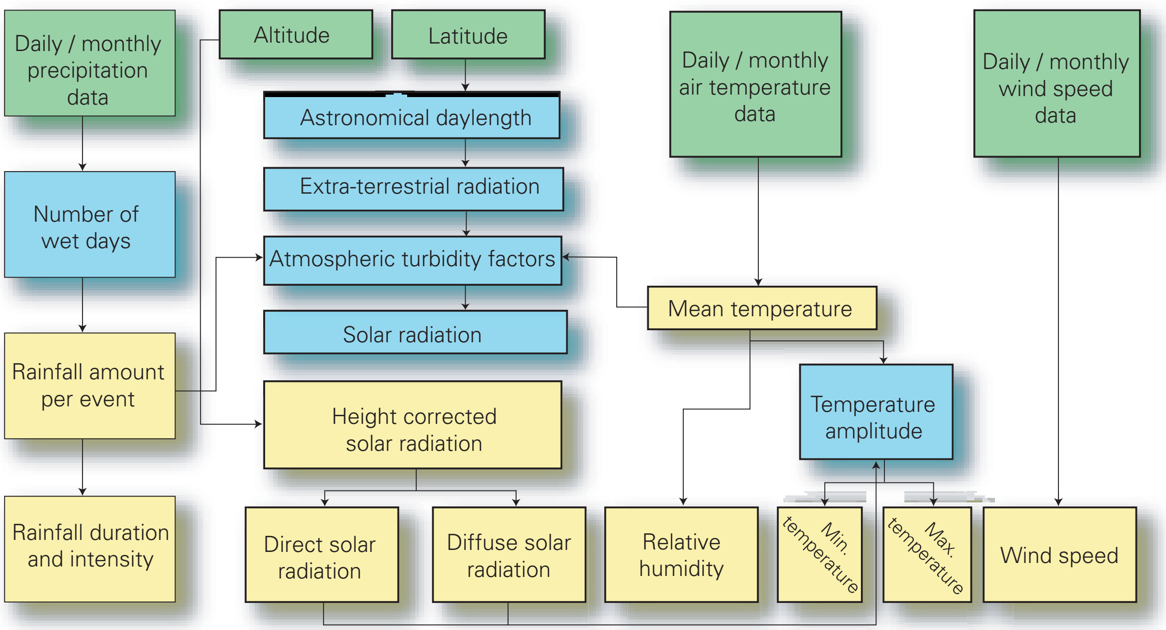
The canopy radiative transfer module

This module considers the heterogeneity of radiation in the canopy, as the necessary precursor to approximating the non-linear response of photosynthesis to irradiance. The model employs a radiative transfer scheme that approximates the transmittance, reflectance and absorption of long wave, near infrared and direct and diffuse photosynthetically active radiation (PAR) by canopy layers, where canopy interactions are determined by the area and distribution of foliage. After Norman (1980) and De Pury and Farquhar (1997) the module separates penetration of direct and diffuse radiation (net of albedo) through a canopy in which two classes of leaves (sunlit and shaded) are distributed in a multi-layer canopy model. This approach allows the explicit description of within-canopy profiles (on a per layer basis) of both environmental (e.g. wind profile, vapour pressure deficit) and physiological (e.g. leaf temperature) variables in response to radiation attenuation. It does so through a canopy with uniform leaf distribution (spherical in the first instance; Russell *et al.*, 1989) as prescribed by Beer's law (Monsei and Saeki, 1953) for each leaf class. The model does not allow for foliage clumping. By dynamically calculating the leaf areas of sunlit and shaded leaves, and their mean irradiance, mean layer assimilation, transpiration and conductance rates are obtained, adjusted for the photosynthetic capacity of each leaf class. Through integration, data are upscaled to approximate total canopy photosynthesis and gas exchange. In each layer, sunlit leaves are assumed to receive both direct and diffuse radiation from the macroclimate model; shaded leaves receive diffuse light only, assuming no radiative energy transmittance through leaves. The within-canopy profiles of leaf nitrogen follows the predicted distribution of absorbed irradiance through each canopy layer, separately for sunlit and shaded leaves and assuming a uniform leaf angle distribution (spherical). Seasonal variation of nitrogen content in foliage can also be represented with suitable input. Given the separate descriptions of sun and shade leaves and within-canopy variation of photosynthesis, the module allows non-uniform vertical profiles of photosynthetic capacity to be developed.

The gas exchange and carbon productivity module

Within each canopy layer, and to account for the changing light environment, the gas exchange and carbon productivity module operates at the leaf level. The well-tested theoretical representation of C_3 photosynthesis developed by Farquhar *et al.* (1980) and von Caemmerer and Farquhar (1981) has been widely used and tested across a range of species and that describes the regulation of ribulose 1,5-biphosphate carboxylase and electron transport in the leaf. This has been combined with additions from Long (1991), McMurtrie and Wang (1993) and Friend (1995), with further adaptation. In turn the modified C_3 photosynthesis model is tightly coupled with the C_3 version of the Ball *et al.* (1987) stomatal conductance model that provides a robust phenomenological description of stomatal behaviour. This coupling is required in order to predict leaf response to varying environmental conditions including atmospheric CO_2 concentrations. After Farquhar *et al.* (1980), leaf nitrogen content (linearly) influences two of the rate-limiting photosynthetic processes, namely

Schematic representation of the weather generator structure.



the potential maximum velocity of fully activated Rubisco that is inhibitor free (V_{cmax}) and the maximum potential rate of electron transport (J_{max}). After Friend (1995), the module explicitly describes the role of nitrogen as a major influence on photosynthesis through influencing the Rubisco concentration in soluble leaf proteins involved in electron transport. Leaf nitrogen content also (linearly) influences mitochondrial (dark) respiration. After Ball *et al.* (1987), internal leaf CO_2 pressure (C_i) is determined within the leaf as a function of the interactions between CO_2 assimilation and stomatal conductance to CO_2, regulated by the leaf boundary layer and mesophyll cell surface resistances to CO_2 transfer. The same processes are assumed to apply for water vapour. As assimilation (demand) and conductance (supply) are inter-dependent, the values of C_i and assimilation are resolved by iteration, and account for both leaf water potential and canopy temperature. Foliage respiration is accounted for within the assimilation model. The balance of whole plant respiration during the leafy and non-leafy periods is approximated using a Q_{10} function, based on actual whole system respiration using eddy-covariance measurements of CO_2 flux which are data measured at each site.

The canopy rainfall interception module

The tree canopy partitions gross rainfall into three downward water fluxes (free throughfall precipitation, canopy drip and stemflow) and an upward gaseous flux, intercepted water vapour resulting from evaporation. Along with meteorological conditions that determine the conditions for evaporation and canopy properties (evaluated from stand structure and growth as well as by management practices), the precipitation process, i.e. amount, intensity and its varying distribution in time and space, regulates rainfall interception. The canopy water environment module describes rainfall interception and wet canopy evaporation according to the revised analytical model of Gash *et al.* (1995). In this model each rainfall event is decomposed into three phases, a wetting up phase before canopy saturation occurs, a phase of canopy saturation and a drying phase after rainfall has ceased. Each phase contributes differently to the interception loss process, which is determined by the canopy structure and meteorological conditions. The canopy structure is characterised by four parameters, namely the canopy and trunk water storage capacities, the canopy cover fraction and the trunk diversion coefficient. The meteorological conditions are described through the ratio of mean evaporation rate from the wet canopy over mean rainfall rate. There are four main assumptions implicit in the model:

1. There should be enough time between storms to allow the canopy to completely dry.
2. There is no evaporation from the trunks during the storm.
3. No water drips from the canopy before saturation.
4. The ratio of average evaporation rate over average rainfall rate is equal for all storms.

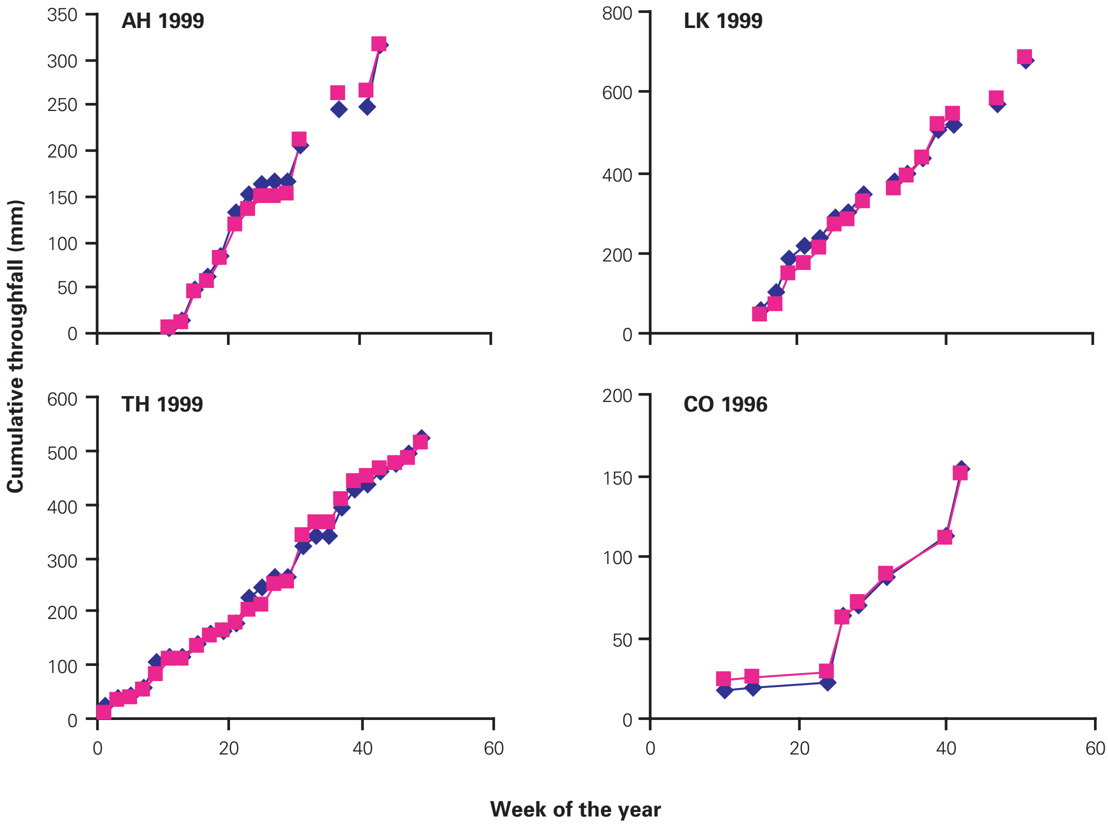
Figure 3 shows a comparison of observational data for throughfall (rainfall minus interception) with simulated module outputs.

The evapotranspiration module

After Ritchie (1972), selected outputs from all modules are used to parameterise the Penman-Monteith equation (Thompson *et al.,* 1981; Burman and Pochop, 1994). In turn this equation is disaggregated to approximate daily leaf and canopy level evapotranspiration, bare and shaded soil evaporation and wet canopy evaporation, separately for wet and dry days as determined by the climate module.

Figure 3

Throughfall for two oak sites (Alice Holt (AH) and Lakes (LK)) and two conifer sites (Thetford (TH) and Coalburn (CO)) for the year 1999.



The soil hydrology module

This module outlines a daily timestep, multi-horizon capacity model of soil-water balance which requires climate data, together with soil survey and laboratory-measured physical data as input. The module simulates the generation of surface runoff, lateral and vertical drainage and the formation of transient perched water tables. It has been designed for application over a wide range of soil lower boundary conditions that commonly occur in most temperate high latitude countries such as the UK, that range from free-draining to impermeable. At each time step, after having computed the rainfall interception, wet canopy evaporation, tree transpiration, bare and shaded soil evaporation, light interception and photosynthesis, the water balance is updated for each soil layer as detailed in Evans *et al.* (1998).

A summary of the general features of ForestETp is provided in Table 1. A comparison of process components from a range of stand and ecosystem models operating at various temporal and spatial scales highlights significant commonality of approaches between the models; differences tend to refer to the scale of resolution in process description. The comparison indicates that ForestETp is comprehensive in the range of relevant processes simulated by the model. The principal innovations are the addition of a weather generator model, to downscale widely available gridded observational meteorological data and the use of generic parameters from available databases.

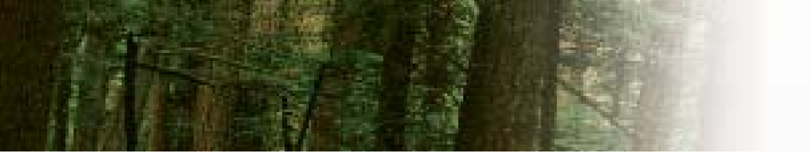


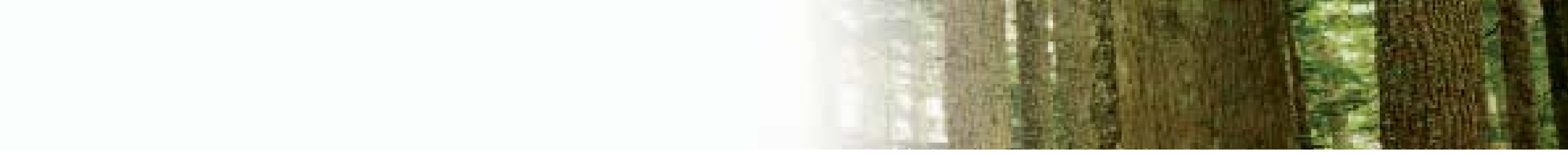
Table 1

General features of the ForestETp model.

Process	Strategy	Key references
Weather generator	Stochastic-deterministic, site-scale model downscaling widely available monthly timestep input data to the daily scales	Richardson (1981), Ross (1983), Hutchinson (1991)
Radiative transfer	Direct and diffuse radiation are accounted for though a canopy in which two classes of leaves (sunlit and shaded) exist	Norman (1980), De Pury and Farquhar (1997)
Photosynthesis	Biochemical model where photosynthetic rate is limited either by RuBP regeneration or by Rubisco kinetics	Farquhar *et al.* (1980), von Caemmerer and Farquhar (1981)
Stomatal conductance	Ball and Berry stomatal conductance model	Ball *et al.* (1987)
Rainfall interception	Tree canopy partitions gross rainfall into three downward water fluxes (free throughfall precipitation, canopy drip and stemflow) and an upward gaseous flux, resulting from evaporation of the intercepted rainfall	Rutter *et al.* (1975), Gash *et al.* (1995), Valente *et al.* (1997)
Evapotranspiration	Evapotranspiration is computed using the Penman-Monteith equation separately for the tree transpiration, bare soil evaporation, shaded soil evaporation and rainfall intercepted water	Thompson *et al.* (1981), Burman and Pochop (1994),Ritchie (1972)
Hydrology	Multi-horizon capacity model of soil–water balance simulating the formation of transient perched water tables and the generation of surface runoff and lateral drainage	Evans *et al.* (1998)

The integrated site model

Testing of the integrated model (excluding the weather generator) has been conducted against published data on whole-ecosystem exchanges of CO_2 and water vapour collected in UK and European forest stands using the eddy-covariance technique (CARBOEUROPE project). Simulation experiments were conducted for each site at the daily timestep using observational meteorological data as input. Model output was evaluated by comparison with experimentally derived approximations of Gross Primary Production (GPP) and evaporation data provided by Falge *et al.* (2001). As shown in Figure 4 which the comparison between observational data and model output at the daily timestep for a coniferous site in Finland (Hyytiälä), the model is well able to reproduce the whole system whole-ecosystem exchanges of CO_2 and water vapour. The overestimation by the model of evapotranspiration can in part be explained by deviations in the observational record, as outlined below. Some temporal divergence between the simulated observed data is also evident, resulting from the use of fixed ecophysiological parameters used in the model, while some variability is known from field data. Across sites, the model showed good agreement for GPP (R^2 ranging from 0.51 to 0.79 with an average R^2 of 0.69), with no significant bias detected. The whole ecosystem evapotranspiration presents a slightly lower correlation (range 0.35–0.62, average 0.47). As shown in Figures 5 (a) and (b), annual timestep simulations were significantly better during dry days (without precipitation) than during rainy days. This difference between wet and dry estimates would suggest errors with the instrumental data, rather than with model outputs. A small bias has been detected with the model presenting higher values than a slight overestimation of the evaporation, possibly



resulting from the use of a daily rainfall interception model and on the quality of eddy-covariance measurement during rainfall event.

Given the good approximations of GPP (R^2 ranging from 0.51 to 0.79 with an average R^2 of 0.69) and whole system evaporation (range 0.35–0.62, average 0.47) obtained at the site scale, national scale approximations have been developed, as shown by Figures 6 and 7. These simulations use spatial datasets, such as the National Soils Database for England and Wales (National Soils Research Institute, Cranfield University) and gridded climatologies such as that developed by the Climate Research Unit, University of East Anglia, as input. Scotland has had to be excluded from the simulation experiments, as soils data are the copyright of the Macaulay Land Use Research Institute which makes data available on a licence fee basis only. Given the mechanistic approach of the model it is possible to disaggregate the signals into constituent components, as shown for example in Figure 6.

Comparison of modelled GPP and ETp with measurement over 5 years. For GPP two methods (□ and ○) have been used to estimate the value from NEE and are shown with the model predictions (solid line). For Etp the measured (●) and simulated (○) are shown.

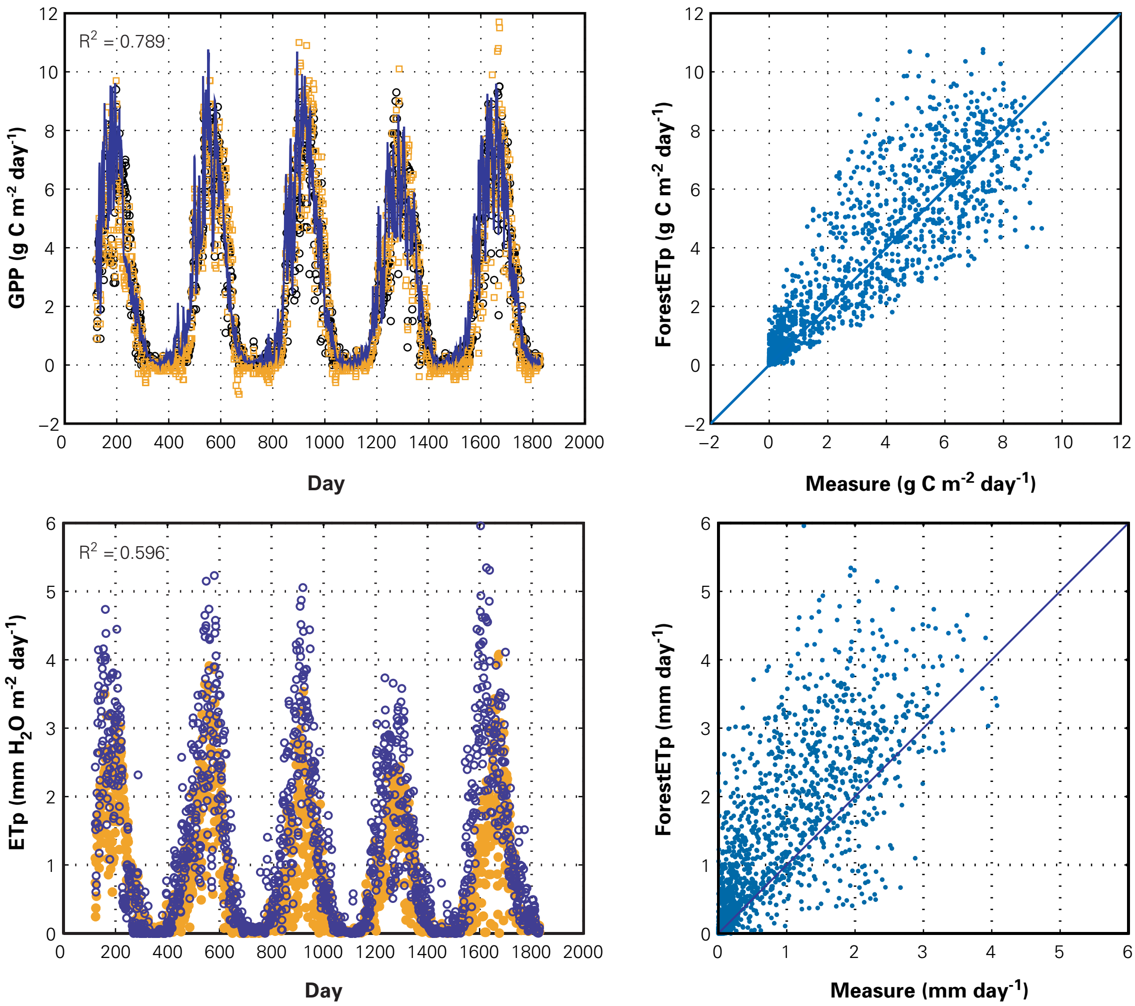
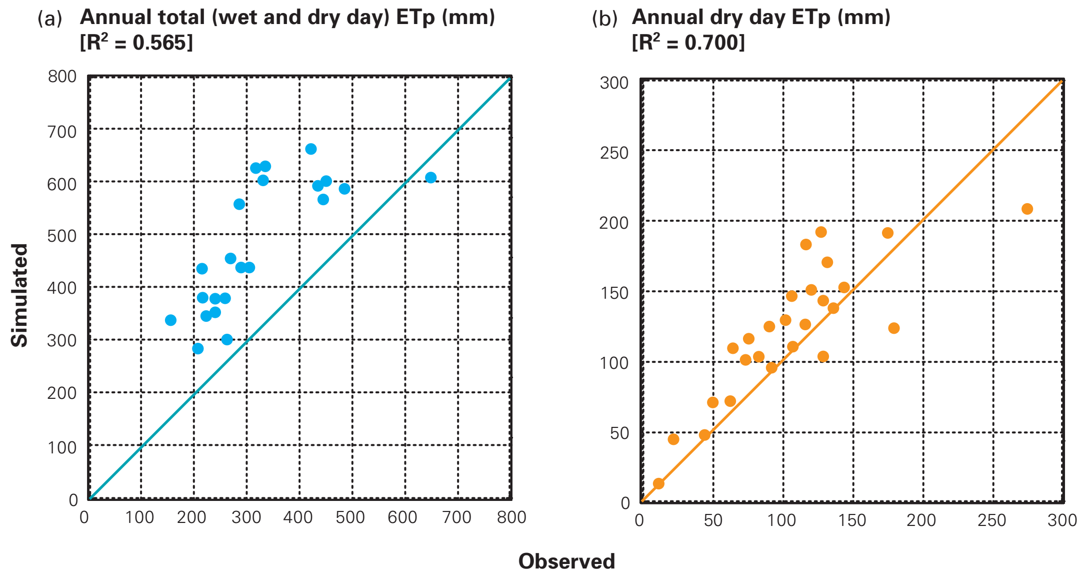


Figure 5

Comparison between modelled and measured system evaporation at the annual timestep for: (a) total (wet and dry day) evaporation; (b) dry day evaporation only.



The ForestETp 3-D model

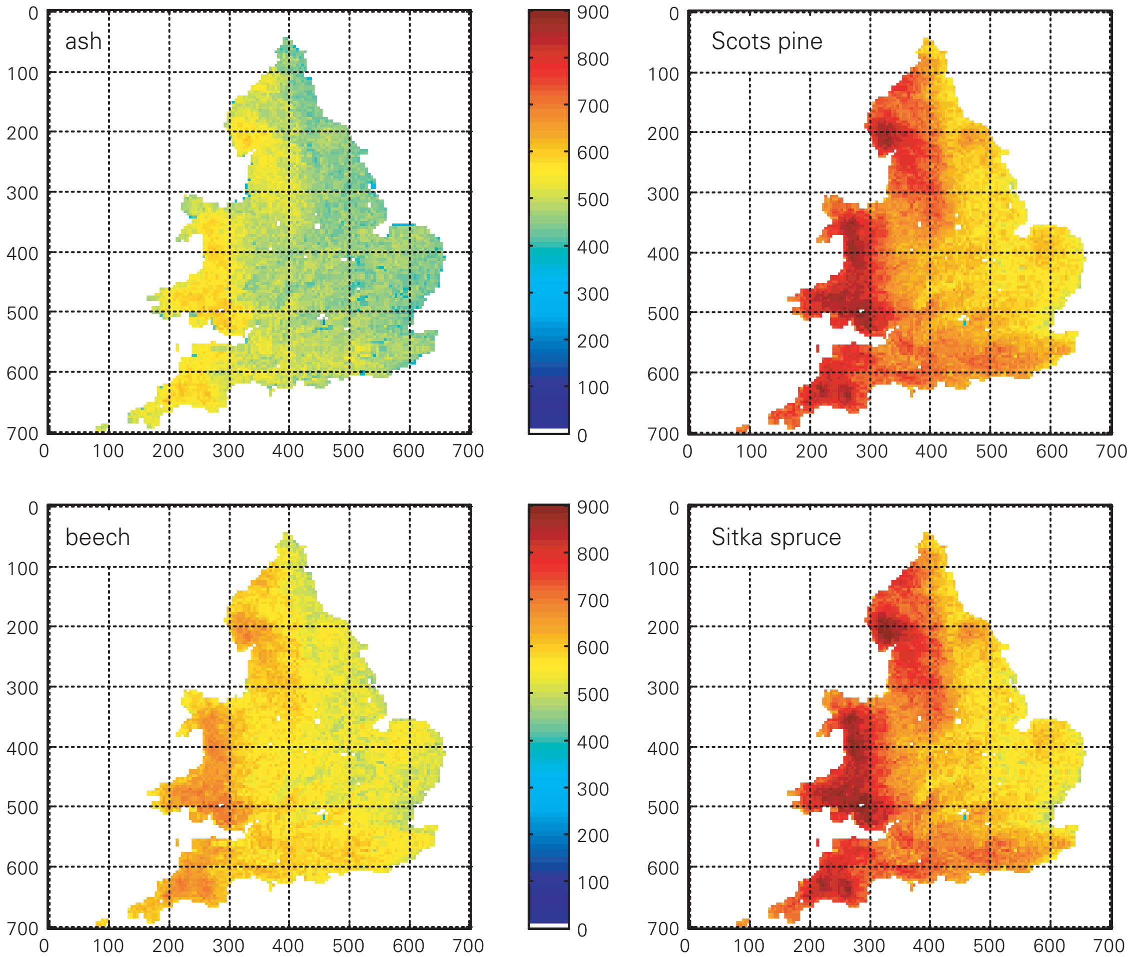
ForestETp 3-D is an extension of the stand-scale model (ForestETp 1-D) that simulates the relevant processes involved in the water and carbon cycle of a forested catchment. Model extension was required to obtain better approximations of (a) water available for plant growth at any point in the catchment and (b) the impact of land cover and land change on catchment discharge. In particular, the 3-D model accounts for the effects of topography and the heterogeneity of surface properties on the water and carbon budget, while requiring a minimum of input parameters. Again, the model was specifically developed to make use of widely available spatial data as its input source.

Computation in the ForestETp 3-D model is divided into two main steps:

- In a preliminary step, the TOPOG Digital Elevation Analysis models (Dawes and Short, 1994; O'Loughlin, 1986) are used to separate the catchment into discrete elements as a function of topography using a flow net technique. These elements have an irregular shape defined by topographic contours and flow lines which has been shown to be more realistic for representing convergence and divergence of lateral flows than classical scared grids (Dawes and Short, 1994). For each topographic element local properties such as slope, aspect and drainage percentage to adjacent downslope neighbours are calculated. By overlaying a soils and/or vegetation map of the area to the topography, it is also possible to account for the heterogeneous distribution of soil types and/or tree properties in the catchment.
- In a second phase, the ForestETp 1-D model, modified to account for incoming lateral water flows, is run for each element at every timestep to compute the energy balance, photosynthesis, evapo-transpiration fluxes, surface runoff and drainage. Solar and long-wave radiation are corrected for slope and aspect and, if required, rainfall can also be corrected for elevation. At the end of each timestep runoff and drainage are distributed to the downslope elements, or to a stream/river if no connecting downslope element is found. All daily fluxes are then aggregated to compute mean values at the catchment scale.

Figure 6

Simulated annual forest system evaporation (mm m^{-2} year^{-1}) assuming total land coverage by ash, Scots pine, beech and Sitka spruce.

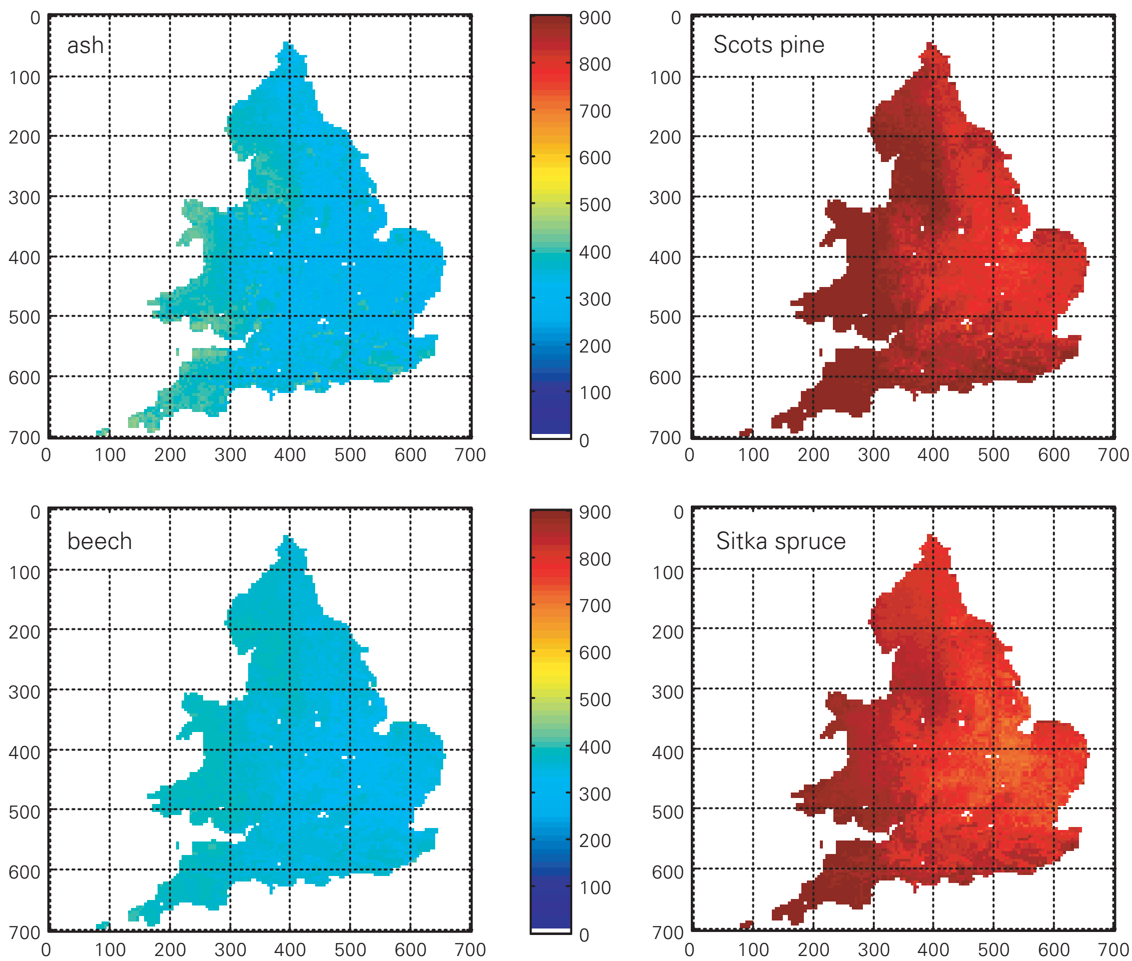


Outputs are available as (a) temporal series for a particular point or averaged over the catchment and (b) spatial maps for a particular day or as means for an entire period.

Evaluation of the ForestETp 3-D model has been conducted using long-term monitoring data on streamflow collected in the Coalburn catchment. Simulated streamflow is computed as the sum of lateral sub-surface drainage and surface runoff generated by those topographic elements bordering the river (confluence elements). Observed and simulated streamflow were then compared at the daily, monthly and annual time steps. Figure 8 shows the daily observed and simulated streamflow for a 7-year period (1993 to 1999); the model is efficient (R^2=0.80) over the entire period. On average the model underestimates peak discharge and slightly overestimates recessions after each rain event. This can be explained through a poor quantification of lateral soil hydraulic conductivity. At the annual time scale, streamflow volumes are, on average, well reproduced, with a small underestimation for the past two years (7% and 6% respectively), possibly due to underestimation of rainfall for some particularly strong events. Nevertheless, results indicate the model is well able to reproduce the volumes of water transferred to the river and, by derivation, the total catchment evapotranspiration and water balance, at the daily, monthly and annual timesteps.

Figure 7

Simulated annual gross primary productivity (kg C year^{-1}) assuming total coverage by ash, Scots pine, beech and Sitka spruce.



The ForestGrowth model

The ForestGrowth model represents a further extension of the ForestETp 1-D model, where carbon units simulated by this model (net of respiration) are allocated to tree compartments such as foliage, branches, stem and roots, to dynamically simulate trees and stand growth. Figure 9 shows a typical example of model output, interfaced with an existing graphical representation system (McGaughey, 1997). The output illustrates how the model can be used to generate stands of different structure and age, and, with appropriate model parameterisation, the growth dynamics of stands composed by different species.

Conclusions

Forest Research is developing a suite of mechanistic models simulating the dynamics of a range of biological, biophysical and physical processes that determine the growth of trees and forest stands. Extensive model testing is being undertaken to verify the predictive ability of models under a range of growth conditions representative of those observed in the UK and beyond. The structure of the model allows scenario testing to be undertaken to assess the impacts of, for instance, management and rapid environmental change on the growth dynamics of forest stands. Operating at the landscape scale, models appear well able to represent the impacts of, for example, land cover dynamics on the water cycle.

Figure 8

Comparison between observational (pink line) and simulated (purple line) streamflow for the Coalburn catchment over the period 1993–1999 using the ForestETp 3-D model.

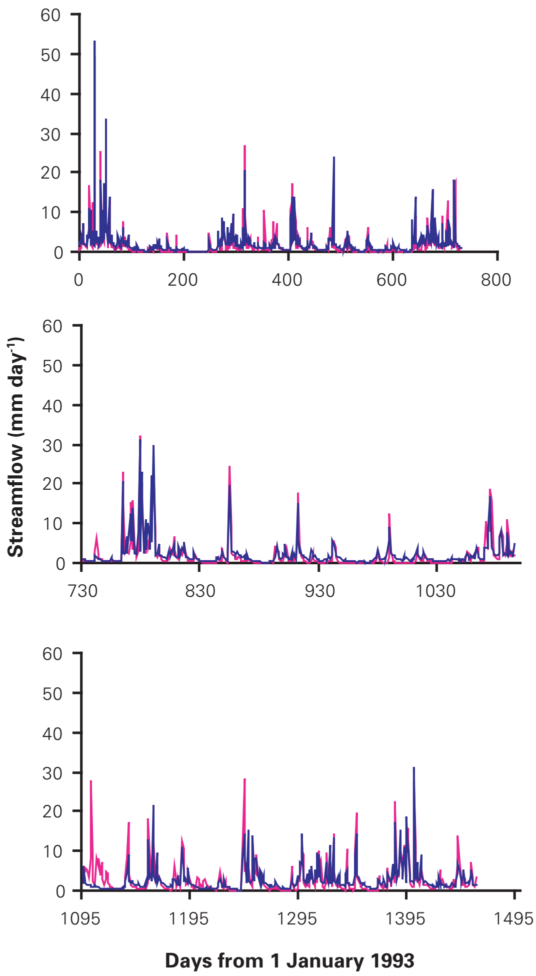
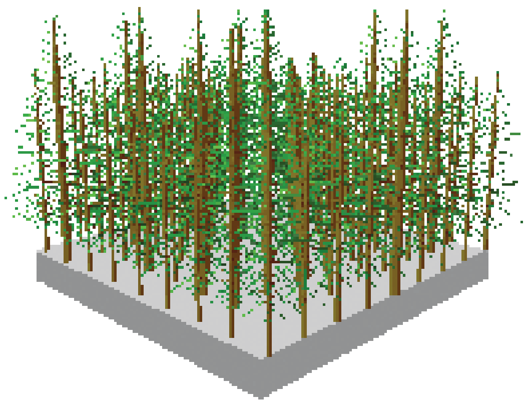


Figure 9

Outputs of the ForestGrowth model, interfaced with the Stand Visualisation System developed by USDA (McGaughey, 1997). The visualisation tool is unable to project model simulations of root biomass.



Further work is being undertaken to develop new model applications which meet the diverse requirements of evidence-based research in support of operational forestry. Further work is being undertaken to develop operational tools from the research applications outlined above. One such instance is ForestETp 3-D that will become a simulation system available to forest managers challenged with meeting the requirements of the European Water Framework Directive. It is foreseen that similar operational tools will increasingly be required to forecast and inform decision-making and policy to meet the challenges of multi-purpose forestry and rural land use.

Acknowledgements

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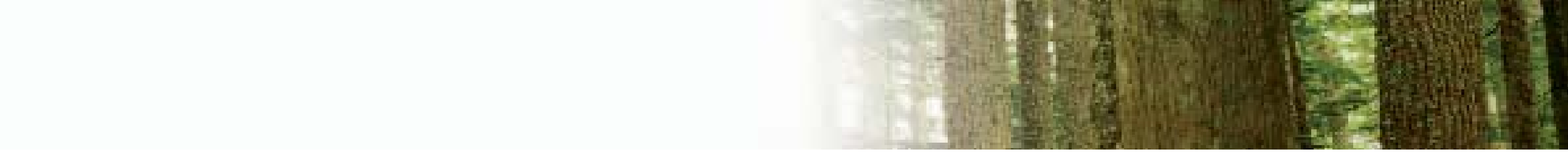

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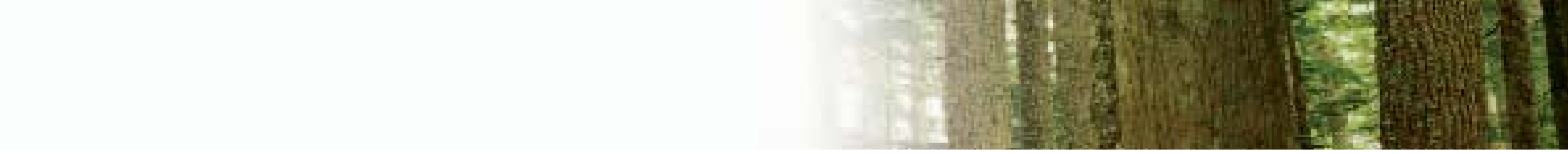
Research in support of the UK Biodiversity Action Plan: forest management and priority species

Alice Broome, Chris Quine, Roger Trout, Elizabeth Poulsom and Brenda Mayle

Background

The research programme in support of the Species Action Plans (SAPs) began in 1998, using in-house expertise and building partnerships with experts/researchers in other organisations in order to meet the Forestry Commission's commitment to the UK Biodiversity Action Plan (UKBAP). The work undertaken within the programme is directed by the targets agreed within the SAPs, and has at the core an aim to understand how forest operations and woodland management impacts upon the Priority species. The goal is to pass this information on to forest managers and policymakers in a form that can be used to conserve and benefit species.



Introduction

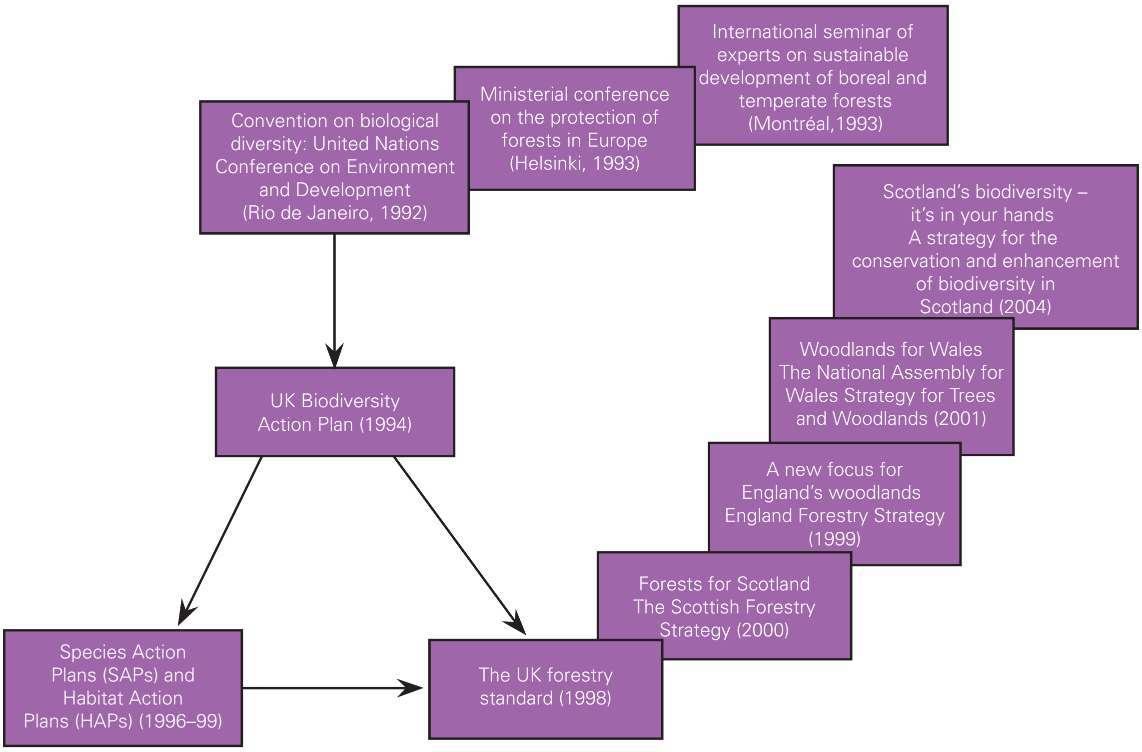
Policy context

In response to the Convention on Biological Diversity signed at the Earth Summit in Rio de Janeiro in 1992, the UK government produced the UK Action Plan for Biodiversity (UKBAP; Anon., 1994) and the UK Steering Group's report (Anon., 1995) – see Figure 1. These documents identified our rare native species; 382 species were either in rapid decline or globally threatened, and urgent action was considered necessary for these 'Priority' species. A Species Action Plan (SAP) was written for each, detailing the status, threats and targets for its conservation and recovery. The plans were published between 1995 and 1999. Priority habitats have also been identified and a similar process followed for these (Anon., 1994; Anon., 1995).

The amount of work entailed in carrying out the SAPs is large and the cost has been estimated at around £55 million over the 10 years of the plans (Anon., 2000a). An approach of voluntary partnership has been encouraged with the responsibilities shared between government and non-government organisations (all of which are attempting to find resources within expenditure constraints). Detailed actions are set out for a number of organisations within the plans.

The Forestry Commission (FC) has a clear commitment to the conservation of biodiversity and this is incorporated in the FC's policy statements on sustainable forest management in The UK Forestry Standard (Anon., 1998), and the English, Scottish and Welsh Forestry Strategies (Anon., 1999; Anon., 2000b; Anon., 2001). Each asserts that management should aim to conserve

Policy context for Species Action Plans in the UK.



Priority species and that successful application of forestry strategy should be measured as progress towards the UKBAP targets. The Species (and Habitat) Action Plans have been suggested as a source for policies and practices relevant to the management of biodiversity in planted forests in the UK (Rollinson, 2003). The UKBAP is cited as the 'cornerstone' of the Welsh Forestry Strategy. Specific actions are given in the English Forestry Strategy, e.g. to target grants to enhance woodlands for the benefit of Priority species. More recently, the FC has identified the need for guidance on management requirements of woodland SAP species, in their response to a review of their support of sustainable management of woodlands in England (Anon., 2002). In the government's Scottish biodiversity strategy (Anon., 2004), delivering actions and outcomes of the UK Species (and Habitat) Action Plans is a primary focus.

There are 135 SAPs linked to woodland where the FC is identified as a partner in the work plan and 61 of these where the actions identified are for providing information through research (Table 1). The majority are woodland species ranging from liverworts to mammals, but a few e.g. marsh fritillary (*Eurodryas aurinia* Rottemburg) are open ground species.

Priority species for which the Forestry Commission (FC) is a partner in the delivery of the Biodiversity Action Plan (see Harding, 1999).

Species group	Number of plans where FC is named as a partner	Number of plans where FC is partner in delivery of a research or advisory task	Species for which research is being carried out by FC
Birds	13	10	capercaillie *(Tetrao urogallus)*, Scottish crossbill *(Loxia scotica)*
Mammals	8	7	Bechstein's bat *(Myotis bechsteinii)*, dormouse *(Muscardinus avellanarius)*, lesser horseshoe bat (*Rhinolophus hipposideros)*, otter (*Lutra lutra*), red squirrel *(Sciurus vulgaris)*
Amphibians and reptiles	2	1	–
Vascular plants	15	8	juniper *(Juniperus communis)*, small cow-wheat *(Melampyrum sylvaticum)*, twinflower *(Linnaea borealis)*
Lower plants	33	13	stipitate hydnoid fungi *(Hydnum, Hydnellum, Bankera, Phellodon, Sarcodon)*
Invertebrates	64	22	argent and sable moth *(Rheumaptera hastata)*, chequered skipper *(Carterocephalus palaemon)*, narrow-headed ant *(Formica exsecta)*, pearl-bordered fritillary *(Boloria euphrosyne)*, scarce lime bark beetle *(Ernoporus tiliae)*, Scottish wood ant *(Formica aquilonia)*, waved carpet moth *(Hydrelia sylvata)*

Prioritising research needs

A review of research needs for forestry-related SAPs provided a shortlist of species for which work was a priority (Broome, 1999). The review took account of progress made since the SAPs were published and used a number of criteria to prioritise, including dependence of species on woodland habitats, vulnerability of species to forest operations, emphasis of task on research action and formal role in delivery of the SAP, i.e. Lead Partner/ Contact Point.

The maturity of knowledge on a species determines what action is required. The knowledge of each species and the steps necessary to acquire information to guide conservation is laid out in the Action Plans. As shown in Figure 2 there are five typical stages of knowledge acquisition in understanding the status and requirements of species and identifying applicable conservation management. In this article, the sequence of stages will be explored using the current research programme.

Stages of knowledge acquisition used in research for the Species Action Plans and the type of tasks carried out at each stage.

Stages	Tasks
Distribution and status ↓	• Basic surveys of presence/absence • Assessments of frequency and condition of population
Autecology ↓	• Detailed population level studies to understand habitat requirements
Impacts of management (levels of tolerance) ↓	• Field scale management experiments/trials of measures to enhance habitats
Guidance preparation and knowledge dissemination ↓	• Results of trials/experiments interpreted for guidance notes, presentations/talks etc • Expert advice for particular situations
Monitoring impacts of recommended management	• Systematic checks of species and habitat responses to management, feedback to distribution and status

Distribution, status and condition

Knowledge of distribution, status and condition of species is necessary for underpinning research and conservation actions. For the majority of the species covered by the research programme, much is already known. However basic knowledge on the distribution and condition is lacking for some, and two examples are discussed here.

Scarce lime bark beetle

The scarce lime bark beetle (*Ernoporus tiliae* (Panzer)) is a deadwood specialist that in Britain is believed to feed almost exclusively on small-leaved lime (*Tilia cordata* L.). It has Red Data Book Category 1 (Endangered) designation and has been included on the priority UKBAP list due to its apparent decline in post-war years. The FC is Lead Partner for the SAP. Understanding the current status and distribution of the scarce lime bark beetle in England was necessary to meet the SAP target of providing advice to landowners and managers on the presence and conservation management of the species. This was tackled through an extensive survey of small-leaved lime woodlands, over two seasons, by an expert under contract to FC. Past records of *E. tiliae* were gathered to establish sites from which the beetle was once known and these, along with the remaining major small-leaved lime areas, were then targeted. Lime stands were assessed for beetle presence and colony size and the structure of their deadwood habitat was recorded. Based on these findings a change in species status has been proposed and the information gathered will allow site management guidance to be targeted to the key locations of *E. tiliae* (Drane, 2003; Broome *et al.,* submitted) – see Figure 3.

Juniper

Juniper (*Juniperus communis* L.) forms an important component of a range of semi-natural vegetation types and is one of Britain's three native conifer species. It is widely distributed throughout Britain in a variety of habitats but only in Scotland is it found as part of the woodland ecosystem. Juniper has been designated a Priority species due to its decline in distribution and poor population viability and regeneration ability.

Investigating the extent and condition of woodland juniper on FC ground formed our contribution to a Scotland-wide survey of juniper. The project was led by Scottish Natural Heritage (SNH), to provide the evidence on which to set priorities for regional action in the maintenance and restoration of juniper populations.

A sample of three 10 km squares within each Natural Heritage Zone (Anon., 1997) with historical records for juniper were selected and juniper occurrence mapped. Based on this, 1 km squares containing woodland, open ground and prostrate juniper (J. *communis* subsp. *nana*) populations were surveyed in detail. Information was collected on population size, health (disease, fire and browsing damage) and age structure of the bushes, and regeneration potential and characteristics of the sites where juniper grew.

Analysis of juniper extent and condition by 10 km square provides an idea of where the species is secure to where it is extremely vulnerable. Areas have been identified for conservation action for all juniper types: open, montane and woodland (Sullivan, 2003). Woodland juniper made up one-third of the sample and a more detailed review of this data is under way.

Autecological research

Knowledge of the basic requirements of a species is fundamental to its conservation. Without such information, managers do not know the type of habitat that should be maintained or provided. Detailed studies, usually conducted at the population level, provide information on specific requirements and may indicate what habitat features are critical for a species survival.

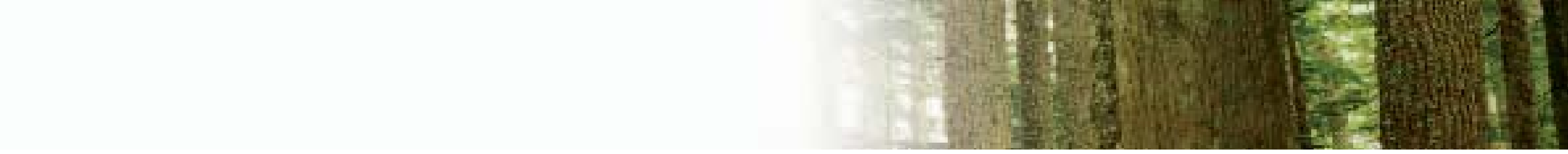
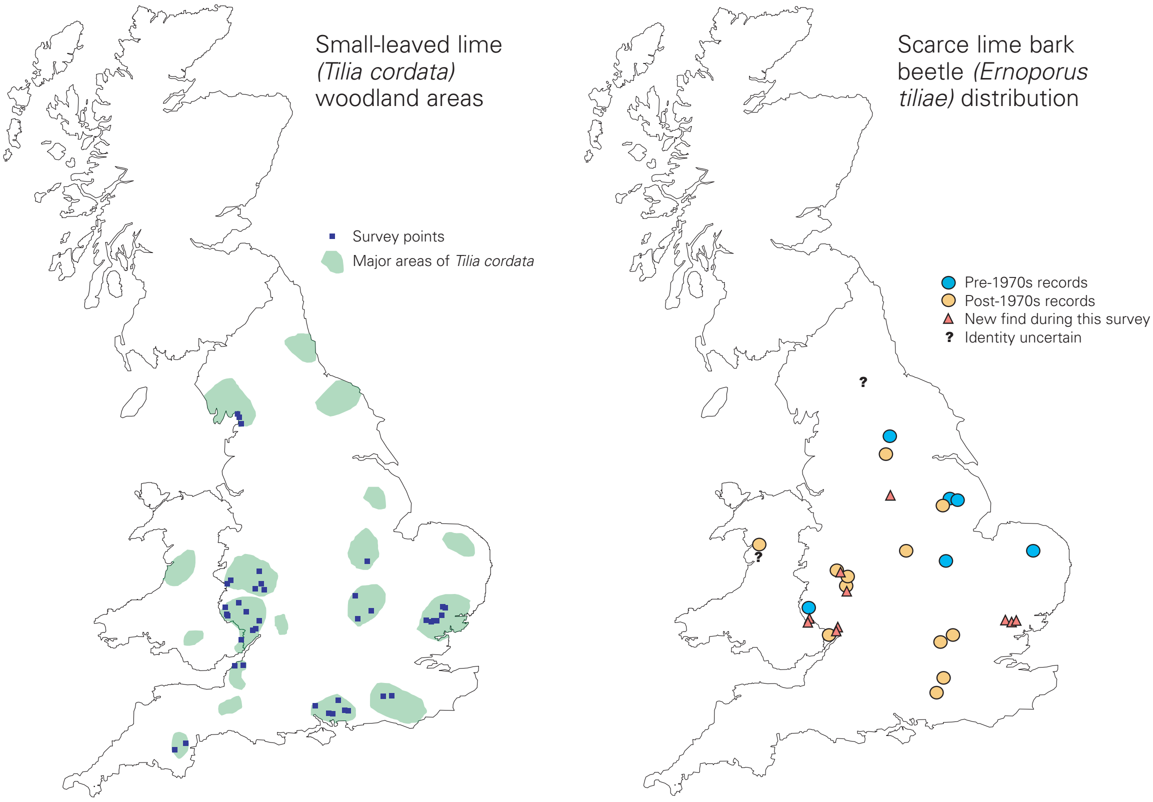


Figure 3

Scarce lime bark beetle *(Ernoporus tiliae)* survey results and recommendations.

The survey re-established *E. tiliae* presence at most of its historical locations in England (total 17 sites). This is a picture not of decline but of restricted range and habitat requirements: *E. tiliae*'s distribution is very local but widespread. Red Data Book (RDB) status change is suggested from RDB1, a status reserved for those species with a single population or occurring in vulnerable habitats or in continuous decline, to RDB3, owing to the beetle's dependence on a vulnerable habitat.



Argent and sable moth

The habitat requirements for many of the species in the research programme are already known. An exception to this is the argent and sable moth (*Rheumaptera hastata* L.), shown in Figure 4. This species of day-flying moth is found in a northern and southern form (subsp. *nigrescens* and subsp. *hastata*, respectively). The southern form is considered to be very rare, with only a few locations of known presence and a growing number of counties from where it is now extinct (Green, 2001). It was thought that the species was associated with lowland birch regrowth or

Argent and sable moth *(Rheumaptera hastata* L.).

scrub in coppice or ride situations. Gauging the importance of woodland or coppice management for this species required an understanding of microhabitat requirements. Over the past three years, in conjunction with Butterfly Conservation, populations have been studied in three woodlands in lowland England. Sapling birch (*Betula* sp.) up to a metre tall, that are in full sun for most of the day, appear to be essential for the larvae of this species. The results imply that management must seek to retain birch in actively coppiced sites and on well-lit ride sides (Green, 2004).

Impacts of management: threats and opportunities

Understanding how forest management practices affect species is central to this stage of research. Experiments that explore the impacts of operations ranging from those perceived as beneficial to those considered detrimental are used as the preferred basis for management guidance.

Common dormouse

Traditionally, the common dormouse (*Muscardinus avellanarius* L.), shown in Figure 5, is associated with broadleaf woodlands and coppice dominated by hazel. However the species has been found on many ancient woodland sites that have been planted with conifers in the past (PAWs sites). There is an increased move towards restoring such woodlands by conifer removal, raising the question of whether this would be detrimental to the dormouse. The ecology of dormice in conifer sites and methods of conserving dormice that are consistent with various silviculture systems are required research actions in the SAP.

A conifer removal experiment has recently been initiated in Wyre Forest, in the Midlands, in an area where Forest Research (FR) has been studying dormice for some years. Studies of population size, habitat use and home ranges in

Figure 5

Common dormouse *(Muscardinus avellanarius).*
(Chris Pierce, Sussex Wildlife Trust)

the area provide baseline data. Three thinning treatments and a small-scale clearfell treatment have been applied to a 17 hectare area. The impacts of damage to dummy nests by different harvesting systems have been investigated. Dormouse use of the woodland after harvesting will be studied through nest box occupation level and radio-tracking and will help identify practices that are least disruptive to the population.

Twinflower

Twinflower (*Linnaea borealis* L.), illustrated in Figure 6, is a creeping perennial which regenerates vegetatively, producing single clone patches considered to be self-incompatible, i.e. fertilisation and seed set will not occur when pollen is supplied by flowers of the same clone (Neiland and Wilcock, 1997; Kohn and Ennos, 2000). Now restricted to the pinewoods of NE Scotland, twinflower was once more widespread, occurring in old pine plantings in northern England. Shading is considered to be one of the main threats to the species. Intense shade is thought to kill the plants but some shade is considered necessary for good growth and flowering (Erriksson, 1988). A key target in the SAP is to achieve self-sustaining populations capable of sexual regeneration.

Figure 6

Twinflower *(Linnaea borealis).* (Cath Price)

Understanding what light levels are most beneficial and how these can be achieved through stand manipulation appears important. A collaborative project between Plantlife, SNH and FR is under way at a privately owned mature pinewood in Speyside which has been thinned to an experimental design. Monitoring responses of 26 twinflower colonies has been carried out before, immediately after and one year after thinning; plot light levels and stand characteristics have been assessed pre- and post-thinning. Preliminary results suggest that increased light levels and/or disturbance have a detrimental effect on twinflower growth and flowering (Maier, 2002) but it will be several years before the colonies are expected to respond fully to the treatments.

Providing guidance

Converting research findings into guidance is an essential stage in the research process. Guidance provided by the SAPs programme varies and encompasses practical management guidance through to strategic advice to support forest policy decisions; examples of both types are given.

Juniper

Recently there has been much interest among land managers in planting juniper either by expansion of existing populations or inclusion in new planting schemes (Falconer, 2002; Woods, 2003). Guidance was needed on the best methods for growing juniper and for establishing plants in the field. Results from propagation and establishment trials carried out by FR over the past 10 years have been drawn together in a FC Information Note: *Growing juniper: propagation and establishment techniques* (Figure 7), where implications of the findings for managers are discussed. Topics covered include the advantages and disadvantages of growing juniper from cuttings or from seed, where and how to collect seed to maintain the genetic character of populations and how to strike cuttings and germinate seed. To help with successful establishment, advice is provided on the importance of weed control, types of shelters that are most effective and the impacts of fertiliser on bush growth. This guidance was developed particularly for managers involved in the practical management of juniper in the Uplands.

Information Note 50 on growing juniper.


INFORMATION NOTE

SUMMARY

INTRODUCTION

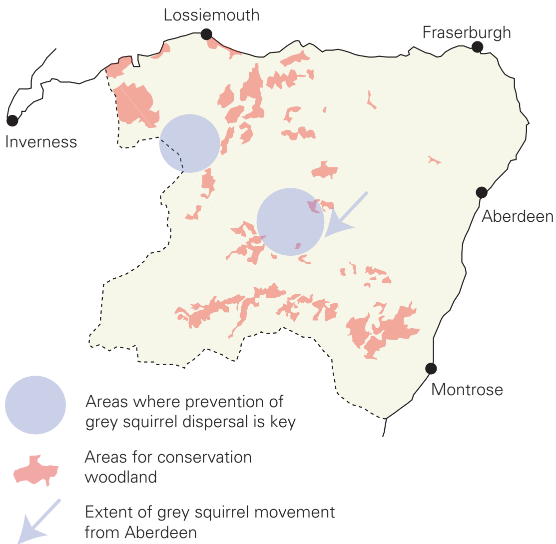
Red squirrel

Britain's native squirrel, the red squirrel (*Sciurus vulgaris* L.), is in serious decline in England and Wales but remains widespread and locally common in Scotland (Anon., 1995). The ecology of the species has been researched for many years and there is now a good understanding of the habitat requirements and the main reasons for its decline. Red squirrels are core woodland species that can survive in both deciduous and conifer habitats but appear unable to compete with grey squirrels in deciduous habitats or when the woodlands are small and fragmented. Conservation efforts have focused on identifying large conifer woodlands as red squirrel refuges. The method for refuge identification has been laid down in a set of rules based on squirrel population status, and woodland and landscape characteristics (Reynolds and Bentley, 2001).

Scotland, in contrast to England and Wales, has a substantial number of potential woodland refuges, and guidance was required on which woodlands to prioritise for conservation action. The refuge identification rules were applied to all woodlands in north and central Scotland using Geographical Information Systems (GIS) analysis. This analysis drew together information from national datasets such as the National Inventory of Woodlands and Trees (Anon., 2000c) and site data, for example woodland composition and management that were gathered during discussions with woodland managers and owners. The project report (see Poulsom *et al.,* 2004) provides a list of woodlands ranked by suitability for red squirrel conservation and an analysis by region of key woodland complexes and their qualities as squirrel refuges (Figure 8). Guidance available in the report may help to inform decisions on Forest Habitat Network design and targeting of woodland management incentives.

Figure 8

Priority woodlands for red squirrel conservation in Grampian.



Monitoring the effect of recommended management

Management guidance is normally based on the results of designed experiments and expert knowledge/opinion. Where possible it is important to monitor the impacts of recommended management as a check on whether the management is appropriate and as a way of refining the guidance. This type of work is suitable for species whose ecology and response to management is already well known. Examples are given of two such current studies: capercaillie and chequered skipper butterfly.

Capercaillie

The capercaillie (*Tetrao urogallus* L.), Figure 9, is a woodland grouse which in Britain is restricted to the pinewoods of Scotland. After becoming extinct in the late 1700s, it was reintroduced in the 19th century, and its reintroduction numbers peaked in the 1970s (approximately 20 000 birds). The population has since fallen to under 1000 (in 2002); if this rate of decline were to continue it is estimated that the species would become extinct by 2010 (Caledonian Partnership, 2003). Urgent Conservation Management for Scottish Capercaillie is a partnership project bringing together more than 20 private forest owners, government and non-government organisations to carry out practical measures to improve habitat for capercaillie (with part funding from the European Commission's LIFE-Nature Programme). Research carried out both here and in Scandinavia has provided a clear picture of the habitat requirements for capercaillie, and management to create these optimal conditions is being undertaken as part of the LIFE project.

One action is the thinning of areas of Scots pine stands to improve the forest floor vegetation for capercaillie. To ascertain that management prescriptions are correct, thinning has been carried out to an experimental design (using four thinning treatments) at two sites: Easter Ross and Strathspey. Vegetation monitoring is under way; measurements have been made before thinning and will continue for each year for the duration of the project.

Development of a high cover of blaeberry (*Vaccinium myrtillus* L.), which is linked to the light climate of the woodland floor, is known to be key for capercaillie survival as blaeberry is host to the invertebrates on which the capercaillie chicks feed. The numbers of invertebrates that blaeberry will sustain is also thought to be linked to light levels; the aim is to develop the project to investigate these issues.

Chequered skipper butterfly

The more specialist butterflies are becoming increasingly rare in Britain as the semi-natural habitats which they depend upon become fragmented or disappear (Asher *et al.,* 2001). This is particularly a problem in southern England where the pressure for land is greater. Butterflies are generally warmth-loving species and the greatest species diversity tends to be found in the south of Britain. Some of Britain's rare butterfly species are able to survive in the cooler north where semi-natural habitats tend to be more abundant, and where the correct micro-climate characteristics can be found (Asher *et al.,* 2001).

Figure 9

Male capercaillie *(Tetrao urogallus)*.

One such species is the chequered skipper (*Carterocephalus palaemon* Pallas) which is now confined to an area of the Great Glen in Lochaber where the northern climate is moderated by four large lochs: Linnhe, Lochy, Arkaig and Eil. This area is also rich in other butterfly species including the pearl-bordered fritillary (*Boloria euphrosyne* L.), another UKBAP Priority species. In recognition of this, FC Scotland, in partnership with Butterfly Conservation are managing a large site on the shores of Loch Arkaig as a butterfly reserve. The site consists of an area of open ground with scattered woodland, and two blocks of mature Sitka spruce (*Picea sitchensis* (Bong.) Carr.) dominated conifer plantation, described in Figure 10.

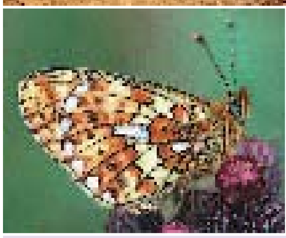
Figure 10

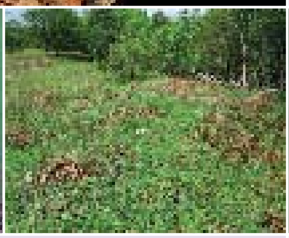
Monitoring of habitat management at the Forestry Commission's butterfly reserve by Loch Arkaig in Lochaber, north west Scotland. (Butterfly photos: David Whitaker; habitat photo: Paul Kirkland)

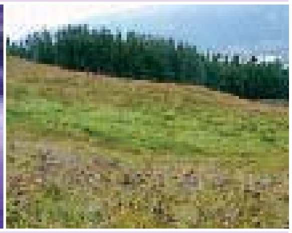
The site is located 14 miles north of Fort William, on the north shore of Loch Arkaig. It comprises 80 ha of open ground with scattered woodland, bracken, dry heath and acid bog, and 260 ha of mature Sitka spruce-dominated conifer plantation.

The site is being managed for the two UKBAP species, the pearl-bordered fritillary and the chequered skipper. The habitat requirements of these species are well understood.

The majority of the butterflies are to be found in the open area. Summer grazing by cattle is being used to maintain and improve the ground vegetation for butterflies. Effectiveness of this management regime is being monitored by FR.







Larvae of the pearl-bordered fritillary require violets growing among thin bracken litter. The violet leaves are food for the larvae and the bracken litter provides resting sites which are at higher temperatures than the surrounding vegetation.

The chequered skipper larvae feed on purple moor-grass, but as they do not pupate until the late autumn they will only survive on tussocks that are growing vigorously and will continue green into the autumn. Such tussocks occur in flushed conditions only. Some level of shelter is also required and purple moor-grass in flushed conditions with surrounding tree cover provides the ideal conditions.

Phases in the restructuring of conifer plantation are colour coded. Non-coloured area has already been felled and is the site where FR is monitoring vegetation development.

Results from the baseline survey of the clearfelled area show that food plants and nectar sources already exist, albeit at very low levels.

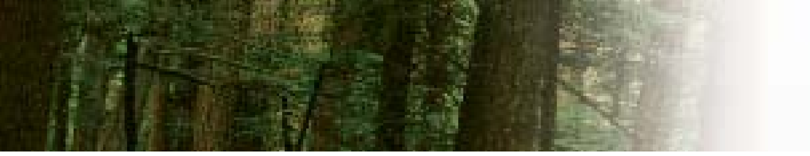
At this site, the majority of the butterflies are to be found in the open areas, especially among the scattered woodland where there is more shelter. In the past, sheep and deer have grazed the area, but the grazing regime has been changed to summer grazing by cattle only. The aim is to improve the vegetation structure for pearl-bordered fritillary larvae, increase the nectar sources and stimulate tree regeneration on the more exposed parts of the site. Provision of such precise conditions requires careful management and the effect of the management prescription designed to deliver these needs to be monitored. FR have designed and are implementing the monitoring at the butterfly reserve. Using permanently marked quadrats, vegetation composition is being assessed annually in early summer, with the aim of detecting significant changes in butterfly food-plant availability. On a broader scale, the occurrence of nectar sources and tree seedlings are also being assessed across the site through a series of permanently marked transects.

In the conifer plantation, the FC have embarked upon a process of restructuring, with sequential areas being felled and replanted over the next 30 years. As the woodland is restructured, open areas will be created, if only temporarily. For a time, these might support the food plants and nectar sources for the target butterflies. Harvested coupes are being monitored from shortly after felling until the replacement crop closes canopy to chart the development and decline of ground vegetation. This should identify whether suitable ground cover can develop, at what time this is likely to happen, and for how long it will persist. Such information will allow timing of felling to be scheduled so as to provide a continuity of butterfly habitat throughout the forested area.

Links to other research programmes

The research programme described above is part of the biodiversity research grouping within FR. There are links between many of the work areas and information generated can be of use in other research programmes. For example:

- Autecological and management data is being organised and delivered through the Habitats and Rare, Priority and Protected Species decision support system (HaRPPS).
- Data can be used to build species profiles for use in the model Biological and Ecological Evaluation Tool for Landscape Ecology (BEETLE) which will allow the suitability of habitats at the landscape scale to be assessed (Watts *et al.,* in prep.).
- Guidance on conservation measures for a species may also require consideration of its genetic conservation. This is particularly true for juniper, which can show distinct differences in genetic character between populations. Being able to assess genetic variability of species in order to advise on the importance of a local population's conservation is likely to become increasingly important.



New SAPs research areas

The research programme has now been running for four years and research activities are taking place in all of the areas that were identified as priorities at its outset. The programme is evolving and new work is planned. New work areas for 2004–05 include supervision of a project to identify potential priority woodlands for Bechstein's bat (*Myotis bechsteinii*), collation of data on wood ant distribution in Scottish forests (including *Formica aquilonia* Yarrow and *F. exsecta* Nylander), habitat management and grazing trials for black grouse (*Tetrao tetrix* L.) and supervision of a PhD on stipitate hydnoid fungi (*Hydnum, Hydnellum, Bankera, Phellodon, Sarcodon* spp.). The work of the programme has also developed in response to changing research needs and pressures exerted by the forestry, environmental and conservation sectors. As a result, new species that are being, or will be, given attention include otter (*Lutra lutra* L.), small cow-wheat (*Melampyrum sylvaticum* L.) and the pine marten (*Martes martes* L.).

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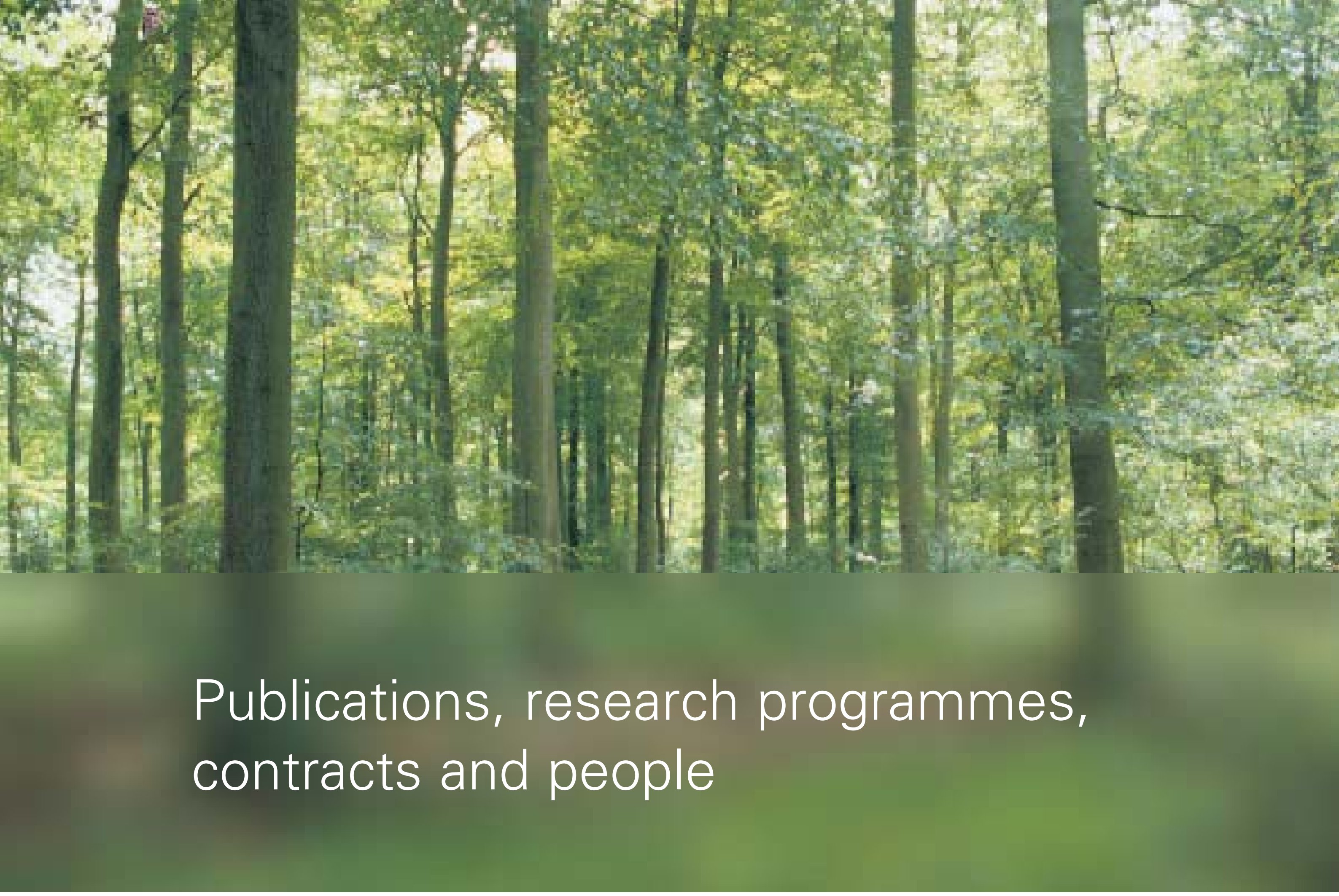

Publications, research programmes, contracts and people

Forestry Commission technical publications

Publications by Forest Research staff

Major research programmes undertaken by Forest Research

Research contracts awarded by Forest Research

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Forestry Commission technical publications

The following titles were published during the year ending 31 March 2004.

Reports and plans

Forest Research annual report and accounts 2002–2003 (£23.00)

Forest Research corporate plan 2003–06 (free)

Forest Research framework document 2003 (free)

Leaflets and brochures

The quest for sustainable energy: woodfuel meets the challenge (free)

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A code for insect collecting, 3rd edition (free)

The various series of technical publications listed below are published for the Forestry Commission by Sustainable Forestry Group. New titles are listed here as authors are mainly from Forest Research. Authors outwith the Agency are indicated by an asterisk.

Bulletin

126 *Phytophthora disease of alder in Europe*
edited by John Gibbs, Cees van Dijk* and Joan Webber (£16.00)

Conference proceedings, books and reports

Biodiversity in Britain's planted forests: results from the Forestry Commission's Biodiversity Assessment Project edited by Jonathan Humphrey, Richard Ferris and Chris Quine (£10.00).

Crossplan: integrated, participatory landscape planning as a tool for rural development edited by Simon Bell (£12.50).

The silviculture and management of coppice woodlands by Ralph Harmer and Jonathan Howe (£12.00).

The potential of applied landscape ecology to forest design planning: progress in research with special reference to Glen Affric and Sherwood Forest edited by Simon Bell (£19.00).

The restoration of wooded landscapes: proceedings of a conference held at Heriot Watt University, Edinburgh, 14–15 September 2000 edited by Jonathan Humphrey, Adrian Newton, Jim Latham, Helen Gray, Keith Kirby, Elizabeth Poulsom and Chris Quine (£17.50).

Guideline

Forests and water guidelines, 4th edition (£9.00)

Information Notes (free)

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

48 *Forests, carbon and climate change: the UK contribution*
Mark Broadmeadow and Robert Matthews

49 *Red band needle blight of pine*
Anna Brown, David Rose and Joan Webber

50 *Growing juniper: propagation and establishment practices*
Alice Broome

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Steve Lee and Robert Matthews

56 *Restoration of neglected hazel coppice*
Ralph Harmer

Inventory Report

National inventory of woodland and trees – Great Britain
Steve Smith and Justin Gilbert (£15.00)

Practice Guides

14 *Restoration of native woodland on ancient woodland sites* Richard Thompson, Jonathan Humphrey, Ralph Harmer and Richard Ferris (£9.00)

15 *Reducing pesticide use in forestry*
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Max Hislop, Mark Twery and Heini Vihemäki (free)

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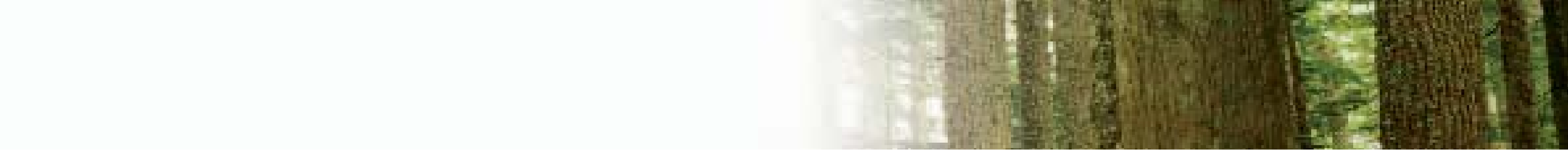

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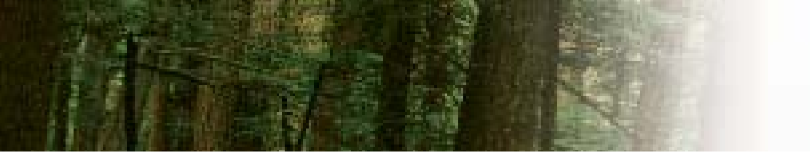


Major research programmes undertaken by Forest Research

Programmes funded by the Forestry Commission

Entomology Branch

Plant health

Hugh Evans, Nick Fielding and Christine Tilbury

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

Restocking pests

Stuart Heritage

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

Impact of insects on tree growth

Nigel Straw

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

Integrated Forest Management

David Wainhouse, Roger Moore and Hugh Evans

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

Mechanisms of tree resistance to insect attack

David Wainhouse

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

Advisory services

Christine Tilbury

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

Environmental Research Branch

Soil sustainability

Fiona Kennedy and 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, Kirsten Foot and Tony Hutchings

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

Forest hydrology

Tom Nisbet

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

Effects of air pollution on trees

Dave Durrant and Andy Moffat

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

Climate change

Mark Broadmeadow

Predict and model the impacts of 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.

Mensuration Branch

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.

Pathology Branch

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.

Silviculture (North) Branch

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 upon timber quality

Barry Gardiner, Jason Hubert, Elspeth Macdonald and Shaun Mochan

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

Silviculture of upland native woodlands

Richard Thompson and Colin Edwards

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

Alternative silvicultural systems in conifer forests

Bill Mason, Colin Edwards and Sophie Hale

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

Remote sensing

Juan Suárez

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

Silviculture and Seed Research Branch

Alternative establishment systems

Ian Willoughby and Richard Jinks

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

Energy coppice and poplar research

Ian Tubby

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

Lowland native woods

Ralph Harmer

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

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.

Social research unit (inter-Branch)

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

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

Technical Development Branch

Large-scale forestry harvesting

Colin Saunders

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

Large-scale ground preparation, seed sowing and planting

Steve Morgan, Andy Hall and Bill J. Jones

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

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

Andy Hall

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

Forestry operations on derelict and reclaimed land

Bill J. Jones

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

Wood for energy

Andy Hall and Paul Webster

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

Chemical weeding

Bill J. Jones

Evaluate equipment, application techniques and safety.

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 Improvement Branch

Selection and testing of conifers

Steve Lee

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

Breeding and production of conifers

Steve Lee

Clonal archives: conservation, advanced breeding material. Improved seed: controlled pollination, seed orchards.

Improvement of broadleaves

Ned Cundall

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

Origin and provenance of conifers

Sam Samuel

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

Genetic conservation

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.

***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.

Woodland Ecology Branch

Biodiversity evaluation and indicators

Jonathan Humphrey

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

Forest habitat management

Jonathan Humphrey, Russell Anderson and Helen Armstrong

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

Species Action Plans

Alice Broome, Roger Trout, Chris Quine and Brenda Mayle

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

Landscape ecology

Kevin Watts and Chris Quine

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

Ecological site classification and decision support systems

Duncan Ray

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

Squirrel management

Brenda Mayle

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

Deer population ecology and management

Robin Gill, Helen Armstrong and Brenda Mayle

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

Tree protection

Roger Trout

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

Woodland Surveys Branch

National inventory of woodland 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.

Programmes 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 lugging 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.

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.

Modelling of *Heterobasidion* infection in European forests.

Phytophthora in European oak decline.

Urgent conservation management for Scottish capercaillie.

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

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

Risk analysis for *Phytophthora ramorum.*

Timber cladding, northern periphery.

Programmes funded by individual organisations

CCW/FCW
Woodland habitat network strategy for Wales.

Department for the Environment, Food and Rural Affairs
Development of site-specific yield model for ash in lowland England and Wales.

Species boundaries on Phytophthora.

Yield models for energy coppice of poplar and willow.

Department for the Environment, Food and Rural Affairs/Loughborough University
Trees and drought in lowland England.

Department for the Environment, Food and Rural Affairs/Natural Environment Research Council
Cause-effect relationships for pollutant inputs to UK woodland ecosystems.

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

EC/Highland Birchwoods
Conservation of native oakwoods.

EC/Scottish Natural Heritage
Restoration of wet woods.

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.

Health and Safety Laboratories
Vibration exposure of chainsaw operators.

ITE
Terrestrial effects of acid pollutants.

UK emissions by sources.

Madeira National Park
Mammal control.

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

Terrestrial carbon dynamics.

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

Raleigh International
Huemul ecology research for the conservation planning in Southern Chile.

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

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.

Testing methods for monitoring beaver impacts on terrestrial vegetation in Knapdale.

Red squirrel habitat mapping.

SCRI
Woodcore samples.

Sheffield University
CTCD data management.

Southampton University
Short rotation coppice (poplar).

USDA
Phytophthora ramorum.

Woodland Trust
Weed control using non-chemical methods.

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.

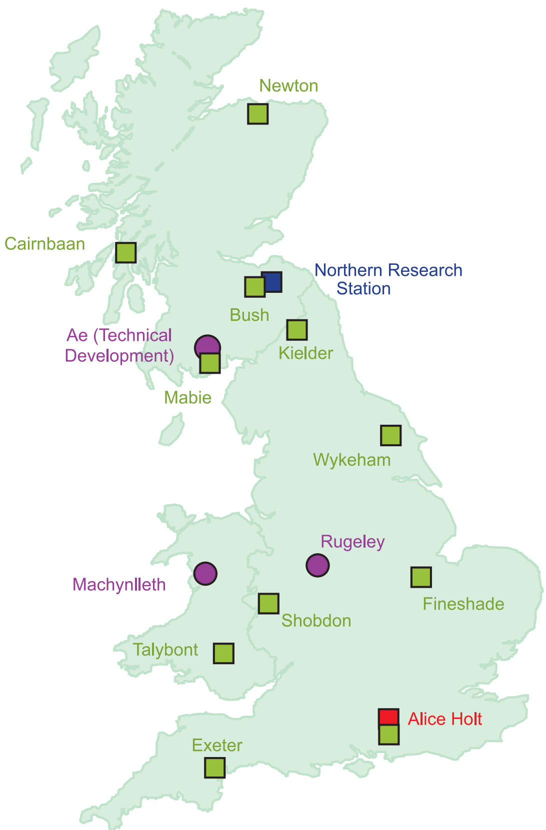
University of Ulster
Feeding ecology of the large pine weevil.
Impact of defoliating insects on forests.

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

Forest Research people

Staff as at 31 March 2004, in Branches, Sections and Technical Services based at:

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



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

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

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

Head of Northern Research Station
- Bill Mason, BA, BSc, MICFor

Personal Secretary
- Madge Holmes

Since June 2004 the new FR structure shown on page 2 has been in place.

*Denotes part-time.

Administration Branch

- Ken Charles, FMS, *Personnel and Administration Officer, Head of Branch*

Central Services
- Mike Wheeler
- Mandy Sennett*
- Amanda Smith*
- Bevan Stephens
- Mike Young

Personnel
- Wendy Groves
- Janet Lacey
- Calum Gordon

Typing
- Sally Simpson*
- Heather Russell*

Administration, NRS
- Martin Abrahams, *Head of Section*
- Gerry Cockerell
- Evelyn Hall
- Esther Ker
- Heather Edmonds*
- Linda Legge*
- Roz Shields*

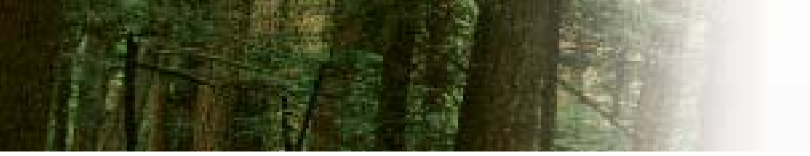
Finance and Planning Branch

- Tony Cornwell, FCMA, *Head of Branch*
- Gilly Anderson*
- Laura Caless
- Peter Filewood
- David Georghiou, BA
- Carol Knight*
- Carole Martin
- Alison Melvin, BA
- Janet Turner

Communications Branch

Photography and Publications
- George Gate, *Head of Section and Acting Head of Branch*
- Glenn Brearley
- Jenny Claridge, BSc, ARCS
- Sally Taylor *(also with Library and Information)*
- John Williams

Library and Information
- Catherine Oldham, BA, MA, DipLib, MCLIP, *Head of Section and Librarian*
- Eleanor Harland, MA, DipLib, *Assistant Librarian*
- Kirsten Hutchison, MA
- Thelma Smalley*



Entomology Branch

- Hugh Evans, BSc, DPhil, FRES, *Head of Branch*
- Sara Brough, BSc
- Gillian Green, BSc*
- Martin Jukes, CBiol, MIBiol
- Shirley Stephens*
- Nigel Straw, BSc, PhD, FRES
- Christine Tilbury, BSc
- David Wainhouse, MSc, PhD, FRES
- Stuart Heritage, MBA, CBiol, MIBiol, *Head of Section*
- Roger Moore, BSc, PhD

Environmental Research Branch

- Andy Moffat, BSc, PhD, *Head of Branch*
- Lorraine Adams, BSc
- Sue Benham, BSc
- François Bochereau, BSc, MSc
- Caroline Kilbride, BSc
- Mark Broadmeadow, BSc, PhD
- Samantha Broadmeadow, BSc, MSc
- Sylvia Cowdry*
- Peter Crow, BSc, MSc
- Dave Durrant, BA
- Kirsten Foot, BSc, MSc, EngD
- Tony Hutchings, MSc
- Elizabeth Luttrell, BSc *(also with Woodland Ecology Branch)*
- Anthea McRiley, BSc
- Tom Nisbet, BSc, PhD
- Rona Pitman, BSc, PhD
- Geoffrey Sellers, BSc, MSc, PhD
- Danielle Sinnett, MSc
- Hugh Thomas, BSc, MSc
- Ernest Ward, BSc, MSc, CChem, MRSC
- Elena Vanguelova, BSc, MSc, PhD
- Rene van Herwijnen, MSc, PhD
- Christine Whitfield*
- Matthew Wilkinson BSc, MSc

Mensuration Branch

- Professor Sam Evans, MA, PGDip, PhD, PhD, *Head of Branch*
- Catia Arcangeli, MSc, PhD
- Miriam Baldwin, HND, BSc, MSc
- June Bell
- Eric Casella, MSc, PhD
- Tim Cooper
- Ian Craig
- Cecile De Munck, BSc, MSc
- Paul Henshall, BSc
- Tracy Houston, BSc, MIS
- Ewan Mackie, BSc, MSc
- Robert Matthews, BSc, MSc
- John Proudfoot
- Tim Randle, BSc
- Marc Sayce
- Paul Taylor, MA, MSc, MPhil

Pathology Branch

- Joan Webber, BSc, PhD, *Head of Branch*
- Professor Clive Brasier, BSc, PhD, DSc, Emeritus
- Anna Brown, BSc, PhD
- Sandra Denman, BSc, MSc, PhD
- Anthony Jeeves
- Susan Kirk
- Carol Lishman*
- Elizabeth Orton, BA, MSc
- David Rose, BA
- Joan Rose
- Katherine Thorpe, BA, MSc, DPhil
- Sarah Green, BSc, PhD, *Head of Section*
- Steven Hendry, BSc, PhD
- Grace MacAskill
- Heather Steele, BSc*

Silviculture & Seed Research Branch

- Paul Tabbush, BSc, MSc, FICFor, *Head of Branch*
- Vicky Cunningham, BSc
- Peter Gosling, BSc, PhD
- Ralph Harmer, BSc, PhD
- Lorelie Ives
- Andrea Kiewitt, BSc, MSc
- Richard Jinks, BSc, PhD
- Gary Kerr, BSc, FICFor, PhD
- Liz O'Brien, BSc, PhD
- Matt Parratt, BSc
- Victoria Stokes, BSc, PhD
- Ian Tubby, BSc
- Ian Willoughby, BSc, MBA, MICFor
- Christine Woods, BA

Silviculture North Branch

- Bill Mason, BA, BSc, MICFor, *Head of Branch*
- Julie Barrette, BSc, MSc*
- Alexis Achim, BSc
- Stephane Berthier, PhD
- Colin Edwards, BSc
- Professor Barry Gardiner, BSc, PhD, FRMetS
- Sophie Hale, BSc, PhD
- Alan Harrison, BSc
- Max Hislop, MICFor
- Elspeth Macdonald, BSc, MSc
- Colin McEvoy, BA
- Suzanne Martin, BSc, PhD
- Shaun Mochan, MSc
- Bruce Nicoll, BSc
- Mike Perks, BSc, MSc, PhD
- Stephen Smith, BSc, MICFor
- Juan Suárez-Minguez, BSc, MSc
- Richard Thompson

*Denotes part-time.

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

Statistics and Computing Branch

- Jane Smyth, BSc, *Head of Branch*
- Carol Foden*
- Dai Jeffries, BSc
- Dan Johnson, BSc
- Timothy Knight, BSc
- Geoff Morgan, BSc, MSc, PhD
- Jane Poole, BSc, MSc
- Lyn Pearce*
- Chris Vials, BSc
- Wayne Blackburn, BSc, *Head of Section*
- Stephen Bathgate, BSc, BSc, PGDip
- Lynn Connolly*
- Tom Connolly, BSc, PhD
- Alec Gaw, BSc*
- Alvin Milner, BSc, PhD
- Andrew Peace, BSc
- Lynn Rooney*

Tree Improvement Branch

- Sam Samuel, BSc, PhD, *Head of Branch*
- Stuart A'Hara, BSc, MSc, PhD
- Cathleen Baldwin
- Joan Cottrell, BSc, PhD
- Ned Cundall, BSc, PhD
- Jason Hubert, BSc, PhD
- Allan John, BSc, PhD
- Steve Lee, BSc, PhD, MICFor
- Margaret O'Donnell*
- Rob Sykes

Woodland Ecology Branch

- Chris Quine, MA, MSc, MICFor, PhD, *Head of Branch*
- Russell Anderson
- Helen Armstrong, BSc, PhD
- Alice Broome, BSc
- Tracy Brown, BSc, MSc
- Jonathan Humphrey, BSc, PhD
- Liz Poulsom, MSc
- Duncan Ray, BSc
- Louise Sing, BA, MSc
- Brenda Mayle, MSc, *Head of Section*
- Andy Brunt
- Mark Ferryman
- Robin Gill, BSc, MSc, PhD
- Matthew Griffiths, BSc, MSc
- Elizabeth Luttrell, BSc *(also with Environmental Research Branch)*
- Roger Trout, BA, PhD
- Kevin Watts, BSc, PhD

Technical Development Branch

- Bill Jones, *Head of Branch*
- Bill J. Jones
- Steve Morgan
- Derry Neil
- Norma Nicholson*
- Joyce Rammell, BSc
- Colin Saunders
- Aileen Wallace*

Midlands

- Andy Hall
- Duncan Ireland, BSc
- Martin Lipscombe
- Paul Webster

Wales

- David Jones, EngTech, AMIAgrE

Woodland Surveys Branch

- Steve Smith, BSc, BA, MBA, *Head of Branch*
- Graham Bull
- Christine Brown
- Justin Gilbert, BSc
- Shona Cameron
- Esther Whitton

Field Stations

Technical Services (North)

- Kate Fielding, *Head of Branch*

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
- Martin Mckinnon, BSc
- Steven Osborne, BSc
- Steven Sloan

Inver

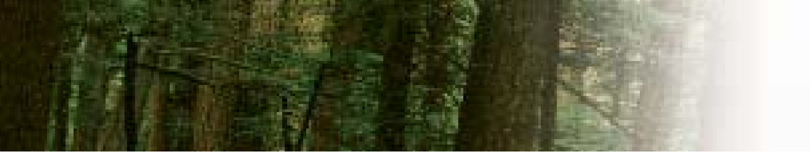
- Nick Evans
- Bill Rayner

Bush Nursery

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

*Denotes part-time.

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



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

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

Kielder
- Terry Gray
- Mike Ryan
- Len Thornton

Mabie
- James Duff
- Joanna McGregor*
- Hazel MacLean
- Harry Watson
- James White

Newton and Lairg
- Alistair MacLeod, *Head of Stations*

Newton
- Hazel Andrew*
- Allison Cowie
- Andrew Kennedy, BSc
- Finlay McAllister, BA, BSc
- Fraser McBirnie
- Stuart McBirnie
- Hugh MacKay, BSc
- Stephen O'Kane
- Colin Smart
- Linda Tedford

Lairg
- Alexander Bowran
- Calum Murray
- Duncan Williams

Technical Services (South)

- Norman Day, *Head of Branch*

Alice Holt
- Nick Tucker, *Head of Station*
- Jamie Awdry
- Bob Bellis
- Sue Bellis
- Tony Bright
- Kate Harris
- Steve Coventry
- Ian Keywood
- Vicky Lawrence
- Tony Martin
- Ralph Nickerson
- Doug Nisbet
- Jim Page
- Bill Page

Alice Holt Workshop
- John Davey
- Mike Johnston

Exeter
- Dave Rogers, *Head of Station*
- Alan Ockenden
- Dave Parker
- 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*
- Brian Hanwell, BSc
- Jason Jones
- John Price
- Sharon O'Hare*
- Richard Nicoll

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

*Denotes part-time.

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

PhD students linked with Forest Research

Helen Billiald (Sussex University)
Lois Canham (University of Stirling)
Lauren Crawford (Imperial College)
Richard Curtis (University of Gloucester)
Hannah Drewitt (University of Durham)
Sharon Flint (Manchester Metropolitan University)
Samantha Gale (Abertay University)
Caroline Hacker (Imperial College)
Joe Hope (University of Stirling)
Jack Johnston (Ulster University)
Amanda Lloyd (Newcastle University)
Anna Manoukiants (University of Brighton)
Tanya Ogilvy (Edinburgh University)
Vini Pereira (Imperial College)
Pernille Schiellerup (University College London)
Helen Sellars (University of Liverpool)
Helen Shaw (University of Stirling)
Suzanne Swanwick (Cranfield University)
Janine Tan (Ulster University)
Louise Timms (Imperial College)
Alessandra Timarco (Reading University)
Georgios Xenakis (Edinburgh University)
Liz Young (University of Portsmouth)

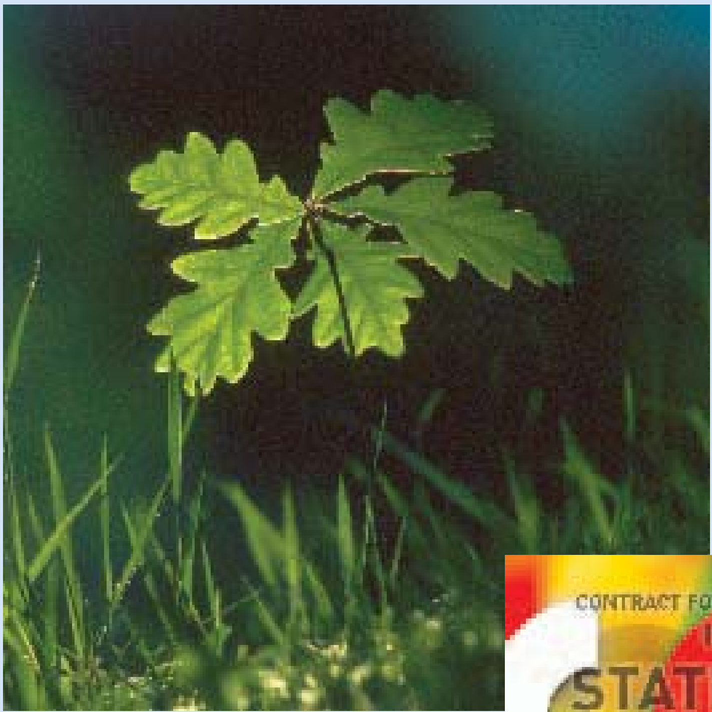
Research associate

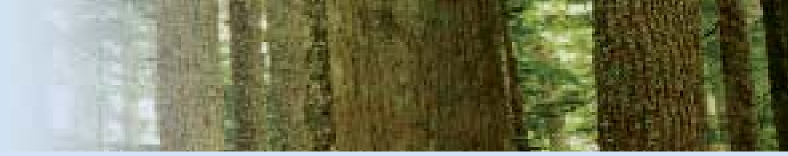
Steve Petty, PhD

*Denotes part-time.

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

Accounts for the year ended 31 March 2004





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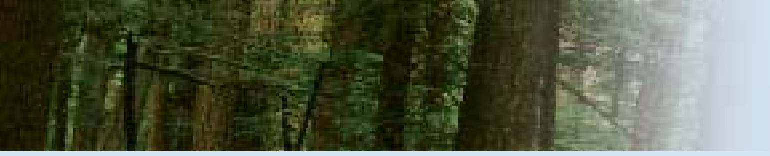


Foreword

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.

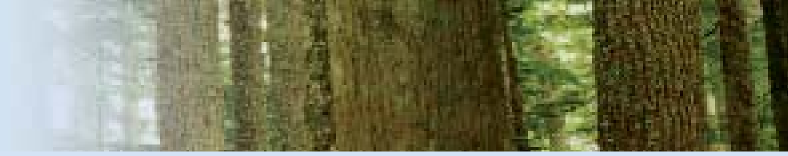
From 1 April 1997, the Agency assumed ownership of and responsibility for the assets and liabilities appropriate to the research activity, which were included in the Forestry Commission Statement of Assets and Liabilities as at 31 March 1997. It also assumed ownership of the building assets it occupies, 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 impact 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 one of a number of separate accounts produced and audited by the Commission and are consolidated into the overall 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 6 in the Annual Report.

4. Review of Activities

This is Forest Research's seventh year of operation as an Agency. Forest Research produced a net operating surplus of £410,000 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 £469,000 (6.2%)
- other management costs increased by £176,000 including provisions for employer liability claims (9.3%)
- materials and service costs reduced by £98,000 (4.0%)
- income from Forestry Commission customers increased by £353,000 (3.3%)
- income from external customers reduced by £24,000 (1.4%)
- the notional cost of capital reduced by £236,000 in the main due to the reduction in the Government standard interest rate from 6% to 3.5%

The net surplus for the year after cost of capital of £384,000 and depreciation was £26,000, representing a cost recovery rate of 100.2%.

After adjusting the total surplus for items not involving the movement of cash and for capital expenditure, bank account movements and income, the net cash inflow for the year was £763,000, of which £251,000 was transferred to the Forestry Commission, the balance being held in Agency bank accounts.

Additions to fixed assets in the year were £376,000.

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 2003–04 indicates that 99.97% 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.

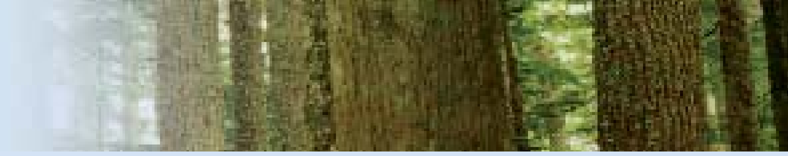
9. Management

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

Rt. Hon. Margaret Beckett MP	*Secretary of State for the Department for the Environment, Food and Rural Affairs*
Elliot Morley MP	*Parliamentary Secretary (Commons) for the Department for the Environment, Food and Rural Affairs (to 12 June 2003)*
Ben Bradshaw MP	*Parliamentary Under Secretary (Commons), Department for the Environment, Food and Rural Affairs (from 13 June 2003)*

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

Jim Lynch	*Chief Executive (from 1 July 2003)*
Peter Freer-Smith	*Research Director*
Ken Charles	*Head of Personnel and Administration*
Tony Cornwell	*Head of Finance and Planning*
Bill Mason	*Acting Head, Northern Research Station*



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

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 £21,000. There were no further assurance or other non-audit services.

Professor J.M. Lynch

Chief Executive and Agency Accounting Officer

19 October 2004

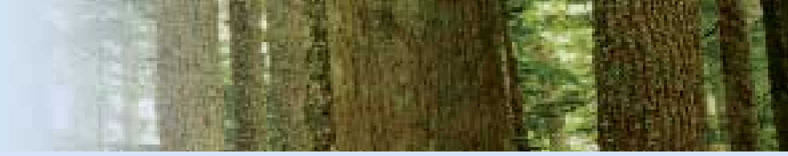
Statement of Forestry Commission’s and Chief Executive’s Responsibilities

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, set by Ministers, 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*.

On 1 April 2003, the Forestry Commission changed its structure to reflect a step change in co-operation with rural affairs departments in England, Scotland and Wales. This is underpinned by concordats worked up individually between each rural affairs department and the relevant Forestry Commission National Office. The required changes included:

- the Forestry Commission's Forest Enterprise agency was devolved into three bodies, including Forest Enterprise England, charged with managing separately the public forests in England, Scotland and Wales;
- an Executive and two Non-executive Commissioners for each country were appointed to the Board of Forestry Commissioners. The Board also delegated to National Committees in each country responsibility for country-specific issues; and
- a new ministerial committee, involving Ministers from England, Scotland, Wales and Northern Ireland was formed to discuss international issues and any crosscutting issues where collaboration would be advantageous and to monitor the effectiveness of the new arrangements.

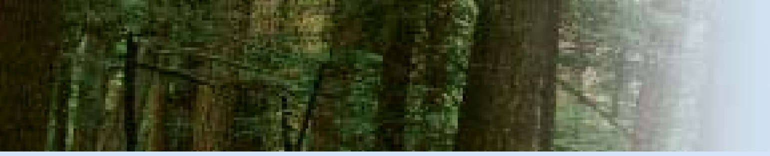
The Forestry Commission Research Agency remained a GB-wide agency funded by the UK Parliament.

The accountability arrangements for the Director General as Principal Accounting Officer of the Forestry Commission are set out in the Memorandum at Annex 4.1 of *Government accounting*. The Chief Executive of the Agency is responsible 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.

The Chief Executive also operates a separate Agency Executive Board to provide leadership and direction for the Agency.

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 2004 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. The process includes a Forestry Commission risk management policy document approved by the Forestry Commission's Executive Board. The Forestry Commission has a departmental Risk Improvement Manager who is supported by a risk champion for each body, including the Agency. During the year, the Head of Personnel and Administration of Forest Research has acted as risk champion for the Agency, including responsibility for maintenance of the risk register.

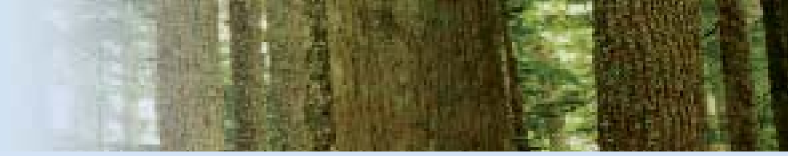
4. The risk and control framework

In response to the structural changes and further central developments in the operation of Audit Committees within the public sector, changes to the membership and terms of reference of the Forestry Commission Audit Committee were made during the year. These included strengthening the non-executive representation on the Committee to include a member per country, as well as executive representation from across the organisation, including the Agency, to allow the Committee to continue to fulfil its overarching Forestry Commission-wide role. The Committee met four times during the year to agree its revised role and responsibilities and to consider a range of reports from management, internal audit and external audit. For the first time, the Committee advised the Accounting Officers on the draft accounts prior to signature. As part of the Forestry Commission's governance framework, the Board of Commissioners received oral reports on Committee business during the year and a more formal annual report on the discharge of its duties at the end of the year.

The country Executive Commissioners and Agency Chief Executives were provided with more detailed advice on the work of Internal Audit in particular, and control in general, via local Internal Control Committees (ICCs). In line with the countries, the Forest Research Audit Committee was reconstituted as an ICC in 2003–04. The Agency's ICC covers all aspects of the Agency's business. The Committee met twice during the year to set its terms of reference, to establish formal arrangement for the provision of internal audit services and to receive progress reports on audit activity and risk management. In early April 2004, the Committee reviewed the results of audit work during the year and agreed an updated audit strategy for 2004–05 onwards including forward planning, resources and charging arrangements.

Work on implementing the risk management initiative continued during the year with the revision of the risk register. Following a recent internal review of the Agency's management structure, this will include updating management responsibility for risk in 2004–05 to incorporate the new research Heads of Division, where appropriate. At the corporate level, a seminar involving all relevant parts of the organisation, including Internal Audit, was held in early June 2004 to review progress during 2003–04 and consider next steps, including training for risk champions. Any points of relevance to Forest Research in terms of changes to Forestry Commission policy and procedures will be advised in due course. The group will meet again in the autumn to review progress.

The Agency has a service agreement with the Forestry Commission's Internal Audit unit that operates to prescribed Government Internal Audit Standards. They submit regular reports, which include the Head of Internal Audit's independent opinion on the adequacy and effectiveness of the Agency's system of internal control, together with recommendations for improvement. The Audit planning process is subject to regular update to ensure that it remains focused on the key risks to the Agency.



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 Board and the Audit Committee, and a plan to address weaknesses and ensure continuous improvement of the system is in place.

My review of the effectiveness of the system of internal control is informed by:

- the work of the internal audit team;
- the results of accounting inspections;
- the work of the health and safety team;
- the Forestry Commission Audit Committee and Forest Research ICC;
- the risk improvement manager; and
- comments made by the external auditors in their management letter and other reports.

The Head of Internal Audit has prepared an annual report and assurance statement to the Agency Accounting Officer. The overall opinion is that internal control within Forest Research generally provides *substantial* assurance that material risks to the achievement of objectives are adequately managed. The evidence, based on audit coverage last year coupled with the results from previous years, is that risk is generally well managed across the control spectrum with no major weaknesses identified.

Whilst not affected to the same extent as the Forestry Commission and the Forest Enterprise Agency by the Forestry Devolution Review outcome, Forest Research has nevertheless been subject to some recent, and ongoing, significant changes to its governance and control framework. These include the appointment of a new Chief Executive and subsequent structural review; the consequential appointment of new Heads of Division; a revised Research Strategy; and the proposed implementation of a formal Quality Assurance scheme. In terms of the Forestry Devolution Review, it has also been a participant in the introduction of the service board culture for corporate activities. Some of these changes have only recently been put in place, some are still ongoing and others, such as the shared services regime, will take time to bed in. The Head of Internal Audit will evaluate the impact on control of these changes by undertaking a review of the effectiveness of the corporate governance framework and associated risk management processes within the Agency in 2004–05.

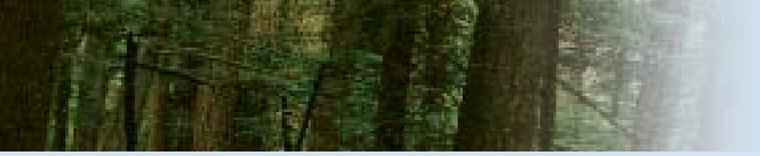
6. Significant internal control problems

No significant internal control problems were identified.

Professor J.M. Lynch

Chief Executive and Agency Accounting Officer

19 October 2004



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 158 to 172 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 161 to 163.

Respective responsibilities of the Agency, the Chief Executive and Auditor

As described on page 152, 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.

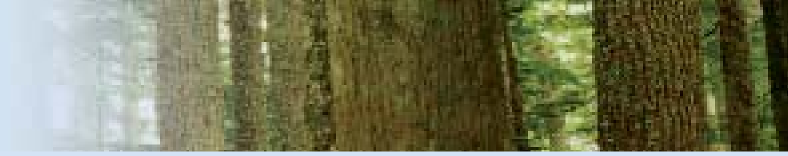
I report my opinion as to whether the financial statements give a true and fair view and are properly prepared in accordance with the Government Resources and Accounts Act 2000 and Treasury directions made thereunder, and whether in all material respects the expenditure and income have been applied to 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 153 to 155 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:

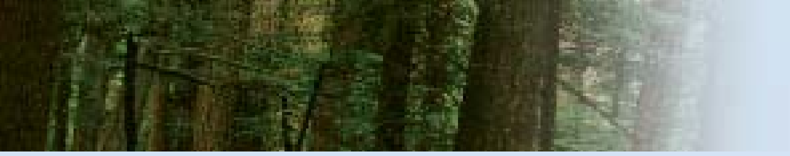
- the financial statements give a true and fair view of the state of affairs of the Forest Research Agency at 31 March 2004 and of the surplus, total recognised gains and losses and cash flows for the year then ended and have been properly prepared in accordance with the Government Resources and Accounts Act 2000 and directions made thereunder by Treasury; and
- in all material respects the expenditure and income have been applied to the purposes intended by Parliament and the financial transactions conform to the authorities which govern them.

I have no observations to make on these financial statements.

John Bourn
Comptroller and Auditor General

25 October 2004

National Audit Office
157–197 Buckingham Palace Road
Victoria
London SW1W 9SP



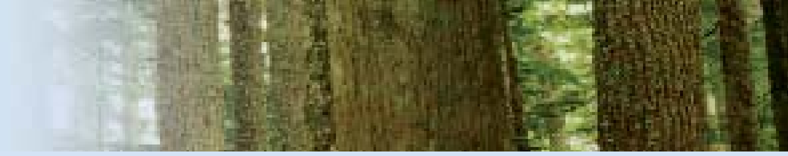
Income and Expenditure Account for the year ended 31 March 2004

	Notes	2004 £000	2003 £000
Income			
Income from research, development and survey services			
Forestry Commission customers	2	**11,186**	10,833
Non-Forestry Commission customers			
European Commission		**844**	510
Other		**807**	1,165
Total income		**12,837**	12,508
Expenditure			
Staff costs	3	**7,997**	7,528
Other management costs	4 & 5	**2,075**	1,899
Materials and services	5	**2,355**	2,453
Total expenditure		**12,427**	11,880
Net operating surplus/(deficit)		**410**	628
Notional cost of capital	8	**(384)**	(620)
Net surplus/(deficit) for the year		**26**	8
Transferred to General Fund		**26**	8

Statement of Total Recognised Gains and Losses for the year ended 31 March 2004

	2004 £000	2003 £000
Net surplus/(deficit) for the year	**26**	8
Revaluation surplus/(loss) for the year	**376**	500
Total recognised gains/(losses)	**402**	508

The notes on pages 161 to 172 form part of these accounts.

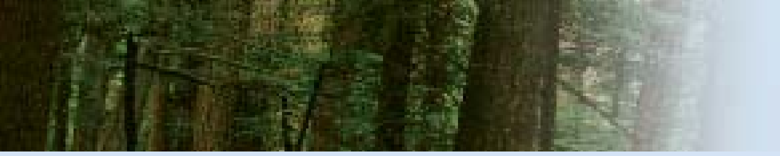


Balance Sheet as at 31 March 2004

	Notes	**31 March 2004 £000**	31 March 2003 as restated £000
Fixed assets			
Tangible assets	6	**10,731**	10,378
Intangible assets	7	**36**	
		10,767	10,378
Current assets			
Stocks and Work in progress	9	**536**	162
Debtors	10	**613**	1,031
Cash at banks and in hand	11	**512**	-
		1,661	1,193
Current liabilities			
Creditors – amounts falling due within one year	12	**715**	660
Provisions for liabilities and charges	13	**150**	-
		865	660
Net current assets		**796**	533
Total assets less current liabilities		**11,563**	10,911
Taxpayers Equity			
General Fund	14	**6,926**	6,523
Revaluation Reserve	15	**4,637**	4,388
Total Taxpayers Equity		**11,563**	10,911

Professor J.M. Lynch
Chief Executive and Agency Accounting Officer
19 October 2004

The notes on pages 161 to 172 form part of these accounts.



Cash Flow Statement for the year ended 31 March 2004

	Notes	2004 £000	2003 as restated £000
Reconciliation of net surplus to net cash flow from operating activities			
Net surplus/(-) deficit for the year		**26**	8
Notional cost of capital	8	**384**	620
Depreciation	4 & 6	**485**	389
(Profit)/loss on disposal of assets		**11**	5
Decrease/(-)Increase in stocks and work in progress		**(374)**	97
Decrease/(-)Increase in debtors		**418**	(560)
Increase/(-)Decrease in creditors		**55**	(81)
Increase /(-)Decrease in provisions		**150**	
Less increase in capital creditors		**(28)**	
Net cash inflow from operating activities		**1,127**	478
Capital expenditure			
Payments to acquire tangible fixed assets		**(340)**	(503)
Payments to acquire intangible fixed assets		**(36)**	-
Increase in capital creditors		**28**	-
Capital expenditure – cash outlay		**(348)**	(503)
Non-cash inter-country transfers		**(16)**	9
Total net cash inflow/(-) outflow		**763**	(16)
Financing			
Cash surplus(-)/deficit transferred to/funded by Forestry Commission		**(251)**	16
Increase/(decrease) in cash		**512**	-
Reconciliation of net cash flow to movement in net funds			
Increase in cash and bank		**512**	-
Net funds at 1 April 2003		**-**	-
Net funds at 31 March 2004		**512**	-

The notes on pages 161 to 172 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 2003–04 *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 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 2003–04.

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

1.3 Valuation of Assets

Land and buildings were subjected to a triennial revaluation as at 31 March 2002 by professionally qualified land agents employed by the Forestry Commission following the principles set out in the *Royal Institute of Chartered Surveyors Appraisal and Valuation Manual*. Research and office equipment is revalued every three years using prevailing current prices for replacement items. Between revaluations, tangible asset values are updated annually using appropriate indices provided by the Commission's District Valuers.

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 (the lower limit has been changed from 4 to 3 years to bring FR treatment in line with the rest of the Forestry Commission).

1.5 Intangible Assets

Form 1 April 2003, purchases of software with an acquisition value of £1,500 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 £1,500 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 provisions for bad and doubtful debts are set aside on the basis of a review of individual debts at the end of the year.

1.8 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 (VAT)

The Forestry Commission is registered for 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. Exchange differences are taken to the Income and Expenditure Account. Exchange rate gains as at 31 March 2004 amounted to £19,476.53.

1.13 Insurance

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

1.14 Pensions

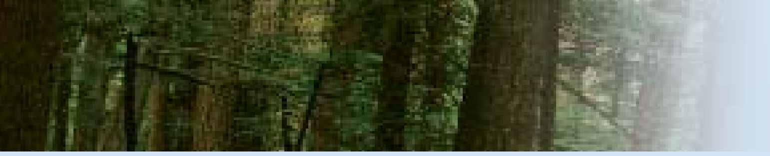
Past and present employees are covered by the provisions of the Principal Civil Service Pension Scheme (PCSPS), which is a defined benefit scheme and is unfunded. The Forestry Commission recognises the expected cost of providing pensions on a systematic and rational basis over the period during which 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 Compensation Scheme

The Forestry Commission is required to meet the additional cost of benefits beyond the normal pension scheme benefits in respect of employees who retire early. For Agency staff leaving after 1 April 1999, excepting those who left during 2000–01 under the provisions of the Modernising Government Fund, future liabilities for monthly 'compensation' payments will be shown in the Agency's accounts. To date, there have been no early retirements meeting this criterion.

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. Following 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 for 2003–04. The relevant parts of the 2002–03 figures have been restated in the 2003–04 accounts to reflect the accounting policy.



Note 2. Income from Forestry Commission and Forest Enterprise

The Agency undertakes a significant proportion of the Forestry Commission's overall annual research programme in the form of specifically commissioned projects to deliver agreed outputs. A separate annual charge is agreed for each project based on full cost recovery. These charges amounted to £9.6 million. Costs established in one year are used to determine project charges for future years. The Agency also provides research and survey services for Forest Enterprise and other parts of the Forestry Commission on a full cost recovery basis.

Total income from Forestry Commission customers consisted of:

	2004	2003
	£000	£000
Research, development and other services to:		
Forestry Commission	**10,808**	9,797
Forest Enterprise	**378**	1,036
	11,186	10,833

Note 3. Staff Costs and Numbers

3.1 Employee costs during the year amounted to:

	2004	2003
	£000	£000
Wages and Salaries	**6,618**	6,285
Social Security Costs	**506**	424
Employer's Superannuation Costs	**864**	797
Agency Staff Costs	**9**	22
	7,997	7,528

To comply with RAM 2003–04 costs of temporary staff, engaged from employment agencies, have been included with staff costs.

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. A full actuarial valuation was carried out 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 2003–04, employers contributions of £864,000 were payable to the PCSPS (2002–03:£797,000) at one of four rates in the range 12% to 18.5% of pensionable pay, based on salary bands. The scheme's Actuary reviews employer contributions every four years following a full scheme valuation. Rates will remain the same in 2004–05, subject to revalorisation of the salary bands, but will increase in 2005–06. The contribution rates reflect benefits as they are accrued, not when the costs are actually incurred, and reflect past experience of the scheme.

Employees joining after 1 October 2002 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 Dr Peter Freer-Smith, Research Director, the highest paid member of the Board, was £62,869.50. That of Professor Jim Lynch, Chief Executive, with effect from July 2003 was £54,630.72. 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 31/3/04 and related lump sum £000	5 CETV @ 31/3/03 £000	6 CETV @ 31/3/04 £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 £
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
William Mason	40–45		0–2.5 plus 2.5–5.0 lump sum	15–20 plus 50–55 lump sum	256	280	11	0
2002–03								
Jim Dewar	10–15		0–2.5	25–30				
Peter Freer-Smith	50–55	800	0–2.5	10–15				
Ken Charles	35–40		0–2.5	15–20				
Tony Cornwell	35–40		0–2.5	0–5				
Bill Mason	40–45		0–2.5	10–15				

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 above 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).

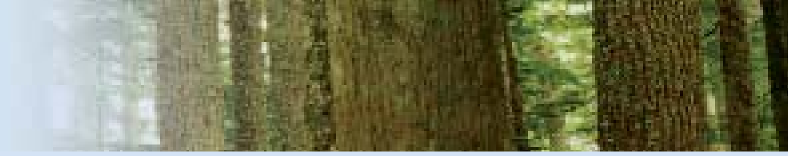
Employee contributions are set at the rate of 1.5% of pensionable earnings for classic and 3.5% for premium and classic plus. Benefits in classic accrue at the rate of 1/80th of pensionable salary for each year of service. In addition, a lump sum equivalent to three years pension is payable on retirement. 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 Cash Equivalent Transfer Value (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 The average number of employees (full-time equivalents) during the year was 278 (2002–03: 280).

3.6 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 eight individual members of staff at 31 March 2004. The total outstanding value of all loans (15) was £64,172.40.

Note 4. Other Management Costs

Other management costs are stated after charging:

	2004	2003
	£000	£000
Loss on disposal of fixed assets	**11**	5
Auditors' Remuneration	**21**	19
Depreciation of Fixed Assets	**485**	389
Travel and Subsistence	**458**	460
Staff Transfer Expenses	**20**	68
Training	**112**	134
Building Maintenance	**381**	431
Utilities	**259**	220
Computer Supplies	**77**	96
Provision for claims for employer liability	**150**	-
Other Expenditure	**101**	77
	2,075	1,899

Note 5. Charges from the Forestry Commission

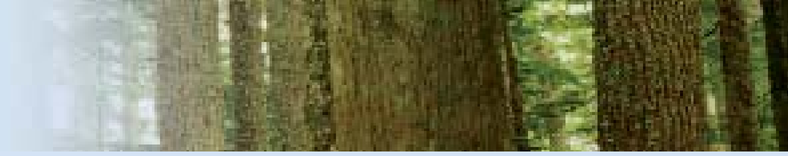
Included within Other Management Costs and Materials and Services are charges from the Forestry Commission and Forest Enterprise amounting in total to £986,462 (2002–03: £1,018,580).

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

Note 6. Tangible Fixed Assets

	Freehold Land and Buildings	Machinery and Equipment	Total
	£000	£000	£000
Valuation:			
At 1 April 2003	**8,932**	**3,628**	**12,560**
Additions	11	329	340
Disposals	(9)	(85)	(94)
Transfers	131	(36)	95
Reallocation	25	(25)	–
Revaluation adjustment	376		376
At 31 March 2004	**9,466**	**3,811**	**13,277**
Depreciation:			
At 1 April 2003	**168**	**2,014**	**2,182**
Provided in year	184	301	485
Disposals	(1)	(82)	(83)
Transfers	(8)	(30)	(38)
At 31 March 2004	**343**	**2,203**	**2,546**
Net book value:			
At 31 March 2004	9,123	1,608	10,731
At 31 March 2003	8,764	1,614	10,378

Fixed assets were revalued as at 31 March 2004 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 £6.0 million and £2.6 million respectively at 31 March 2004.



Note 7. Intangible Fixed Assets

	2004	2003
	£000	£000
Balance at 1 April 2003	–	–
Additions	36	–
Balance at 31 March 2003	36	–

Intangible 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. The addition in 2003–04 is the value as at 31 March 2004 reflecting applied enhancements during the year. Consequently, no amount has been amortised in 2003–04.

Note 8. Cost of Capital

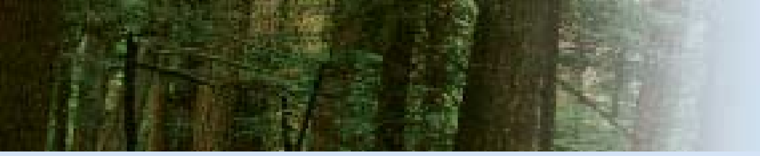
Notional cost of capital based on 3.5% (2002–03: 6%) of average total assets less current liabilities employed in 2003–04 amounted to £384,287 (2002–03: £620,068).

Note 9. Stocks and Work in Progress

	2004	2003
	£000	£000
Research Work in Progress	**536**	162
	536	162

Note 10. Debtors

	2004	2003
	£000	£000
Amounts falling due within one year		
EC debtors	**236**	457
Other Trade debtors	**167**	350
Other debtors	**21**	51
Prepayments	**136**	100
	560	958
Amounts falling due after one year – house purchase loans	**53**	73
	613	1,031



Note 11. Cash at Banks and in Hand

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. The balances at 31 March 2004 were £512,283.61. 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

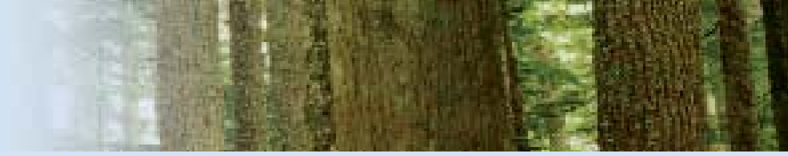
	2004	2003 as restated
	£000	£000
Payments received on account	**241**	350
Trade creditors	**441**	310
Other creditors including taxation and social security costs	**33**	
	715	660

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 2004 the amount held in Forest Research Bank accounts on behalf of partners was £348,884.55 (31 March 2003: £517,386.92).

Note 13. Provisions for Liabilities

	2004	2003 as restated
	£000	£000
Balance brought forward	–	–
Provided in year	150	–
Balance carried forward	150	–

Provision has been made for legal claims against the Agency in respect of all known claims where legal advice indicates that it would be prudent to make a provision. Expenditure is likely to be incurred over a period of one to two years.



Note 14. General Fund

	2004	2003
		as restated
	£000	£000
Balance brought forward	**6,523**	5,869
Transfer from revaluation reserve – disposed assets	**127**	
Movement in year		
Net surplus/(-) deficit for year	**26**	8
Transfer of fixed assets from/(-) to other Forestry Bodies	**133**	1
Cash surplus to(-)/ deficit from Forestry Commission	**(251)**	16
Non-cash inter-country transfers	**(16)**	9
Notional cost of capital	**384**	620
Balance carried forward	**6,926**	6,523

Transfers of fixed assets to and from other parts of the Forestry Commission include buildings and equipment. A research office and stores in Scotland were transferred to the Agency (net value £140,000) while three greenhouses (nil value) were transferred to the Commission. Copying and video-conference equipment (net value £7,000) were transferred to the Commission.

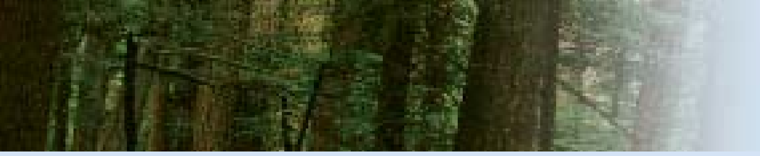
Note 15. Revaluation Reserve

	2004	2003
	£000	£000
Balance brought forward	**4,388**	3,888
Transfer to General Fund – disposed assets	**(127)**	
Revaluation surplus for the year ended 31 March 2004		
Land and Buildings	**376**	500
Balance carried forward	**4,637**	4,388

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 2004 was £1,645.02.



Note 17. Losses Statement

Losses totalled £2,769 from 2 cases (2002–03: £1,042 from 2 cases). Special payments totalled £14,985 from 49 cases (2002–03: £5,702 from 14 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, income from these sources being no more than 6.6% 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 £410,000, which, after allowing for the cost of capital, represented a cost recovery of 100.2% (2002–03: 100.1%).

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