Our Research

This year, our *Annual Report and Accounts* includes new introductory overviews that briefly illustrate the breadth of research in each of our five working areas, outlining a selection of current projects and showing their impacts. Each overview is followed by two technical Highlight articles that delve into other projects in a little more detail.

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Further information on these topics is available from the Forest Research website – specific links are given where suitable.

Biometrics, Surveys and Statistics

Fully understanding the potential of our woodland resources requires an accurate picture of the size, location and composition of forests and woodlands. Our teams working on biometrics, surveys and statistics contribute a range of critical scientific approaches, from statistical analysis and data management to surveying and measurement, modelling and software engineering. Often working behind the scenes, they contribute to many of our research projects. This year, we've made significant progress across a range of diverse activities – here are a few examples.

Developing surveys and monitoring

Robust science relies on rigorous methodology. Our statisticians work alongside other researchers to design appropriate surveys and experiments for a broad range of projects. Over the past year, this has included designing social forestry questionnaires and surveys (page 33), and devising a suitable method to estimate the 'timber miles' travelled by Scottish wood (page 39).

Native Woodlands Survey for Scotland

On behalf of Forestry Commission Scotland, our surveyors are creating a high-resolution digital map for the Native Woodlands Survey for Scotland (NWSS). For the first time, the project will fully survey all native woodlands in Scotland, rather than using a plot- or sample-based survey. This will enable Forestry Commission Scotland to create a database of information on Scotland's native woodlands, to assess the condition of all native woods and pinpoint which areas may need changes in management. The survey programme will also increase understanding of the potential of Scottish woodlands and their likely survival in the longer term – two key considerations when devising management plans.

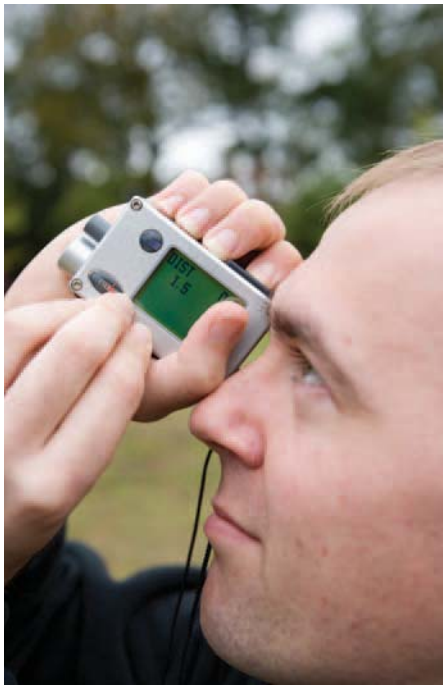
Remote sensing in surveys

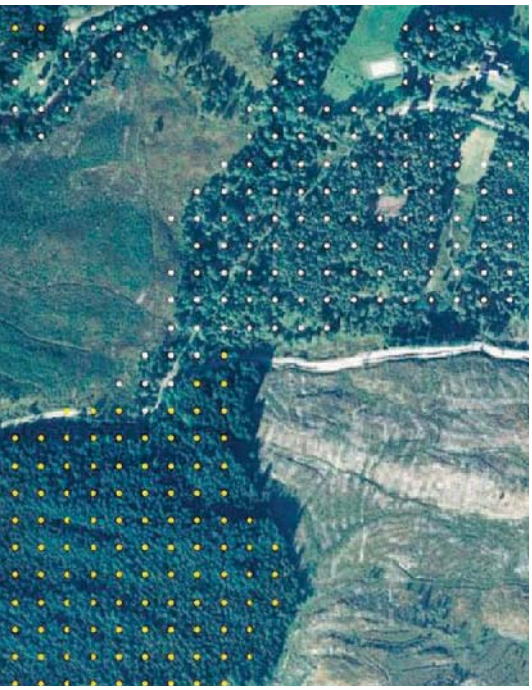
Our survey researchers have been testing the capabilities of airborne laser scanning (ALS) for producing inventory data to support forest-management decisions at tactical and operational levels. This relatively new remote-sensing technique has proved its value as a cost-effective aid to inventory systems. ALS can detect tree height, canopy dimensions and the spatial distribution of dominant tree types within a stand. This level of detail – never before achieved by any other sensor – improves our understanding of stand dynamics, how trees grow, their stability and timber potential.

Remote sensing used in models

International collaboration between Forest Research and other organisations is helping to advance knowledge about the allometric relationships (i.e. the different growth rates and proportions) of trees growing in close proximity. This is improving understanding of the spatial distribution of dominant types, and the effects this may have on both the growth dynamics of individual trees and the stability of stands of trees. For example, data generated by ALS were input to an adapted version of our wind-risk model ForestGALES. The results have increased understanding of the effect of stand structure on the likelihood of wind damage.

By highlighting the characteristics of those trees in a stand that are most vulnerable, we have been able to refine estimates of the probability of wind damage. Consequently, we can now make more-accurate predictions of wind damage than can be generated from stand information gathered in the field or from existing Forestry Commission woodland databases. Since this information can be obtained in a semi-automated manner, ALS can provide a cost-effective alternative to field data collection, and can increase the operational use of ForestGALES by forest practitioners. Further information is available from **www.forestresearch.gov.uk/forestgales**





Integrating forest monitoring systems

Forest Research has also contributed to the development of proposals for the Integrated Forest Monitoring project. This work will update and integrate four existing monitoring systems that collect a range of data, from photosynthesis to tree height, in order to better answer current and future needs. Future monitoring systems are likely to use stratified sampling based on woodland classification using species, management, soil and meteorological data. The integrated monitoring system will combine data from different sources to allow the estimation of quantities of interest using modelling techniques. Further details of our survey work is available at **www.forestresearch.gov.uk/surveys**

Modelling and data systems

Forest Research has been developing and improving an extensive collection of growth and yield models, several of which have recently been finalised and presented to their user communities for testing and feedback. For example, our modellers recently assisted the Department for Environment, Food and Rural Affairs (Defra) in creating 'opportunity maps' showing where short-rotation coppice can be most successfully grown. This involved using models based on data collected from the largest network of short-rotation coppice field trials in Europe. In addition, another model for predicting short-rotation coppice growth and yield under changing environmental conditions was presented to Defra and other stakeholders, including policy-makers and end-users. More details on the model can be found at **www.forestresearch.gov.uk/src**

The modelling team is also testing and refining a model that focuses on rainfall interception by tree canopies. Experiments at two different sites – Alice Holt in Surrey and Thetford in Suffolk – measure how much rain is intercepted at the canopy level. The model accurately simulates the rainfall interception at these sites, providing quantitative information on an important component of a forest's water balance. Work is underway to evaluate the model's suitability across Britain and to provide guidance and predictions for policy-makers on how forests may affect the amount of rainfall available for recharging groundwater levels under future management and climate scenarios.

Timber production forecasting for British forests

Our researchers work closely with the Forestry Commission to forecast the availability of annual timber volume from the national forest estate, both public- and private-sector. Potential timber production over 20 years is predicted by a set of models that are modified for different regions and forest types to reflect important variations in management practices. These include, for example, the wider adoption of continuous-cover forestry systems, which avoid clear felling. The published forecasts are used directly by the forest industry in decision-making for future investment, as well as in long-term planning of supply. They also form the basis of UK timber statistics, as reported to the United Nations. More details can be found at **www.forestry.gov.uk/forestry/hcou-4u4jgx**

Evaluating the carbon benefits of forestry

With the increasing importance of climate change, it has become necessary to estimate the value of climate-change mitigation by UK forests. This involves quantifying carbon dynamics of typical UK forests, considering the management techniques that maximise long-term carbon stocks, and evaluating what carbon emissions can be displaced by switching from fossil fuels to wood-based energy sources.

This year, Forest Research has been closely involved in research into the potential impacts of forest carbon management. This has included providing Forestry Commission England with forecasts of the carbon dynamics of woodlands under different management regimes to inform the development of a woodfuel strategy. We have also provided information on changes in forest carbon stocks, enabling economic analyses of the costs and benefits of forest carbon management.

Modelling the spread of diseases

As part of a recently completed EU project, our modellers have been working with experts in tree health on an experiment in Portugal to study pine wilt disease. This has included providing calibration and validation of the Forest Research ForestETP model – an ecological model adapted to simulate the impacts of the disease across Europe.

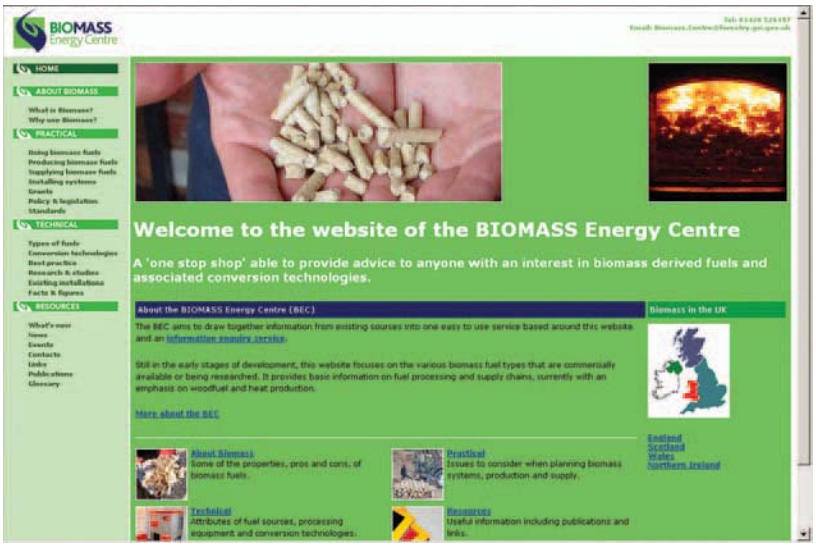
Woodfuel and biomass energy

Ian Tubby and Andy Hall

Forest Research has been studying and developing systems associated with the production, processing and end use of biomass and woodfuel for over two decades. This research experience, combined with a proven capability for technology transfer, ensured that FR was well placed to develop a 'national focus of knowledge and analysis on biomass energy', as recommended to government by the Biomass Task Force in October 2005. As part of government response to these recommendations, the Biomass Energy Centre (BEC) was launched in April 2006 to provide information on biomass-derived fuels and associated conversion technologies. Managed by Forest Research on behalf of the Forestry Commission and the Department for Environment, Food and Rural Affairs (Defra), the BEC has provided impartial and up-to-date advice and guidance in response to about a thousand enquiries and requests for information in its first year. Many of these enquires are received via the dedicated website **www.biomassenergycentre.org.uk** (Figure 1).

Figure 1

The website of the Biomass Energy Centre: www.biomassenergycentre.org.uk



Throughout the year the BEC has played an important part in initiatives to develop a sustainable biomass sector, and is integral to the woodfuel strategy published by Forestry Commission England in March 2007. The BEC also works with Forestry Commission Scotland and with the Wood Energy Business Scheme in Wales. The Centre continues to develop links and information-delivery mechanisms with regional bodies and local organisations across the UK.

A significant number of responses to enquiries received by the BEC draw on results emerging from the Woodfuel Research Centre, home to Forest Research's growing portfolio of biomass-related investigations. A large proportion of this work is highly applied with direct relevance to industry, and is purchased centrally by the FC. Increasingly, projects are funded by other organisations such as Defra, the Institute for Grassland and Environmental Research, the EU and the Welsh Assembly. As well as enjoying good links with other research groups in the UK, the Woodfuel Research Centre contributes to international consortia such as the International Energy Agency Task 31: 'Biomass Production for Energy from Sustainable Forestry'. The Woodfuel Research Centre hopes to build on this sound start and to broaden knowledge and research experience in the coming year.

Simulating the impact of pinewood nematode

Sam Evans, Makihiko Ikegami and Hugh Evans

Simulating the effects and impacts of a pest of pine trees is providing a new perspective on predicting pest risk. The pinewood nematode *(Bursaphelenchus xylophilus)* is an organism that usually lives on dead or dying pine trees. It is spread by longhorn beetles (genus *Monochamus*), which can introduce the organism into healthy trees without any apparent effects on plant activity. In some cases, however, and in a number of geographical regions, pinewood nematode has been found to cause the rapid death of mature pine trees. A body of evidence shows that the organism induces wilting of susceptible pine species (Figure 1), and is significantly affected by seasonal variation in water availability. Under certain environmental conditions the severity of wilting can result in death of the host plant. Pinewood nematode has been found in Portugal since 1999, so evaluating its potential risk to European pine species under a European climate is essential for devising appropriate management strategies to prevent its further expansion.

Forest Research has used current understanding of tree growth processes to develop a model describing and simulating what happens in cases of infestation with pinewood nematode. The model describes the physiological behaviour of the tree host and its interaction with the nematode to predict the likelihood of tree death. Simulations run for sites in the Iberian peninsula, including those where fatal infestation occur, indicate a high likelihood of host death, both immediately and in the year following infestation with pinewood nematode. Within the model, the principal predictors of tree mortality are high temperature and low precipitation in summer, and medium temperature and high precipitation in autumn. Elsewhere, where environmental conditions do not result in significant tree stress, pinewood nematode does not result in wilting and host death. An ongoing observational experiment in Portugal, using *Pinus pinaster* trees infested with pinewood nematode, suggests a good correlation between simulated and observed results. It is proposed that, with further refinement and validation, this model may be suitable for developing a generic framework to predict the vulnerability of different hosts to pinewood nematode across a range of geographical regions.

Figure 1

Wilting in pine trees, caused by pinewood nematode

Ecology

Our ecology teams carry out research into woodlands and forests using a number of different approaches. In particular, we're investigating methods to conserve biological resources, such as species and habitats; we're also researching how to safeguard and enhance woodland biodiversity, and examining the impact of animals on woodland ecosystems. Here, we highlight some of our recent research.

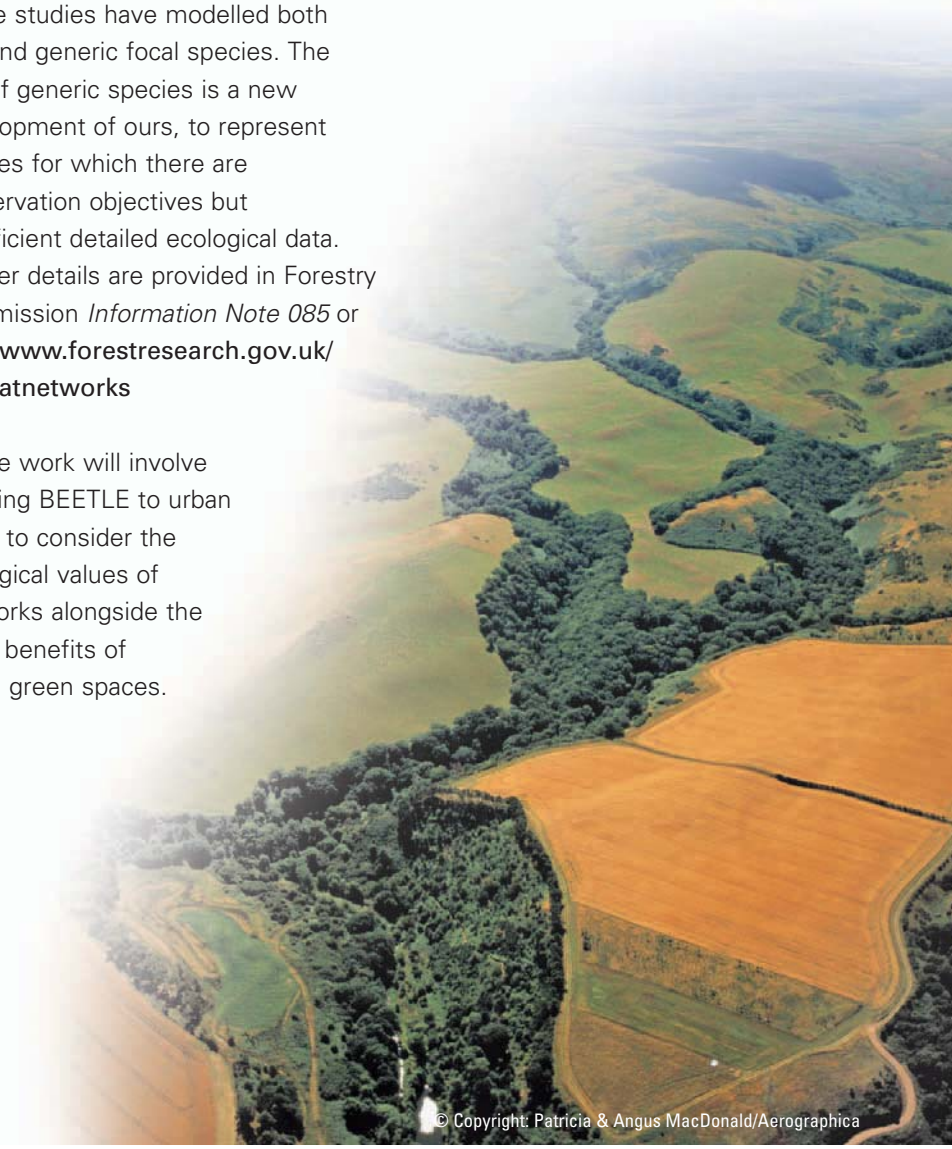
Implementing landscape ecology through habitat networks

Despite considerable conservation efforts at different sites, research and monitoring has revealed a continuing decline in biodiversity. This is thought to be due to the effects of habitat fragmentation and a reduction in habitat quality, associated with intensive land management. These factors, combined with increased policy interest in changing land use, concern about the impact of climate change and developments in ecological theory, highlight the need for a more sophisticated approach to landscape ecology.

Our research into landscape ecology is increasing understanding of how biodiversity is affected by forest management practices at a landscape scale. This is highly relevant to the ecology and management of British forests, helping to inform forestry and landscape planning practices.

Recently, our work has focused on habitat networks, which link and expand habitats, making them capable of sustaining greater biodiversity. In the past, a structural approach considered only those habitats that are linked physically. Habitat networks consider the landscape from a more functional point of view, taking into account the ability of some organisms to move across surrounding land from one region of suitable habitat to the next. In this way, more sophisticated analyses of landscapes become possible. The landscape is no longer defined by areas of 'habitat' and 'non-habitat', but as an overall matrix that comprises various habitat areas of varying attractiveness, or hostility, to particular organisms. Our suite of Biological and Environmental Evaluation Tools for Landscape Ecology (BEETLE) is now widely identified as the tool with which to assess habitat networks using Geographic Information Systems (GISs). As well as woodland, BEETLE can also help analyse other open ground habitats of concern. Over the past year, the suite of tools has been used in a number of projects across Great Britain: supporting the development of habitat network strategies, helping to integrate the concept of networks into local development plans, and targeting grant aid for environmental improvement and forest expansion. These studies have modelled both real and generic focal species. The use of generic species is a new development of ours, to represent species for which there are conservation objectives but insufficient detailed ecological data. Further details are provided in Forestry Commission *Information Note 085* or from **www.forestresearch.gov.uk/habitatnetworks**

Future work will involve applying BEETLE to urban areas to consider the ecological values of networks alongside the other benefits of urban green spaces.



Assessing the impact of mammals on habitats

We are involved in an ambitious project to study the impacts of deer on habitats. Entitled 'Collaborative frameworks in land management – a case study of wild deer in Britain', the project is funded by the Rural Economy and Land Use programme (RELU) and brings together a multi-disciplinary group of scientists from a number of research centres. The project aims to improve understanding of both the impacts of deer on land and the attitudes towards these impacts among a range of stakeholders, including owners, managers and users of the countryside. Forest Research scientists are contributing both social and ecological expertise to this project.

Other work has developed a range of assessment methods to obtain greater insights into the problems encountered by land managers when grazing by deer and/or domestic stock causes damage to habitats or valuable crops. For example, a method has been developed to assess the degree of over-grazing in upland and lowland woods for the Department for Environment, Food and Rural Affairs (Defra). Another, more in-depth method has been devised to help Forestry Commission England monitor progress to encourage favourable conditions in 80 woodland Sites of Special Scientific Interest (SSSIs). Further details about our work on herbivore impacts is available at **www.forestresearch.gov.uk/reludeer**

Disseminating knowledge on biodiversity

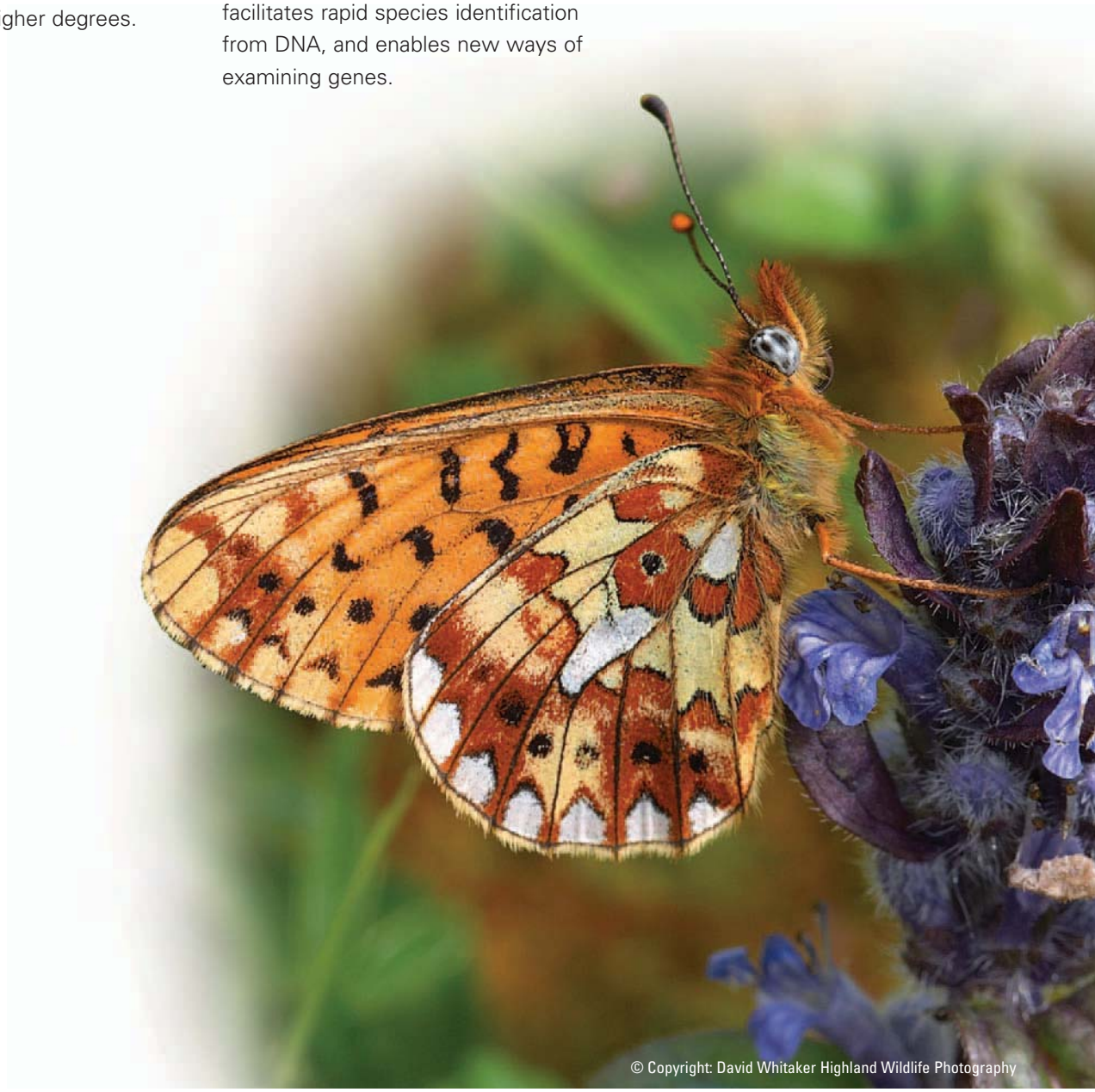
Assembling complex ecological information to be of practical use to managers of forests, woodlands and other priority habitats provides a particular challenge. Forest Research is working on decision-support tools to achieve this, and has been deeply involved in the organisation of knowledge to form new Forestry Commission Biodiversity Guidelines. These Guidelines support the UK Forestry Standard; they are supplemented by a wider range of Practice Notes and other detailed information that helps practitioners to implement policy and make site-specific decisions.

We are also exploring new ways of making information available. For example, a decision-support system for Habitats and Rare, Priority and Protected Species (HARPPS) will shortly be presented as a web-based tool. HARPPS will provide information for managers seeking to understand what they need to do to enhance the prospects for particular species or habitats, and how they might modify management activities to achieve this. We also disseminate knowledge informally, and regular updates on our ecology research are available from our online newsletter *ECOTYPE* at **www.forestresearch.gov.uk/ecotype**

Researching molecular genetics

The detailed information held by systems such as HARPPS is underpinned by rigorous research. Our work continues to focus on a number of habitats and species of particular conservation interest (as introduced in the article by Broome and colleagues in Forest Research's *Annual Report and Accounts 2003–2004*). Increasingly, our investigations are carried out in collaboration with universities and other institutes through shared work or joint funding of higher degrees.

We are currently exploring the potential value that molecular genetics may add to these studies, in terms of both population structure (e.g. selecting the best strategy and most suitable species to expand native tree populations) and by providing insights into how landscape structure influences plant and animal populations. The recent acquisition of a real-time Polymerase Chain Reaction (PCR) machine has also opened up a new range of possibilities for ecological studies and molecular diagnostics. The machine facilitates rapid species identification from DNA, and enables new ways of examining genes.



Criteria for changing forest land use

Duncan Ray, Chris Quine, Louise Sing, Max Hislop and Fauzia Davidson

Figure 1

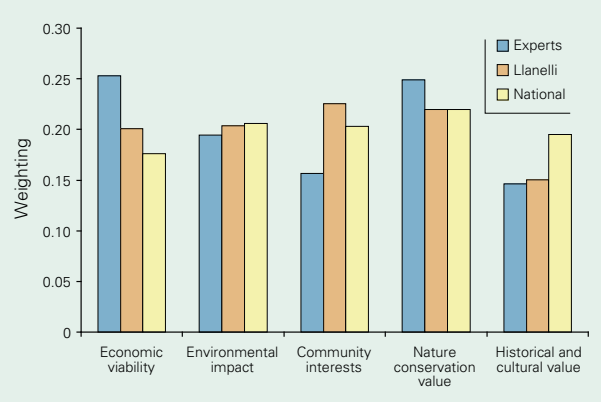
Social scientist Max Hislop facilitating a meeting with Friends of Pembrey Forest, June 2006

Sustainable forest management balances the role of forests in providing goods and services for local and national economies, communities and the environment. In Wales, it has been recognised that some areas of conifer forest do not provide the required sustainable benefits. Forestry Commission Wales (FCW) and the Countryside Council for Wales (CCW) funded a study to examine the issues and develop policy recommendations to guide the change of some forest to other land-use types, including the restoration of priority habitats.

A multi-disciplinary project team reviewed forest policy and drivers for land-use change in Wales, and used multi-criteria decision analysis (MCDA) as a framework for assessing the need for change at two scales. At the national scale, all areas of coniferous woodland were assessed as candidates for change, within a geographical information system (GIS). At the local scale, more detailed data could be incorporated to evaluate particular candidate areas or other forest areas of local concern not identified in the national MCDA.

Figure 2

Variation between interest groups in the weighting of five main issues



This Figure shows some of the results for the national MCDA analysis. If weightings were equally distributed, each issue would have a weighting of 0.2, as the sum of the weights equals 1.

Workshops with expert stakeholders identified criteria for the MCDA and appropriate measures for assessing the options. Community-group meetings based in Llanelli in the summer of 2006 (Figure 1) and a national survey of 1000 people in Wales provided information on the perceived importance of five issues:

- economic viability
- environmental impact
- community interest
- nature-conservation value
- historical and cultural value

The weightings proposed by different stakeholders for the MCDA tool vary slightly (Figure 2). The expert stakeholder views were more polarised than those of other respondents, and favoured economic and nature-conservation issues over community interests and historical and cultural values.

This type of stakeholder and community involvement will play an important role in improving public participation in forest policy. The MCDA approach provides a structured, consistent, transparent and repeatable tool for supporting decisions. Moreover, the rigour of the approach ensures that a complete range of criteria pertinent to sustainable forest management, and often difficult to measure, can be included in the analysis and inform important decision-making.

Conservation measures for the Scottish capercaillie

Alice Broome, Liz Poulsom, Chris Quine and Roger Trout

The capercaillie *(Tetrao urogallus)* is an iconic bird of the boreal forest and of Scottish pine forests. In Scotland the species became extinct in the 18th century, but was successfully reintroduced in the 19th century. However, numbers have declined again in the past 30 years, prompting concern about the risk of another extinction. The decline seems to be due to a range of factors, including less suitable spring weather, changes in habitat quality, and increased deaths from predation and collisions with fences.

Forest Research is taking part in an ambitious project on urgent conservation management for the Scottish capercaillie, in partnership with Highland Birchwoods, the Royal Society for the Protection of Birds, Cairngorms National Park Authority, Forestry Commission Scotland, Scottish Natural Heritage and co-financed by the LIFE financial instrument of the European Union. Forest Research has been monitoring elements of the project, including habitat enhancement and fence marking.

Different intensities of tree thinning have been carried out on three sites, with the aim of diversifying habitats while also improving the timber crop, and the vegetation response at each site has been monitored (Figure 1). A particular aim was to increase the amount of bilberry *(Vaccinium myrtillus)*, which, together with associated caterpillars and other invertebrates, is an important food for capercaillie chicks. The monitoring has shown slower-than-expected vegetation responses to changes in light availability, and important contributions of pre-existing vegetation cover. Excessive thinning of stands can lead to the expansion of competing species such as heather *(Calluna vulgaris)* and cowberry *(Vaccinium vitis idaea)* at the expense of bilberry (Figure 2), but lack of thinning also results in losses of bilberry.

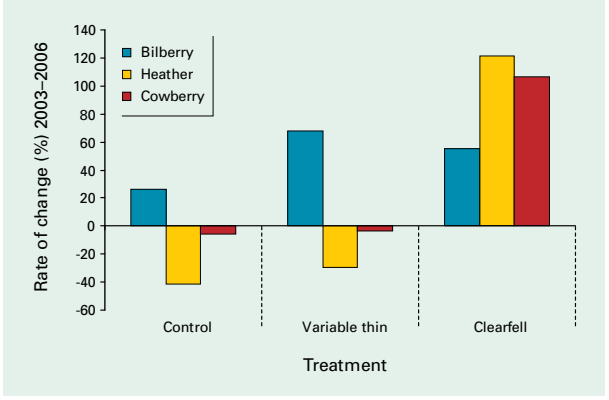
Figure 1

Variable-intensity thinning at Inschriach Forest

Many unwanted deer fences have been removed in core capercaillie areas, but in some places fences are still required. Forest Research has developed various designs, tested their durability and monitored their efficacy in reducing collisions with woodland grouse. New designs have proved robust, and dramatic differences have been observed in the collision rate – for example, on a 14 km fence after marking there was a nine-fold reduction in strike rate of capercaillie and red grouse *(Lagopus lagopus)*, and a six-fold reduction for black grouse *(Tetrao tetrix)*.

Figure 2

Vegetation responses to variable thinning, clearfell and no thinning control at Inschriach Forest



Environmental and Human Sciences

Our research into the environmental and human sciences draws on many elements of sustainable development, looking into environmental, social and economic links to forestry. While based on solid scientific foundations, research in this area is readily of use in practice and provides valuable advice for policy-makers and practitioners. Here, we outline six of our current projects, illustrating some important areas of research and showing the impacts that this work is achieving.

Measuring the benefits of forests to people

In April 2006, we began a two-year project on behalf of Forestry Commission Scotland, called Forestry for People. The project investigates how communities are affected by forestry and seeks to quantify benefits on a range of themes, establishing a monetary value for each, where possible. This is backed up by qualitative research in case-study areas. The themes considered are: livelihoods, education, health, recreation, amenity, culture and community capacity.

An interim report in February 2007 showed that the value of forest-related activities is much higher than expected. For example, 87% of people surveyed believe that woodlands are places to reduce stress and anxiety, 82% agree that Scotland's woodlands are good places in which to exercise and get fit, while 95% feel that woodlands play an important role in the outdoor learning experience of children and young people.

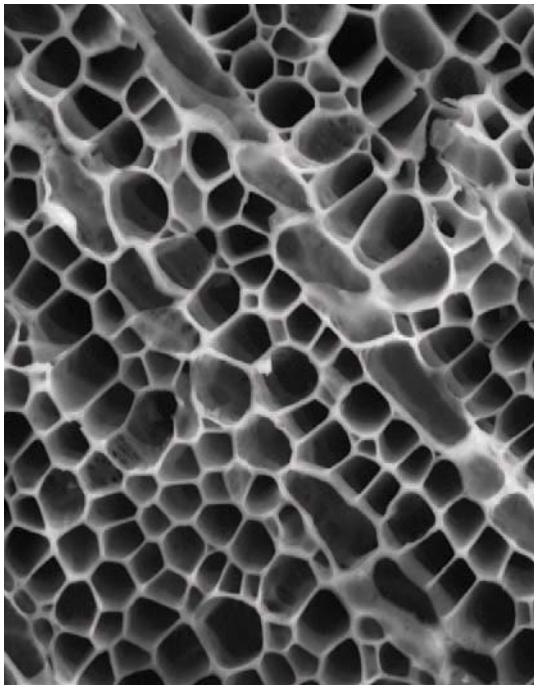
If we attribute economic values to physical and mental health, estimates show that the physical and mental health benefits of woodland recreation are worth up to £18m per year to Scotland's population. Similarly, visits to forests are worth around £40m per year, and having views of woodlands from homes and during daily activity is worth up to £39m per year. In addition, recreation and tourism in Scottish woods were found to support over 20,000 full-time-equivalent jobs.

Work continues on this project, to survey community woodland activities and further explore the relationship between different benefits of woodlands and their perceived values. More information is available at **www.forestresearch.gov.uk/forestryforpeople**

Using charcoal to treat contaminated land

The UK has an estimated 300,000 hectares of land contaminated with organic chemicals and heavy metals, mainly from previous industrial activities. As a result, this land is unsafe for direct redevelopment without first being treated or remediated. Unfortunately, conventional treatments for contaminated soil are becoming prohibitively expensive and labour-intensive, and often involve taking the soil away from the site to be either treated and returned or deposited elsewhere as landfill. As a further complication, different contaminants may require different treatment types.

Forest Research and the University of Surrey have recently patented a much cheaper and potentially more effective approach to soil remediation, using specially prepared and treated charcoals. Preliminary results show that the charcoals promote development of beneficial microbes that can degrade many organic contaminants through a process called bioremediation. Laboratory trials have shown that contaminants such as diesel are degraded up to 20 times faster when treated with the special charcoal materials. Contaminants that are not degraded are held strongly by the charcoal, making them environmentally benign; the charcoals have a strong ability to adsorb up to 20% of their own weight in metal contaminant.



In combination, these properties of bioremediation and chemical retention can help in the redevelopment of difficult sites. The charcoal is easy to apply and is simply incorporated into the contaminated soil. Forest Research and the University of Surrey have now also joined forces with Sheffield University and Aspire Defence Ltd to carry out field trials under a grant received from the Department of Trade and Industry's Programme for Contaminated Land Remediation Technologies. Further information on our research into contaminated land is available at **www.forestresearch.gov.uk/landreclamation**

Predicting soil erosion and pollution due to climate change

Future climate change will affect soil as well as vegetation. Recent research has examined how predicted changes in rainfall may increase the erosion of unprotected soils. In areas where soil is contaminated, this will increase the risk of water pollution.

Our researchers carried out case studies on two sites with a known high risk of water contamination through soil erosion and the subsequent transfer of heavy metals into surface waters. Predictive computer models were run for each site, using different climate-change scenarios.

The results showed a significant and gradual increase in rates of soil erosion with time as a consequence of climate change. However, modelling also showed that re-vegetation, including the establishment of woodland, could mitigate pollutant movement and reduce to well below existing levels the amount of metals transferred to the aquatic environment. Further research is investigating how land management practices could be developed to reduce the impact of climate change to an acceptable degree.

Promoting health through physical activity in forests

In support of the Department of Health campaign to encourage physical activity for all, one of our social research projects is investigating how active people are in the woodland environment, and what prevents increased activity. This research is supporting Active England, a programme run by Sport England, the government agency responsible for advising on, investing in and promoting community sport to create an active nation. The project is currently focusing on visitors to five different forest sites: Haldon (Devon), Bedgebury (Kent), Rosliston (Derbyshire), Greenwood (Nottinghamshire) and Great Western Community Forest (Wiltshire).

At each site, work is underway to monitor and evaluate the habits of users. New events – such as health walks, tai chi sessions and outreach work – have been introduced at some sites to help attract new visitors and encourage them to adopt healthier lifestyles. Researchers are carrying out yearly questionnaires with visitors, and are working to clarify the profile of the population within a 20-minute drive of each site. This will be followed by qualitative research in the surrounding communities amongst both users and non-users of the forest.

The project will particularly investigate key under-represented groups within the community, such as people on low incomes and young people under 16 years old, in order to identify what stops them from being more active, and to propose possible solutions. While still in its early stages, when completed, the Active England research will help forest managers to improve their understanding of the nature and needs of forest visitors. In turn, this will enable them to plan activities to increase the potential for forests to help deliver healthy lifestyles to those living in the area. For more information, visit **www.forestresearch.gov.uk/activeengland**

Mapping unrecorded woodland heritage with LiDAR

Peter Crow

Light detection and ranging (LiDAR) is a technique using laser pulses that can reveal landscape and archaeological features hidden beneath woodland canopies. In spring 2006, large-scale surveys were carried out in the Forests of Dean (Gloucestershire) and Savernake (Wiltshire), with exciting results. The survey in the Dean was the largest single heritage survey of a wooded landscape ever undertaken in the UK. Both surveys were commissioned to contribute to the discovery, mapping and management of historic environment features.

Continued research into the processing and visualisation of the survey data has enabled the production of modelled terrain images which, combined with targeted field survey and vegetation mapping, has increased confidence in their interpretation. These images have already resulted in the identification of hundreds of potentially new features of interest.

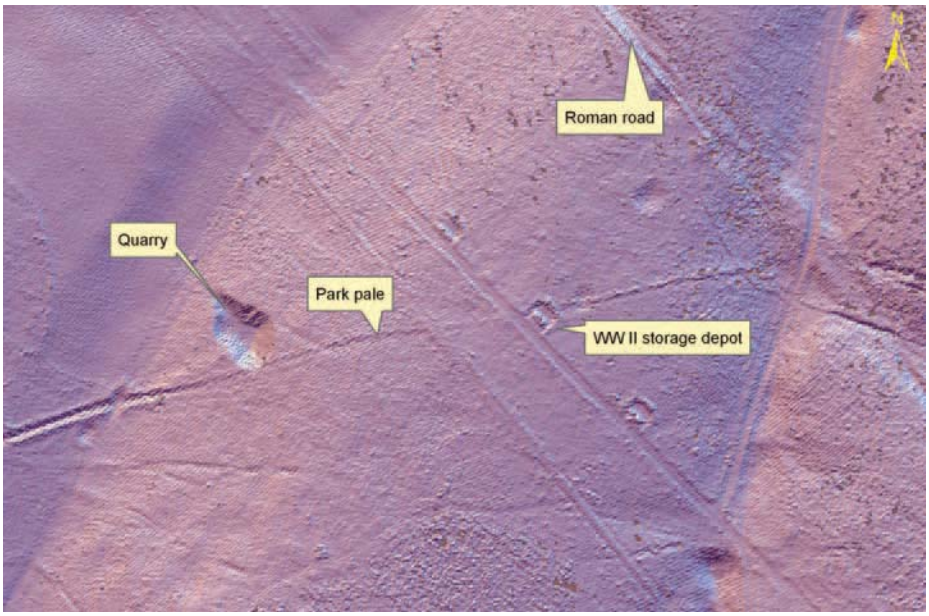
- The Forest of Dean has a landscape affected by mining and quarrying. Visible features include areas of mineral extraction (from small pits to extensive quarries), railways and trackways, spoil heaps and scowles (labyrinths of naturally occurring hollows in the ground that are special to the area). Extensive areas of charcoal production are also shown.
- The landscape at Savernake (Figure 1) is more varied, with quarries and pits for mineral extraction, but also Roman roads, a park pale (medieval boundary bank) and the remains of storage depots from the Second World War.

LiDAR will not work on every type of woodland, and not all the features identified in the data will be a significant part of the historic environment. However, results can be used to target areas for further investigation, and provide both professional archaeologists and local volunteers with maps for future fieldwork. The LiDAR models are being used to help forest planners and managers to refine and enhance plans for forest design, and to identify sensitive areas before the start of forest operations. LiDAR is continuing to generate considerable excitement in both the forest and heritage communities, and further surveys are being considered.

For more information on this application of LiDAR, please see: **www.forestresearch.gov.uk/lidar**

Figure 1

A LiDAR terrain model of the forest floor, Savernake



Dendrochronology and climate change research

Tanja Sanders, Mark Broadmeadow and Rona Pitman

There is an urgent need for guidance on how forests adapt to climate change, particularly with reference to choosing species for woodland creation and re-stocking. Applying knowledge gained from regions that have a climate similar to that predicted for a given site in the future will be increasingly valuable. Analysing the annual growth rings in tree trunks using dendrochronology is one method of assessing the impacts of extreme climatic events of the past.

Extreme events, particularly summer droughts, are likely to prove the principal limitation to tree growth and survival. Waterlogging of the soil in winter, leading to the death of fine roots, and late spring frosts, may also play a part. The effects of changing management practice, atmospheric nitrogen deposition and rising levels of atmospheric carbon dioxide also need to be considered.

To study the effects of climate on past tree growth, a pilot study has been conducted over the past two years at Alice Holt Forest in Surrey. Samples were taken from 20 oak trees (*Quercus robur*; Figure 1) planted in 1820. Preparation followed standard dendrochronological methods, and tree-ring width was measured to a precision of 0.01 mm. Data from individual trees were combined using standard techniques.

The chronology (Figure 2) shows clear annual variation in growth, for the period examined of 1822 to 2005. Years of poor growth are evident and correspond with the recent drought events of 1976, 1983/84, 1989/90 and 2003. A downward trend in growth rate is apparent from 1998 and is the longest period of decline without recovery. Statistical analysis of the chronology indicates that mild spring temperatures and above-average rainfall in early summer result in increased growth, while below-average rainfall in July and August leads to reduced growth.

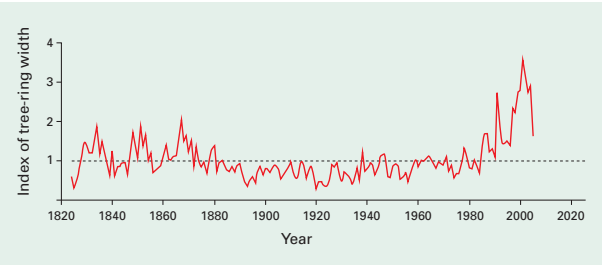
However, the strongest signal in the chronology is the dramatic increase in growth rate between the mid-1970s and 1998. The most likely factor to explain this is the rising atmospheric concentration of carbon dioxide. The decline in growth rate since 1998 is more difficult to interpret, and ongoing measurements will determine whether this is a short-term perturbation or a longer-term growth trend.

Figure 1

Increment cores of oak. The larger vessels indicate the start of the growing season for each year

Figure 2

Annual variation in tree-ring width of oak, 1820–2005



Forest Management

Our forest management researchers investigate a range of subjects relevant to the practical and sustainable management of forests and woodlands. Their work includes research into silvicultural systems (such as continuous cover forestry or low-impact silviculture), timber quality, conifer breeding and tree-seed biology. They also carry out technical development work to evaluate and develop forestry methods and machinery for use throughout the industry. Some of our more recent projects are briefly outlined here to illustrate the scope of our research.

Assessing timber miles

As part of its Scottish Climate Change Programme, the Scottish Executive has set targets for the forestry industry on carbon saving. One of the indicators used to measure this is 'timber miles' – the distance travelled relative to the tonnage of timber moved. This is similar to the concept of 'food miles' recently proposed by the Department for Environment, Food and Rural Affairs (Defra). Information on timber miles could be used to inform ongoing Scottish transport initiatives that aim to improve the sustainability of timber transport, making transportation more efficient and reducing the negative impacts of road haulage on communities.

In 2005/06, an initial scoping study found that the best source of information from which to calculate timber miles was the hauliers themselves. A subsequent study during 2006 identified the hauliers of Scottish timber and collected their mileage/tonnage information to make a first estimate of the current number of timber miles. Preliminary results suggest a very approximate annual total of 281 million timber miles for Scottish roundwood, with an average journey per lorry load of 51 miles. However, this is an initial estimate and further survey work is needed before we can establish accurate figures.

Surveying the structure and condition of native pinewoods

The European Union's directives on habitats and on birds together form a nature-conservation policy that aims to establish a network of protected areas where habitats and species are maintained or restored to favourable conservation condition. This network of special areas of conservation is called Natura 2000. Forest Research was asked to develop a monitoring system to assess the woodland condition in native Scots pinewoods based on the use of stand structure as a surrogate measure of favourable condition. We developed a method that combines measurements of tree parameters (e.g. tree diameter at breast height (DBH) and age, density of trees, saplings and seedlings, percentage damaged, amount of standing deadwood) with site variables (e.g. protection, elevation, canopy cover), based on systematically located 0.05 ha plots. The results are compared to the known structural characteristics of forest developmental phases to establish which phases are present or absent. This indicates the potential future development of the forest without intervention. Those phases that are missing or under-represented (e.g. large mature trees) may require targeted management to ensure continuity of key habitats.

A modified version of this system is being used in a survey of the native pinewoods in Glen Affric. Plots are chosen in different developmental phases, as identified from interpretation of aerial photographs, and the same tree-based parameters are being measured. This will enable an interpretation of current structure and condition on the landscape scale.

Researching tree breeding and genetics

Our research into tree genetics aims to increase the quality of commercially grown trees and to ensure that forests are populated with stock of the most appropriate genetic origin for the specific regional and local geographic variations and predicted climate.

Over the past 40 years, genetic improvement of Sitka spruce has been progressing steadily, from the selection of plus trees (parent trees selected for their superior growth and form) and progeny testing, through the establishment of seed orchards, to the annual production of cuttings from family mixtures.

We have now developed a new addition to the suite of improved Sitka spruce planting stock, known as 'full-sibling families'. These are families with only one mother and one father, compared to previously available improved genotypes based on crosses between several parents. The full-sibling trees grow more vigorously, are straighter and have less variation from tree to tree than standard Sitka spruce. The new full-sibling stock will have significant financial benefits for forest managers by improving timber quality and wood volume, as well as stand uniformity. There is already considerable demand for the new full-sibling seed; commercial nurseries are producing rooted cuttings and the new stock has been available to forest managers all over the country since spring 2007. Further information on our tree-breeding research is available at **www.forestresearch.gov.uk/treeimprovement**

Supporting our national arboreta

Westonbirt Arboretum and Bedgebury Pinetum are among the finest tree collections in Britain. Each site is an important visitor attraction and a valuable resource for education, containing many species of woody plants that are rare or endangered in the wild. Forest Research provides scientific and technical support to the arboreta, most recently including specialist propagation of rare species, support on plant-health issues, database support and audits of the management of the tree collection. Our scientists are also working with the Forestry Commission to coordinate the development of other important tree collections, such as at Kilmun and Brechfa. These activities directly support targets set out in the Global Strategy for Plant Conservation adopted by governments and other parties at The Hague in 2002.

One of our main projects, in collaboration with Bedgebury and the International Conifer Conservation Programme at the Royal Botanic Garden Edinburgh, is concerned with the *ex situ* conservation of populations of some of the world's most threatened conifers. The World Conservation Union (IUCN) lists nearly half of the world's 800 conifer species and sub-species as being of conservation concern. This project aims to establish a series of sponsored conservation plots at Bedgebury for breeding populations of selected threatened species. Some plots already exist at Kilmun. Other work includes developing a phenology-monitoring programme using species within the collections from different bioclimatic regions of the temperate zone.

Managing long-term field experiments

Over several decades, Forest Research has established an extensive network of field experiments of varying duration. In 2004 we began reviewing these ongoing experiments to cleanse and rationalise our experiment database and also to make the information more readily available both within

Forest Research and for the wider scientific community. As a result, we have identified a core of some 600 experiments for long-term retention, the oldest of which dates back to 1922. These are valuable not only for their original purposes but also as a unique and well-documented resource for future field-based research.

To achieve wider dissemination of our experimental information, it was decided that a web-based database would provide the best access. Such a system was already in use in Scandinavia for forest experiment data – the Nordic and Baltic database for long-term forest experiments, known as NOLTFOX. This online database covered many topics in common with ours, had a similar layout to that of our system, and concurred with our aim of using an open-access database to enable wider dissemination of experimental information. Therefore, we joined NOLTFOX in 2006 and our adapted Forest Research database was uploaded onto its site in December 2006. For more details, visit **http://noltfox.metla.fi**

Evaluating remote data capture

Remote data capture from tree-harvesting machinery provides a powerful tool for operators and managers. Many leading suppliers of harvesters and forwarders already use computers to aid machine-control functions, improve fault diagnosis and servicing, and assist in cutting the most profitable range of products from a tree (optimisation). Harvester computer systems have a number of benefits for operators, including increased cutting accuracy, ability to collect data about the stem profiles of the trees being harvested, facility to transfer data via e-mail and GIS, and their useful location-tracking of machinery and products using GPS.

Our researchers are investigating the full potential of such remote systems. In one study, we evaluated a computerised optimiser and found that it gave a higher-value mix of products, so improving financial return. In a separate evaluation, we tested a number of methods for transferring harvester production data, such as by e-mail, disks and computer prints, telephone or handwritten sheets. E-mail was found to be the quickest way to transfer production data between machines or directly to sawmills and offices.

Using digital maps and transferring data electronically between machines can be of great benefit to operators and managers when planning and working on site. These tools help to clearly identify working areas and constraints and, with use of a 'distance calculation' package, enable the most efficient extraction routes to be identified. Our work is continuing to assess the benefits and limitations of remote data management.

Sustainable management of the European forestry–wood chain

Bill Mason, David Edwards, Barry Gardiner, Andy Hall, Jonathan Humphrey, Ian Murgatroyd, Bruce Nicoll and Mike Smith

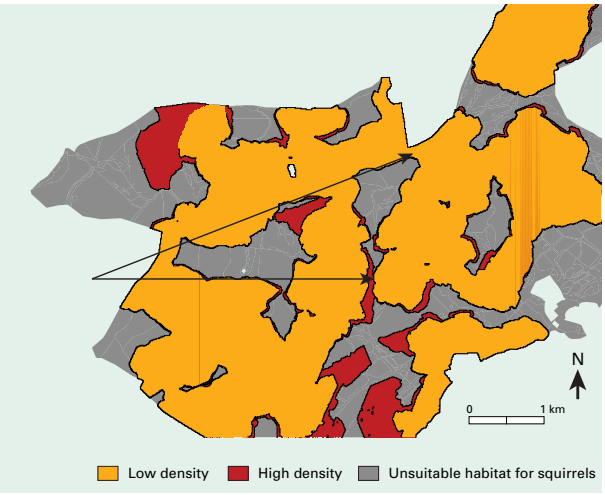
'EFORWOOD' is a four-year project funded by the European Union, to develop a quantitative decision support tool for sustainability impact assessment of the European forestry–wood chain (FWC). Known as ToSIA, this tool should be applicable at both pan-European and country/regional levels, to provide information on many aspects of the FWC from forest management through primary and secondary processing. The project is co-ordinated by Skogforsk in Sweden and involves researchers from 38 organisations including Forest Research.

Forest Research is working on the evaluation of different scenarios for forest-resource management, the implications for environmental and social indicators, and on the interactions between forest and processing industries. The main British case study area is Craik Forest in Forestry Commission Scotland's Scottish Borders Forest District, some 16 km west of Hawick. Craik was selected because over 50 per cent of the forest is Sitka spruce, so it typifies the conifer plantation forests established during the past 50 years which will be supplying increasing amounts of timber to the domestic market over the next 20 years. Craik also has an important population of red squirrels and is used extensively by local communities for recreation. This enables study of the interaction between different intensities and types of management and the consequences for timber flows, biodiversity and social values.

All key information about this forest is digitised, making it possible to explore different scenarios over time using geographical information systems (GISs). The approach is based on an analysis of landscape, ecology and habitat networks, using estimates of functional connectivity. The concept of focal species has been adapted to identify services that represent the economic, environmental and social elements of the forest–wood chain (such as timber value, red squirrel numbers, visitor numbers). Early results suggest that the spatial pattern of harvesting could have a detrimental effect on red squirrel populations by creating areas no longer accessible for squirrels (Figure 1). Other early outputs from this work can be found on the project website: **www.forestresearch.gov.uk/eforwood**

Figure 1

Red squirrels in west Craik, in relation to forest structure



The lines highlight points where felling could isolate squirrel populations.

Creating new broadleaved woodlands by direct seeding

Ian Willoughby, Richard Jinks, Peter Gosling, Ralph Harmer and Matt Parratt

While there are references to direct seeding in Britain dating back to the 15th century, planting is usually regarded as a more reliable method of woodland regeneration. However, there has been renewed interest in using direct seeding as a cheaper method for establishing new broadleaved woodlands, particularly for mixtures of species (Figure 1), and there has been significant progress in overcoming some of the problems associated with the technique.

Under natural conditions, for example, the seeds of many temperate trees and shrubs are dormant when dispersed or collected. They may remain so for up to two years, leaving the sown seed highly vulnerable to damage and death before it can germinate naturally. Recent work at Forest Research has shown that sowing seed that has been artificially treated to break dormancy dramatically increases rates of seedling emergence and survival.

Because seedling emergence is controlled by soil moisture and temperature, choice of sowing date is the second important factor. In particular, seedling emergence of many species is sensitive to high soil temperatures, and sowing in autumn or winter usually gives better results than sowing in spring. Control of competing vegetation is essential, particularly in the first year after sowing, but can be very difficult to achieve among very small, irregularly spaced tree seedlings. However, Forest Research has identified a series of techniques and herbicides that can be used safely to control weeds without damaging tree seedlings.

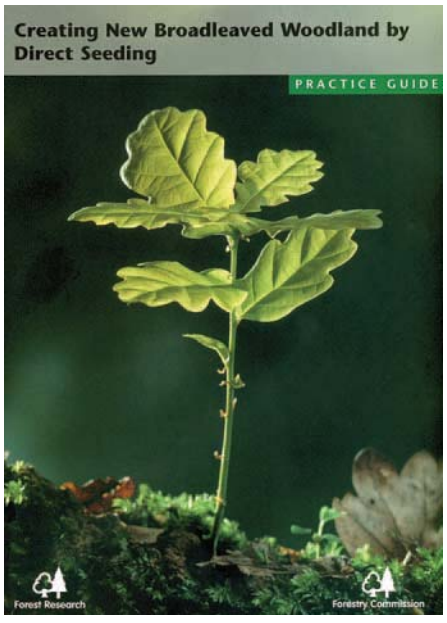
Figure 1

Direct-seeded, native woodland mixture after four growing seasons (2 m pole in foreground), showing variation in structure and naturally occurring open space

Detailed recommendations based on these and other factors, such as sowing rates, site preparation, seed handling, sowing depth, species choice and protection, are contained in a Forestry Commission Practice Guide (Figure 2). Using this guidance, direct seeding can now create new native woodlands in the lowlands that, compared to planting, can cost less, more rapidly create a woodland environment, produce better-quality, high-value hardwood timber, appear more natural, require the use of fewer herbicides, and use on-farm skills and machinery. Current research is also looking at how to use direct seeding for low-cost, high-quality restoration of native species on conifer plantation sites, as discussed in Forestry Commission Information Note 84: *Potential for Direct Seeding of Birch on Restock Sites.*

Figure 2

Direct seeding Practice Guide



Tree Health

Anoplophora Glabripennis

Our research on tree health focuses on assessing and maintaining the health of trees both nationally and internationally. We monitor established pests and diseases, design and investigate possible new methods of control, and work to assess and mitigate potential threats posed by new and exotic insects and pathogens. We also offer a diagnostic and advisory service to anyone requiring assistance or information. A number of our recent projects and developments are described here to demonstrate our work.

Investigating alien invasive species and international trade

While existing pests and pathogens in Britain remain a key component of our work, there is increasing emphasis on wider biosecurity issues, particularly in relation to the threats posed by non-native invasive species. Our researchers support the Forestry Commission's Plant Health service, using scientific study and tailored monitoring to provide guidance on protecting plants, and advice on managing the routes for potential import of pests. For example, we have been investigating the potential of residual bark on imported goods for harbouring bark- or wood-boring insects, even after standard phytosanitary treatments. This work supports the new International Standards on Phytosanitary Measures (ISPM15), which sets guidelines to address risks from wood packaging.

So far, the results of our UK studies show that the ISPM15 standard heat treatment does not prevent colonisation of bark, leaving insects able to invade the wood before export from the country of origin. In addition, one interesting finding has been that the mix of beetle species attacking treated wood has changed – this was also noted during similar studies in the US. Further work is ongoing to assess the actual threat posed by residual bark; the results are being considered by the International Forestry Quarantine Research Group.

International trade in live plants is another possible route for pests to travel between countries. This pathway is increasingly acknowledged as posing the greatest threat, particularly for pathogens that are hard to detect or have not yet been recognised as threats. In 2006, the International Union of Forest Research Organisations (IUFRO) set up a working group on Invasive Alien Species and International Trade to address this issue. Our researchers are contributing to this group, and considerably more work is needed to address requirements for ensuring that imported plants are free from both known and as yet unrecognised pests. For more information on this topic, visit **www.forestresearch.gov.uk/iufroinvasives**

Managing pine weevils

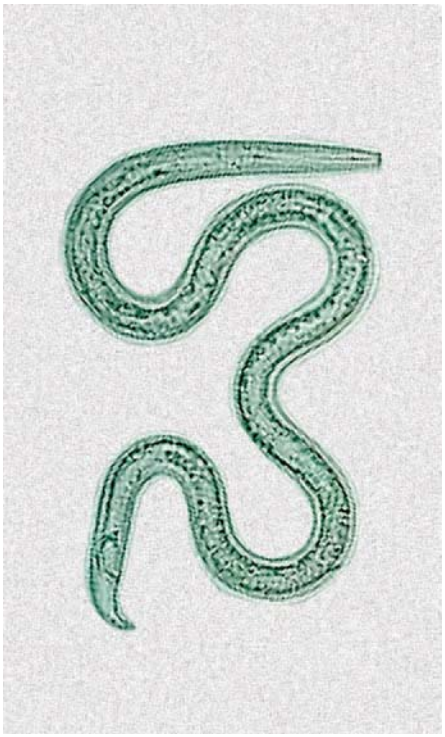
We have made good progress nationally in developing an integrated system for the long-term management of pine weevil (*Hylobius abietis*), which causes extensive damage to the young trees used to re-stock clearfell sites. However, since this damage is often highly variable, routine use of insecticides is often either unnecessary or not fully effective.

Management support systems

Our approach is based around a Hylobius management support system (MSS) that helps forest managers assess if, when and to what extent insecticides are necessary for a particular site. Two different versions of the system are available: one for lowland re-stocking sites, and one for upland sites.

The lowland MSS has been developed in collaboration with East Anglia Forest District and uses a simple stump-monitoring system along with detailed knowledge of the time of felling. As a result, the use of chemical insecticides to protect young plants during re-stocking has reduced dramatically. In upland restocking


Hylobius abietis



sites, the extended lifecycle of the pine weevil requires a more sophisticated approach in order to monitor and predict its populations. Therefore, we have developed an online Hylobius MSS, available through the Forest Research website, which has a simple interactive interface where users can enter information such as site details, time of felling and preferred re-stocking option. The system requires on-site fieldwork to monitor levels of adult weevil presence, using counts of beetles on pine or spruce. It then predicts the level of plant losses for that site. This system is currently undergoing user trials.

Population control using nematodes

Although chemical insecticides are used in current protection strategies, they have no impact on weevil population size. To address this, we have recently launched Forest Biocontrol to provide biological control of *Hylobius abietis*. This offers forest managers the opportunity to reduce weevil populations overall within forest blocks and, over time, can reduce the need for insecticide treatment of re-stock sites. Over the past year, both the Forestry Commission and private-sector customers have used this nematode-application service, with a total of 120 hectares now having been treated successfully. The programme for 2007 is being finalised and we estimate that close to 600 hectares will be treated across Britain and Ireland. Further details are available from **www.forestresearch.gov.uk/nematodes**

Assessing the impact of forest management techniques on pests and diseases

Changes in the way plantation forests are managed are raising new questions and problems in relation to pests and diseases. The development of alternative approaches, particularly continuous cover forestry (CCF) and low-input silvicultural systems (LISS), looks likely to affect the impacts of traditional pest species, such as the pine weevil (*Hylobius abietis*) and green spruce aphid (*Elatobium abietinum*), due to changes in habitat structure and populations of predators and parasites. Forest stands using CCF and LISS are more structurally complex than even-aged forests and have an associated increase in biodiversity. This is considered likely to enhance the populations of insects' natural enemies, resulting in fewer pest problems. However, this hypothesis requires rigorous testing.

A new research programme was established during 2006/07 to compare insect diversity and abundance across forest stands of different types. The 24 study plots, in Mid- and North Wales, range from highly structured, mixed-age stands, typical of CCF systems, to traditional even-aged stands showing little variation between trees. All the plots are located in stands of Sitka spruce, to isolate the importance of structural complexity without the complication of mixing tree species. Insect populations in the plots will be sampled between April and October, using different traps and sampling techniques. An initial 14 plots will be sampled during 2007–09, with the remainder being sampled during 2008–10. The aim is to establish total

insect diversity, the abundance of potential pest species and the populations of natural enemies – and then to relate these factors to the variation in stand structure and tree age. Specific studies on aphids and weevils (*Curculionidae*) will provide more detailed information on these important insect groups. Further information is available from **www.forestresearch.gov.uk/fr/infd-6xafdt**

Researching the spread of red band needle blight

Since the late 1990s, the incidence of red band needle blight (*Dothistroma septosporum*) in Britain has increased very significantly. This disease was first reported in a single group of trees in East Anglia Forest District in 1999 and has now become a serious problem in the district. Annual monitoring has shown an increase in the percentage of Corsican pine (*Pinus nigra* ssp. *laricio*) crop affected from 61% in 2003 to 81% in 2006; the severity of infection has also risen sharply in the same three years.

To establish the geographical range of the disease on the Forestry Commission estate, all Corsican pine stands under 30 years old (excluding those in East Anglia) were checked for the disease in July 2006. Our results showed that of the 9,488 hectares checked, the disease was present in 70% of the stands, covering a total of 6,245 ha. If the data from East Anglia are included, the total area of infected Corsican pine under the age of 30 years is 14,665 ha. The disease was also reported on a further seven pine species during the survey, with lodgepole pine (*Pinus contorta* ssp. *latifolia*) being the most frequently infected species. Although no lodgepole pine was found to be infected with red band needle blight in Scotland during the survey, the disease has since been confirmed in the Moray Forest District.

We set up an experiment to see whether changing current tree-thinning practices could help reduce levels of red band needle blight. Initial results have been promising – in July 2006, one year after thinning, we saw a significant decrease in the extent of crown infection among thinned trees, compared to those that were not thinned. And, further, those areas that were more heavily thinned showed an even greater reduction in crown infection levels. Further information on red band needle blight is available on the Forest research website at **www.forestresearch.gov.uk/redbandneedleblight**

Bleeding canker of horse chestnut: a growing threat?

Joan Webber

Figure 1
Bleeding canker on a horse chestnut

Over the past few years the incidence of a disease known as bleeding canker of horse chestnut *(Aesculus hippocastanum)* has risen markedly in the UK. Symptoms include rusty-brown or black gummy liquid seeping from the bark of affected trunks or branches (Figure 1). Sometimes, the bleeding cankers can be so extensive that infected tissue encircles branches or trunks, causing death of branches or even entire trees in just three or four years.

The first records of horse chestnut bleeding canker in the UK date from the 1960s, and the causal agents were found to be two species of *Phytophthora*, but the disorder was relatively uncommon and limited to southern England. However, between 2003 and 2006, more than 350 reports of bleeding canker on horse chestnut were notified to the Forest Research Disease Diagnostic Advisory Service, with records from England, Scotland and Wales.

Initially it was assumed that climatic changes might have encouraged more infection by *Phytophthora*. However, growing cultures from samples of infected trees usually yielded a different agent – a fluorescent form of the bacterium *Pseudomonas syringae*, which includes pathogens of important crops. In addition, some fluorescent *Pseudomonas* species have been shown to be responsible for several new and emerging diseases on plants.

Work with colleagues at the Central Science Laboratory, York, to sequence the gyrase B gene of *P. syringae* from horse chestnut and compare it with other pathovars of the bacterium, showed that a single strain of *P. syringae* was infecting horse chestnut trees throughout the UK. When the bacterium was inoculated into horse chestnut saplings, necrotic bark lesions gradually formed around the inoculation points, with some bleeding. This confirmed that *P. syringae* could cause bleeding canker of horse chestnut, and the current upsurge of the disease appears to be due to this bacterium and not species of *Phytophthora*.

The impact that *P. syringae* is now having on horse chestnut in the UK is widespread and damaging (see **www.forestresearch.gov.uk/bleedingcanker** for more details). A similar upsurge in bleeding canker has also been reported in the Netherlands, Belgium and France, apparently also due to the same bacterium.

Gypsy moth and oak processionary moth in the UK

Nigel Straw and Christine Tilbury

Gypsy moth (*Lymantria dispar*) and oak processionary moth (*Thaumetopoea processionea*) are native to central and southern parts of continental Europe, and are serious defoliators of oaks (*Quercus* spp.) and other broadleaved trees. Both species have hairy caterpillars (Figure 1), which, unusually for insects in the UK, can pose considerable problems for human health. Hairs from the caterpillars, particularly oak processionary, are extremely irritating to human skin and eyes. In some people, contact or inhalation of the caterpillar hairs leads to a severe asthmatic or allergic reaction.

Gypsy moth, and to a lesser extent oak processionary, have a long history of damaging woodland and urban trees in Europe. Gypsy moth is also a major defoliator of oaks and other trees in eastern North America, where it spread following accidental introduction in the late nineteenth century. Until recently, neither species occurred in the UK, but in 1995 a small population of gypsy moth was found in northeast London, and this population has persisted. A second, larger, outbreak of gypsy moth appeared in Aylesbury, Buckinghamshire in 2005. This population increased in 2006 (Figure 2), when several breeding colonies of oak processionary moth were also discovered in west London.

Forest Research has been closely involved with monitoring these moth populations using pheromone traps, and in developing management strategies. The original outbreak of gypsy moth in London was thought to have started with moths or egg batches transported into the country on vehicles or goods from the continent. However, the more recent outbreaks appear to be associated with direct import of sapling trees from the continent. Trees of this size (2–8 metres tall) are extremely difficult to check and guarantee to be free of infestation and disease, and the arrival of gypsy and oak processionary moths in the UK highlights the potential dangers associated with this new and increasing trade in 'plants for planting'. Higher spring and summer temperatures, most likely due to climate change, are expected to encourage further spread and an increase in population numbers.

Figure 1

Oak processionary caterpillars on *Quercus robur*

Further information is available at **www.forestresearch.gov.uk/protectingtrees**

Figure 2

Numbers of male gypsy moths caught in northeast London and Aylesbury