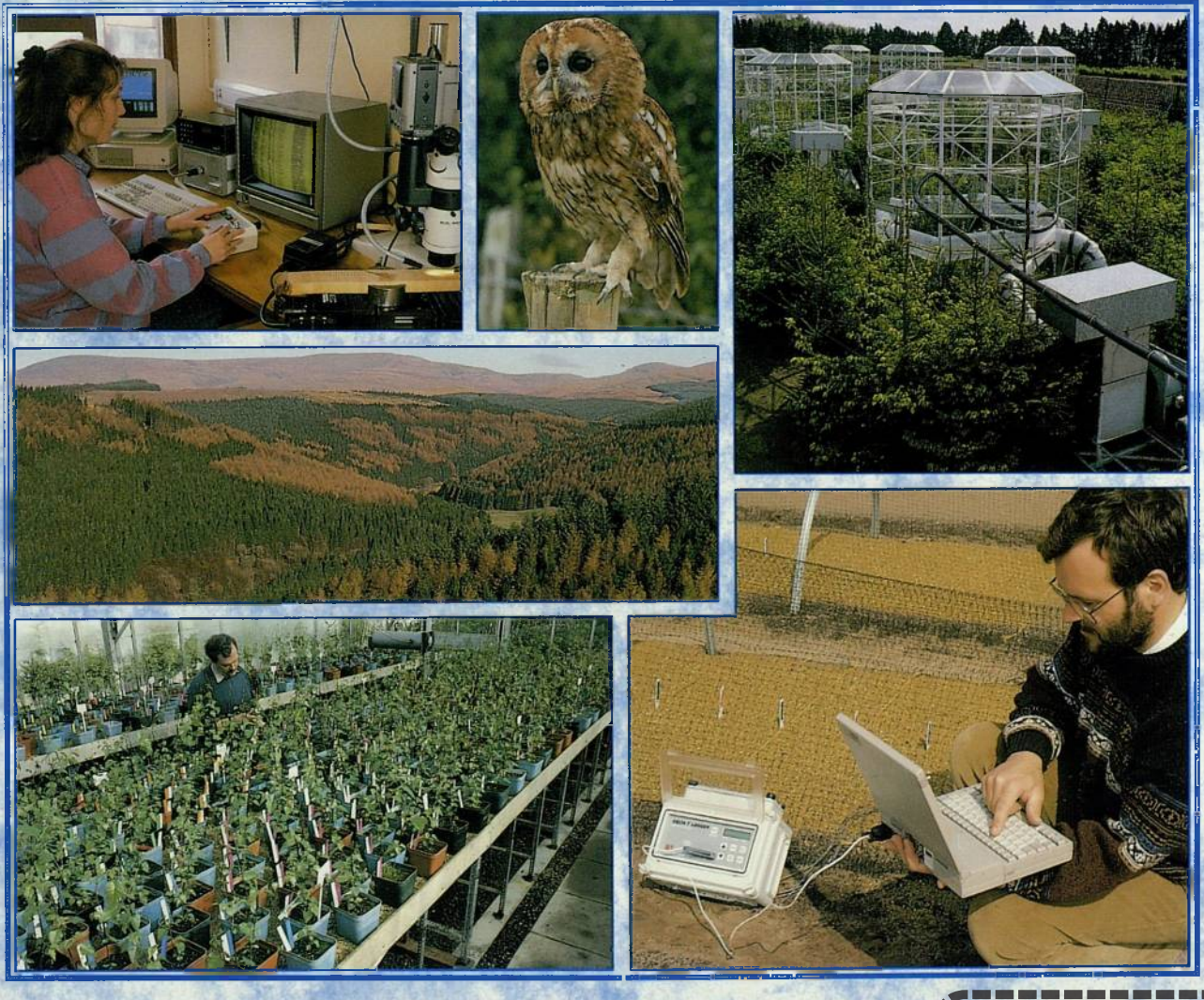
The Forestry Authority

Forestry Commission

REPORT ON FOREST RESEARCH

1994



HMSO

REPORT ON FOREST RESEARCH

for the year ended March 1994

LONDON: HMSO

ISBN 0 11 710327 6
FDC 945.4: (410)
The abbreviated title of this Report is Rep. Forest Res., Edin. 1994

Advisory Committee on Forest Research

Membership at 31 March 1994

Chairman
Dr J.P. Dempster, B.Sc., D.I.C., Ph.D., D.Sc.
The Limes, The Green, Hilton, Huntingdon, Cambridgeshire, PE18 9NA.

Secretary
Dr J. Evans, B.Sc., Ph.D., D.Sc., F.I.C. For.
Forestry Commission, Alice Holt Lodge.

Members
Professor E.C. Cocking, Ph.D., D.Sc., F.I.Biol., F.R.S.
Department of Botany, School of Biological Sciences, University Park, Nottingham, NG7 2RD.

Professor R.M. Cormack, B.Sc., M.A., Ph.D., F.R.S.Ed.
Statistics Division, Department of Mathematical Sciences, North Haugh, St. Andrews, Fife, KY16 9SS.

Dr M.P. Denne, B.Sc., Ph.D.
School of Agricultural and Forest Sciences, University College of North Wales, Bangor, Gwynedd, LL57 2UW.

Professor D. Henderson, B.Sc., F.R.S.Ed., F.L.S.
Larachan, 54 Lonemore, Gairloch, Ross-shire, IV21 2DB.

Professor J.M. Hirst, D.Sc., B.Sc., Ph.D., F.I.Biol., F.R.S.
The Cottage, Butcombe, Bristol, BS18 6XQ.

Professor H.G. Miller, B.Sc., Ph.D., D.Sc., F.R.S.Ed.
Department of Forestry, University of Aberdeen, St. Machar Drive, Aberdeen, AB9 2UU.

Dr W.E.S. Mutch, O.B.E., B.Sc., Ph.D., F.I.C.For.
19 Barnton Grove, Edinburgh, EH4 6EQ.

Dr M.B. Usher, B.Sc., Ph.D.
Scottish Natural Heritage, 12 Hope Terrace, Edinburgh, EH9 4AS.

CONTENTS

INTRODUCTION

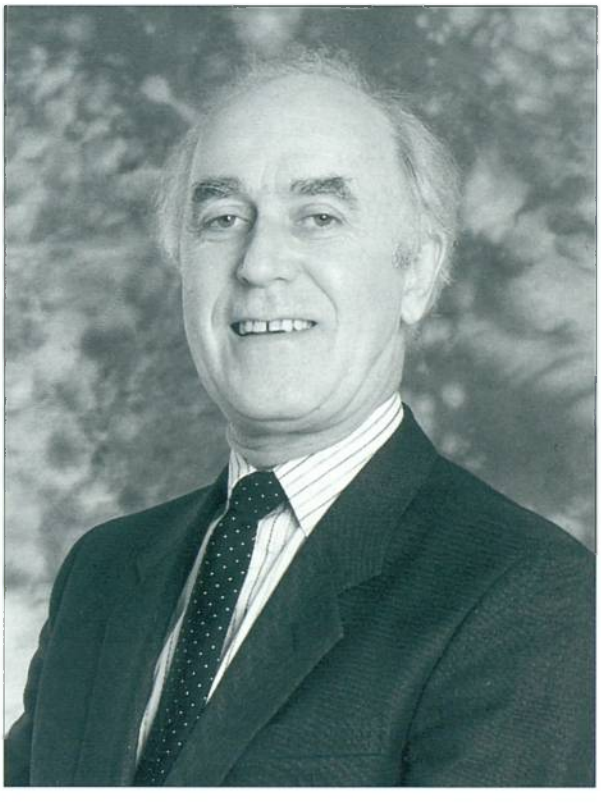
by David Burdekin
Director Research

This Research Report contrasts strongly with that of 30 years ago. Not only has the quality of the publication improved but the content has changed to reflect the changing priorities and the use of increasingly sophisticated techniques. The reason for the historical interest will emerge in due course.

Some of the subjects reported on in the 1964 annual report such as forest entomology and forest pathology are still with us. Others have become much less significant because knowledge and techniques have improved as a result of the application of research findings. This is particularly the case for research into nursery practice, establishment techniques on impoverished upland sites, species choice and vegetation control. But new problems and opportunities have arisen and the report illustrates the increasing emphasis on environmental research, tree improvement and the establishment of trees on former agricultural land.

The 1964 report referred to the installation of the first computer in Research Division, an International Computers and Tabulators SIRIUS. It had seven kilobytes of memory whereas the current Sun System has 200 megabytes i.e. a near 30 000 fold increase in capacity. Foliar analysis was in its infancy and only concerned with three macro nutrients. Today 23 elements can be analysed per sample and analysis can proceed 24 hours a day using the latest spectrospan equipment. A third contrast has been the level of control of the environment such that today trees are being grown experimentally in open-top chambers which simulate the elevated carbon dioxide and ozone concentrations expected in 50 years time. Also, the 1964 report made no direct reference to work at the Northern Research Station which was to open in 1970 on the Bush Estate of Edinburgh University.

The management of research has also changed in this time. The Government's White Paper on Science and Technology entitled *Realising our potential* was published in the autumn of 1993. The document emphasises the importance of research being directed at wealth creation and improving the quality of life. Forestry research can meet both of these criteria. Increasing emphasis is being given to serving customers, to being efficient in the use of resources and to competing for research contracts. These have created a need for additional skills amongst researchers and research managers. As part of the follow up to the White Paper the Division was visited by members of a team scrutinising public sector research establishments. Their report was awaited at time of going to press.



Very significant advances have been made over the past 30 years. Some of the latest achievements in our current forest research are highlighted below.

RESEARCH HIGHLIGHTS

The following is a selection of highlights from the research described in this report. It is necessarily a somewhat arbitrary choice but in the current climate of customer-oriented research a range of examples are discussed in this context.

Impact of insects on tree growth

There is currently little recorded evidence of the impact of insect pest populations on the incremental growth of trees. Serious losses are often proclaimed but measurements are often lacking.

Annual records of populations of *Bupalus piniaria*, the pine looper moth, have been taken since the 1950s. Regression analyses have indicated that some 40–60 per cent of the variation in increment is related to the insect numbers.

The unique set of data for pine looper populations is not available for other forest pests. Experimental studies have therefore been initiated where insect numbers are artificially controlled. Populations are either reduced by insecticidal control or enhanced by introduction of the pest insect. These studies are using both *Elatobium abietinum*, the spruce aphid, and *Rhyacionia buoliana*, pine shoot moth, as models.

Climate change and enhanced CO_2

Research on environmental issues, including that related to climate change, is being given a high priority.

Three open-top chamber experiments comparing tree growth in filtered and ambient air have recently been concluded. Two of these experiments, at Alice Holt and at Glendevon, have been converted into trials with enhanced CO_2. At Glendevon, in a joint project with Edinburgh University and funded by the European Union, the growth of trees is being tested in air with twice the current concentrations of CO_2, with variants of nutrition and water supply. Significant increased growth was noted in the first season especially with additional nutrients and CO_2. At Alice Holt a different array of treatments is being installed, including the interacting effects of CO_2 and ozone.

Timber quality

The sawlog volume potential from British forests is expected to more than double in the next 15 years as a result of the increased planting in the post-war period reaching maturity. In order to maximise returns on these sawlogs information is needed on quality as well as quantity.

A major initiative was started during the year to develop a method for predicting sawlog grade and outturn from data on standing trees. An initial study confirmed the importance of straightness and that this can be consistently assessed within the crop. The method is being developed to improve forecasts of assortments at both the stand and strategic level and to help managers decide on the optimum timing of felling.

The importance of management practices on log quality and timber strength is becoming increasingly apparent. Detailed investigations of data from spacing experiments in non-thinned Sitka spruce have shown that yields of structural grade timber are likely to be reduced if initial planting spacings are greater than two metres. A publication of these results (Brazier and Mobbs, 1993) in *Forestry* won the award for the best paper of the year (the Percy Stubbs and John Bolton King and Edward Garfitt prize for Silviculture awarded by the Institute of Chartered Foresters).

Biotechnology and tree improvement

The Tree Improvement Branch has had a long-term interest in biochemical markers for identifying tree populations, including native Scots pine. More recently, however, the Branch has commissioned research at Nottingham University to investigate techniques for introducing new genes into Sitka spruce. This research has the ultimate aim of producing genetically transformed plants.

Two techniques for the delivery of new genes have been tested. The first used a bacterium, *Agrobacterium tumefaciens*, as the vector and the second was by means of particle gun. Both techniques were successful using a marker gene and the project has been extended for a further year to confirm these results.

Windthrow prediction

There have been significant milestones in the progress of research and technology transfer on windthrow. The Windthrow Hazard Classification has been substantially updated, for the first time since the early 1980s. More accurate estimates of site windiness are now available and this has resulted in a reduction in the area defined as being in the highest risk category.

This new information has been transmitted to the forest growers through publications and seminars. At the same time, researchers at the Northern Research Station organised a very suc-

cessful international conference in Edinburgh on *Wind and wind-related damage to trees.*

Advisory Committee on Forest Research

Three Visiting Groups were set up and reported during the year – the branches involved were Plant Production, Entomology and Site Studies (North).

Mr J. MacLeod (Director, National Institute of Agricultural Botany) and Professor E. Roberts (Reading University) complimented the Plant Production Branch on its income earning capacity and the high calibre of its seed research. Professor M. Claridge (Cardiff University) together with Professor J. Whittaker (Lancaster University) and Professor J. Waage (International Institute of Biological Control) reported on the Entomology Branch. High quality research into the impact of forest insects on trees and into the effects of stressed trees on insect populations was recognised. Income targets, however, were proving more difficult to meet. Dr D.C. Malcolm (Edinburgh University) and Mr C. Spiers (Scottish Agricultural College) were impressed by the new and developing, ecologically based, site classification system being investigated by Site Studies (North) Branch. The group supported the decision to amalgamate the branch with the Wildlife and Conservation Research Branch as the interests of the two were now coinciding.

The annual field visit of the Advisory Committee included visits to Mathrafal, Hafren and Wyre forests in Wales and the Welsh borders to see research on insect pest problems and the role of management in promoting insect biodiversity. This was in preparation for a Visiting Group in 1993 to Entomology Branch. Plant Production and Site Studies (North) branches were also reviewed by Visiting Groups.

Forestry Research Coordination Committee

The Forestry Research Coordination Committee (FRCC), which brings together all the government departments and organisations sponsoring research on forestry, met four times during the year. The Research Users' Forum, established in 1992, met on two occasions. The Forum represents the timber industry, farming, land use, environmental and conservation interests, and has assisted FRCC through identifying research priorities concerned with four topics: land use, low-intensity silviculture, deer and squirrel research needs, and marketing low quality broadleaves. The Forum fulfils an important part of the technology foresight process.

The FRCC has appointed Dr John Rodwell, Department of the Environmental Sciences, University of Lancaster, to chair FRCC's Forestry and Conservation Related Working Group. This sub-committee helps to coordinate research and identify priorities by bringing together senior scientists from the Institute of Terrestrial Ecology, the Forestry Commission and English Nature (also representing the interests of Scottish Natural Heritage and the Countryside Council for Wales).

Nearly £21 million was spent in total on forestry and related tree research in Britain in 1993. This is a small increase over 1992, owing to the inclusion of projects funded by agencies not previously incorporated in the annual collation of research. Research on environmental and conservation aspects continues to attract increased support. For the first time since FRCC began collating research information in 1982, half of all research in 1993 concerned broadleaved tree species, predominantly oak, ash, beech, birch, sycamore, poplar and willow. Research linked to new woodland initiatives, notably planting on farmland and community forests, continues at a high level.

Thanks

Standards of achievement in the Research Division have continued to rise at a time when demands on forestry research have never been greater. As mentioned earlier, progress over the past 30 years has been outstanding.

In the Report for 1964, the post of pathologist was noted as vacant, it was filled by the following year. The appointee became Director some twenty five years later and is now close to retirement. His successor has already been appointed and takes on a challenging programme and a truly expert team of researchers.

To them I would like to express my sincere thanks and best wishes for the future. Forest research has tremendous potential and I am convinced that much will be realised.

ENTOMOLOGY

Overview

Preparation for, and scrutiny by, a Visiting Group to assess the content and direction of the research programme provided the opportunity to examine and set out the aims of the Branch which are reproduced below:

"The principal aim of the Branch is to develop, through high quality research, an in-depth understanding of the processes governing the dynamics of insects on trees and to apply this knowledge to management of forest insects to reduce damage to trees and to enhance insect biodiversity."

Secondary objectives are:

- To study the interactions between tree genotype, environment and insect feeding strategy as a basis for describing the underlying ecological principles.
- To investigate the impacts of insects on tree health, growth and performance as a basis for determining pest status and the need for intervention.
- To respond to damaging insect outbreaks by developing effective pest management strategies using biological agents or best available pesticide application technologies that have minimal impact on the environment.
- To enhance biodiversity, especially of rare and beneficial insects, by provision of appropriate habitats based on knowledge of the role of forest structural components.
- To provide an advisory service to the forest industry exploiting fully the expertise within the Branch.

Excellent progress has been made within the Stress topic, where work has concentrated on the effects of light and nutrient regimes on the physical, chemical and biological attributes of Sitka spruce. Research into the biology of *Hylobius abietis*, a major pest of restocking, has been strengthened as part of a major project to develop an integrated approach for its management in the future.

Pine wood nematode continues to be a significant international plant health issue and during the year the Head of Branch was appointed leader of a European Union (EU) Technical Team that held several meetings with Canadian and USA counterparts and jointly organised an international meeting on the nematode in Brussels. The EU-Canada-USA report from that meeting is now being used extensively as the main source of information on the biology and plant health implications of this important forest pest.

HUGH EVANS

The great European spruce bark beetle – *Dendroctonus micans*

Following the discovery of *Dendroctonus micans* in Britain in 1982, a comprehensive, integrated control strategy has been developed. Restricting the movement of infested timber, and the breeding and release of the specific predator *Rhizophagus grandis* have contributed to the decline in both the number of new outbreaks and the rate of spread of *D.micans*. The *R. grandis* breeding and release programme continues and all new infested sites are treated.

Since 1984, when surveys of spruce forests in the main infested area ceased, annual monitoring to detect changes in the *D. micans* populations has continued. This survey provides information on *D. micans* populations in the absence of further control measures. The trend in percentage infested trees per site is shown in Figure 1, where comparison is made between consecutive years and with the 1984 survey results. Although the data relative to 1984 show a steady overall increase, the year on year figures show a declining trend in population change, including negative values for 1991 and 1992. After sanitation felling was stopped in 1984 populations rose dramatically between 1985 and 1986 (32%). In the following years, the number of infested trees per site shows a

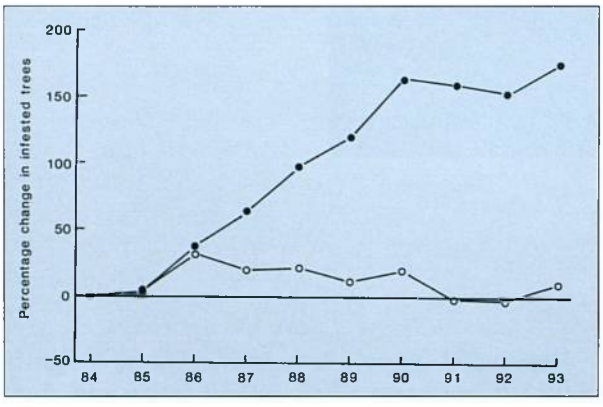


Figure 1. Percentage change in numbers of trees infested per site relative to previous year and to 1984 result.

small steady increase only, followed by a reduction in 1992 and a slight increase for 1993.

This decline is linked to increasing evidence that *R. grandis* are present at most *D. micans* infestations, even at sites where they were not introduced intentionally. *R. grandis* have been found at all new sites containing over 100 infested trees. This confirms that the predator is highly mobile and can find well-established *D. micans* infestations even on the outer edge of the outbreak zone. Despite these encouraging findings, it remains good practice to release *R. grandis* at newly found sites, since the predator is less likely to find small, isolated, infestations.

It is possible that the trends in Figure 1 show the start of a cycle often associated with predator–prey interactions where populations typically fluctuate around a mean value reflecting the density-dependent activity of the predator. Future surveys will determine whether this is the case.

NICK FIELDING AND ALAN WATERS

CONTROL OF PINE BEAUTY MOTH IN SCOTLAND

Counts of pupae in the late autumn of 1992 identified several forest areas in North Scotland that were likely to have dangerously high populations of pine beauty moth (PBM) (*Panolis flammea*). Pupal surveys provide a quantitative measure of population levels and give sufficient notice of outbreak populations to allow a spray operation to be mounted in the following spring. The areas of forest at risk were confirmed by counting eggs during early May. Nearly 4000 ha of lodgepole pine in north Scotland were subsequently sprayed during May, using Dimilin® (Zeneca) ODC in diesel oil. The active ingredient in Dimilin® (diflubenzuron) interferes with the deposition of chitin, which is an essential component of the cuticle of insects. Larvae behave and feed normally until they moult and some plant damage still occurs after treatment, so to minimise damage it is necessary for the chemical to be applied as soon as possible after larvae hatch from the egg.

The areas at risk were sprayed using a target specific, ultra low volume, incremental spraying technique. This allowed a satisfactory level of control to be obtained using the smallest amount of insecticide compatible with this aim, that, depending on population densities, was a quarter of that recommended by the manufacturers. The diluted insecticide was applied, at a rate of one litre ha^{-1}, from a helicopter equipped with small motorised spinning disc applicators. These have been developed to generate droplets within a very narrow size range and to give greater control over spray drift pattern, resulting in increased accuracy of insecticide placement. By carefully controlling droplet size, it is possible to ensure that nearly all of the droplets reach their target. Larger droplets that would normally fall directly to the ground, and very small ones that would create spray drift are avoided.

The spray rig has been developed by Research Division and is entirely self contained (see Plate 1). It is equipped with a generator to provide 110 volts AC power for the pumps and droplet generators which are fed from a 300 litre spray tank. During operation, the spray rig hangs four metres beneath the aircraft (see Plate 2). Because the system is independent of the aircraft and is fixed to the cargo hook with no permanent attachment, it can be attached or detached quickly, reducing helicopter down time and enabling rapid jettisoning should an emergency arise. The flow rate can be calibrated away from the aircraft and it can then be quickly rigged to any helicopter without the need for attachments specific to a particular make of helicopter. It is entirely self powered, making the spray heads and thus droplet spectrum independent of air speed, ensuring that the spray drift can be predicted and confined to the target area.

For optimum control of drift, spraying is undertaken in winds of more than five knots (2.5 m sec^{-1}) with the spray rig at five metres above the crop. Wind speeds above five knots over a forest canopy result in a very turbulent air flow around the tops of the trees. Droplets of a size generated by the special nozzles (70–80 μm diameter) remain in this turbulent flow until they impact on fine or irregular surfaces

such as tree needles, larvae or even the fine hairs on the target larvae. Ninety-five percent of the insecticide applied using this technique is caught by the top metre or so of the trees, the zone where most of the caterpillars are feeding. The method of application allows a very small quantity of insecticide to be effective against the insect pest, whilst ensuring that very little reaches any non-target areas, such as areas of water within the crop or other vegetation outside the forest, through spray drift.

The helicopter was equipped with an electronic track guidance system to ensure that positioning and direction were correct to within narrow pre-defined limits. The track guidance printouts showed that the precision of flight was excellent. Follow up examinations of sprayed areas found that larvae only survived in areas that were specifically excluded from treatment zones. By the end of July, most larvae surviving in non-treated areas had died, probably killed by a combination of an entomopathogenic fungus (*Entomophthora* spp.) and the adverse climatic conditions (low temperatures and high rainfall). Although this combination of agents may have controlled the populations in the spray areas, it would undoubtedly have occurred too late to save the crop, as was seen in some untreated areas.

Overall, the spray operation was very successful, despite several days when spraying could not take place due to unsuitable weather conditions. Pupal surveys in autumn 1993 have shown that there are no known PBM populations of any significance north of the Great Glen.

STUART HERITAGE, ALASDAIR HENDRY, ROGER MOORE, DAVID JOHNSON AND HUGH EVANS

ADVISORY WORK AND PLANT HEALTH

Advisory

Apart from the defoliation of lodgepole pine by *Panolis flammea* in Scotland (see above) and quite widespread needle loss caused by *Elatobium abietinum* on both Sitka and Norway spruce, especially in the western parts of Britain, there were few other reports of insect damage to trees in forest plantations. In southern England the winter moth, *Operophtera brumata*, caused almost complete defoliation of oak in Richmond Park and at Epping by the end of May. The second generation larvae of the large pine sawfly, *Diprion pini*, defoliated about two ha of young Scots pine natural regeneration together with the remaining trees from a 35-year-old, south facing stand, partially windthrown in October 1987. *D. pini* was also reported damaging pine Christmas trees at several localities in southern England and in East Anglia. Damage by the aphids *Cinara confinis* to Nordmann fir and *Adelges cooleyi* to Douglas fir draw attention to the increasing popularity of these trees as alternatives to Norway spruce at Christmas. Large colonies of the spruce bark aphid, *Cinara piceae*, were reported on the stems of Norway spruce grown-on from Christmas trees, especially in south England, East Anglia, the west Midlands and Lancashire.

Severe defoliation of young broadleaved trees by the green leaf weevil, *Phyllobius pyri,* was widely reported from farm woodland and amenity planting schemes. Many species were affected but damage was particularly serious on beech, cherry and hazel in the Cotswold area; ash was noted as being little affected. Larvae of the brown-tail moth, *Euproctis chrysorrhoea*, were again evident on rosaceous trees in the south-east, particularly around the Thames estuary and in the coastal areas of Kent, Sussex and Hampshire. Larvae of the lackey moth, *Malacosoma neustria*, defoliated street trees in the Portsmouth area and alongside parts of the M4 motorway.

Other defoliators seen damaging amenity trees included the sawflies *Caliroa cerasi* on rosaceous trees and *C. annulipes* on oak and lime. The ash sawfly, *Tomostethus nigritus*, caused defoliation of pollarded ash trees in London soon after they flushed in May. This is the third consecutive year such damage has occurred, there having been no earlier cases recorded by the Entomology Advisory Service.

Damage to ball-rooted semi-mature pines by the pine shoot beetle, *Tomicus piniperda*, has again caused serious losses of valuable trees where these were planted near to stands of more mature pine. In Warwickshire all the Scots pine planted at one site were killed as a result of *T. piniperda* breeding galleries girdling and ring barking the main stem. However, adjacent Corsican pine survived with only some shoot damage caused by the adult beetles' maturation feeding.

During 1991 and 1992 there had been many enquiries concerning damage caused to oak heartwood in sawlogs by the oak pinhole borer, *Platypus cylindrus*. These diminished during 1993 but another beetle, the nationally very rare *Lymexylon navale*, was found in boards converted from oak blown in 1987 on the Norfolk/Suffolk border. This insect has not been found before in East Anglia.

Plant health

In 1993 there was an unprecedented number of interceptions of the spruce bark beetles *Ips typographus* and *I. amitinus* in imported pallet wood and dunnage from eastern Europe. Adults of *I. typographus* were also caught in a pheromone trap at Tilbury Dock, Essex. Three European species of bark beetles not found before by Forestry Commission Plant Health Officers were *Orthotomicus longicollis* in spruce from Latvia, *Phthorophloeus spinulosus* in spruce stickers and a *Pityokteines* species, probably *P. curvidens*, from Slovakia. Larvae of longhorn beetles found included *Monochamus sutor, Semanotus undatus* and *Saperda carcharias*. Adults of the North American woodwasp *Xeris spectrum* were caught in pheromone traps baited for *Dendroctonus* spp. at docks in Liverpool and at Newport, Gwent.

TIM WINTER

THE IMPACTS OF INSECTS ON TREE GROWTH

Analysis of ring widths and height measurements of Scots pine from Tentsmuir Forest, Scotland, have shown that past outbreaks of the pine looper moth, *Bupalus piniaria*, have had a significant impact on tree growth. Analysis of Forestry Commission annual pupal surveys that were started in 1954 indicates that the population of *B. piniaria* in Tentsmuir has fluctuated in a semi-regular manner. Peak numbers occurred in 1957, 1962, 1969, 1977 and 1984. Damage caused by these high populations appears to have been a major cause of year-to-year variation in growth increments of the pines, although the effect on growth is delayed. Radial, basal area and volume increments are inversely correlated with the number of *B. piniaria* pupae recorded in the two seasons before that in which tree growth is measured (Figure 2), and height increments are closely related to pupal numbers three years previously. Best fit models from multiple regression analysis, which incorporate pupal numbers and temperature and rainfall data, explain 42–61% of the variation in increment and confirm the dominant influence of past moth numbers.

The reduction in growth caused by *B. piniaria* has been calculated by identifying those years in which the effects of the moth appear to have been minimal (e.g. Figure 2, where $\log_{10}$ (pupae $m^{-2}+1$), $t_{-1}+t_{-2}$ is less than 0.3), and then fitting a growth curve to the mean increments for these years. This curve has then been used to estimate the potential, or expected, growth in years when increments were influenced by *B. piniaria*. Growth loss is calculated as the percentage difference between observed growth and expected growth.

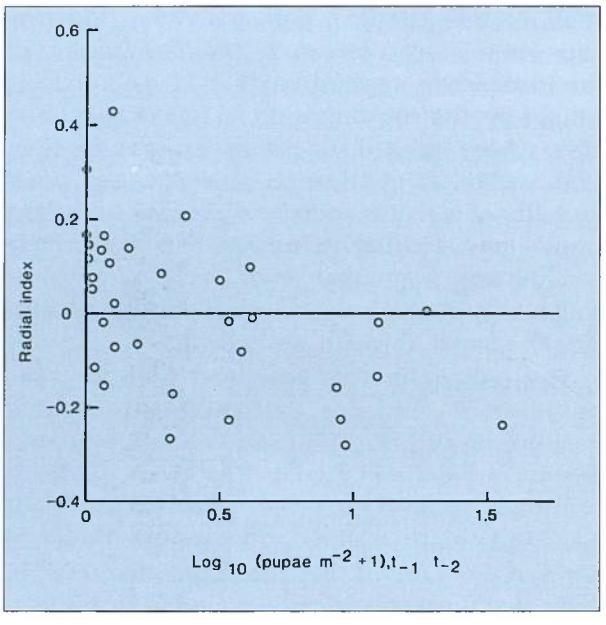


Figure 2. Relationship between radial stem growth of Scots pine at Tentsmuir and the number of B. piniaria *pupae recorded in winter surveys in the previous two years (t_{-1} + t_{-2}) ($r = -0.527$, $P<0.01$). Radial index is the percent deviation of the observed annual radial increment from the average (expected) radial increment, which is obtained by fitting a standard growth curve to the trend in radial increments with time. Positive values represent relatively wider growth rings. Points are mean values for each year 1956–1989 (n = 40 trees).*

The results show that, after a delay of 1–3 years, growth increments were reduced for 2–3 years after each peak in *B. piniaria* numbers. Annual reductions in radial, basal area and volume increments amounted to 9–32% of potential growth, with a total reduction over each outbreak period of between 17% and 25%. In comparison, the effects on height growth were small, variable, and only just significant.

The overall effect of the five outbreaks of *B. piniaria* in Tentsmuir, in the forest compartment studied, has been to reduce average tree volume at harvest by 4.7–6.5%. The effect is small because severe growth loss occurred in relatively few years and mainly during the later life of the trees when incremental growth was declining. The trees analysed were only partially defoliated, and never suffered visible defoliation. Other compartments at Tentsmuir experienced higher *B. piniaria* numbers (although these were reduced by control operations to prevent the trees from being completely defoliated) and may have suffered a greater reduction in growth. However, tree death follow-

ing complete defoliation is still the main threat from severe outbreaks of *B. piniaria*. Defoliation by itself is not usually enough to cause mortality, but the loss of needles weakens trees and renders them susceptible to attack by bark beetles – particularly pine shoot beetle, *Tomicus piniperda* and invasion by pathogens. These secondary agents may cause many of the defoliated trees to die (Bevan and Brown, 1978).

Experimental studies on the impact of pine shoot moth, *Rhyacionia buoliana*, on Bishop pine at Wareham Forest, Dorset, and on spruce aphids in Hafren Forest, Powys, are continuing. Fieldwork at Wareham was completed in 1993 and the data are now being analysed. The study at Hafren was established in 1992 to obtain improved estimates of the impact of aphids on Sitka spruce, particularly in terms of volume growth and the length of the tree recovery period following severe attack. The experiment is designed to quantify the combined and independent effects of green spruce aphid, *Elatobium abietinum*, and root aphids, *Pachypappa* and *Pachypapella* spp., on the growth of young trees in typical plantation conditions. In addition to immediate direct effects, the data will provide base-line information to assess the future impact of climate change which may well result in increased frequency and severity of aphid outbreaks. The site is at 450 m elevation and was restocked in 1991 as part of normal forest operations. The previous crop, also Sitka spruce, achieved a yield class of 14.

Impact is being measured by comparing the growth of trees damaged by aphids with that of trees from which aphids are excluded by the application of foliar or soil insecticides. Treatments are being applied to replicated series of plots intermixed in a fully randomised design, with each plot consisting of 5 × 5 trees. A further series of plots in which *E. abietinum* numbers are raised artificially to mimic epidemic populations has also been included. A considerable effort is being made to record the aphid load experienced by the trees over the year in order to establish quantitatively the relationships between aphid densities, defoliation and growth loss.

NIGEL STRAW, NICK FIELDING AND GILLIAN GREEN

REFERENCE

BEVAN, D. and BROWN, R.M. (1978). *The pine looper moth*. Forestry Commission Forest Record 119. HMSO, London. pp. 1–13.

THE INFLUENCE OF FOREST STRUCTURE ON INSECT DIVERSITY IN BROADLEAVED WOODLAND

As part of the Research Division Biodiversity Programme, an Entomology Branch project is contributing towards identifying those aspects that can enhance insect diversity applicable to the management of productive forests and woodlands.

It has already been demonstrated from our trials that insects increase in diversity and numbers in response to an increase in size of canopy gaps and to the duration of sunlight. To make the best use of canopy gaps, detailed tables have been produced from computer generated graphical plots to identify zones of sunlight duration values according to surrounding tree height, canopy gap dimensions, orientation, latitude and date. Data have also been collected on near-ground air temperature profiles across these zones within canopy gaps on cloudless days throughout the year.

A study of the contribution that native trees and shrubs may make towards encouraging greater insect diversity in a woodland or forest environment has begun. A pilot survey of aspen (*Populus tremula*) carried out with the help of parish tree wardens in Hampshire, has confirmed the present day discontinuous distribution of this species. Sampling of high density and isolated groups of aspens on different sites for insects has commenced with a view to re-introducing the tree species into forests as part of the move towards encouraging a more diverse ecosystem within plantation monocultures. Studies on other components contributing to insect diversity, including the retention of over-mature and dead-wood resources, are also being undertaken.

CLIVE CARTER AND TIM WINTER

ENVIRONMENTAL RESEARCH

Important developments have been the establishment of new experiments on carbon dioxide at two of the open-top chamber sites, and the updating of the chemical analysis service. These developments are described in detail below. Other main areas of work are reclamation of disturbed and derelict land to forestry, forest hydrology, the effects of trees on sites, and environmental change.

After extensive consultation with a large number of interested parties (other Government departments, the water regulatory authorities, conservation agencies, the water industry, fishing interests, universities and other research institutes, etc.) the third edition of the *Forests and water guidelines* was completed and published in November 1993. These guidelines are based on research results and practical experience; they encourage management practices which are sensitive to the freshwater and riparian environment. Changes to the third edition reflect the findings of recent work on forest drainage and on how the scavenging of acidifying pollutants by trees can affect the aquatic environment. This latter issue is addressed by use of the critical loads approach which has now become accepted internationally as the most appropriate framework for policy formulation on pollutant abatement. Freshwater critical loads maps are now used to identify where acidification problems might occur, and the Forestry Authority will require catchment-based assessment of the threat from acidification for some Woodland Grant Scheme applications.

Freshwater and soil critical loads, and pollutant inputs to woodlands and forests continue to be major areas of work in the Branch. Over the last year attention has focused on Loch Dee and on the Upper Halladale catchments in Scotland, and an important paper was published on the pelletised limestone trial undertaken at Llyn Brianne in mid-Wales (Nisbet, 1993). Attention has also returned to the subject of water-use by forests, with an analysis of low-flow data being undertaken with the Tweed River Purification Board, and process studies being established with the Institute of Hydrology in the Coalburn catchment in Kielder.

Research on reclamation continues in the branch, particularly in the South Wales coalfield (Morgannwg Forest District) and on modern landfills. The application of sewage sludge to reclamation and other lowland sites also remains an area of active work. The effects of trees on sites has been a topic of long-standing interest in the Branch. New work has been initiated on this subject as a result of the establishment of Alice Holt Forest as an Environmental Change Network site. Environmental Research, Wildlife and Conservation Research, Entomology and Mensuration branches have all established new measurements as part of this programme. Soil analysis has been undertaken at the c. 74 plots of the European Union/United Nations Economic Commission for Europe (EU/UNECE) national network for monitoring forest condition and ten, new Level II plots are being set up under the new EU regulation on intensive and continuous surveillance of forest ecosystems.

Advisory work has mainly been for the Forestry Authority on environmental issues, although income has been earned from advisory and consultancy work, and from charges for chemical analysis. Organisation of meteorological data has been an increasingly important job, and an automatic weather station is being installed at Alice Holt. Jobs completed by the Instrumentation Section include construction of insect samplers, a soil penetrometer, CO_2 control equipment, tensile test equipment for fencing wire, a device for measuring root pressure and a geared movement device for a tripod mounted dendrometer.

PETER FREER-SMITH

REFERENCE

NISBET, T.R. (1993). The effects of a pelletized limestone treatment on drainage water acidity within a forest catchment in mid-Wales. *Journal of Hydrology*, **150**, 521–539.

Chemical analysis service

A chemical analysis service was first set up in laboratories at Alice Holt Research Station, Surrey, in 1965 to provide macronutrient analyses of foliar material. The service was designed both for use by the Forestry Authority Research Division, and as a basis for prescribing fertilizers to Forestry Commission forest districts. Limited soil analyses were also undertaken, principally for research purposes. In the last five years, the chemical analysis service has expanded considerably, and a wide range of forestry related materials is now received for analysis each year. This follows the developing need to measure biological and environmental materials quantitatively, for both statutory requirements and basic research.

The backbone of the service remains the analysis of macronutrients in foliar samples (see Figure 3): an average of 6000 samples are processed each year, some 10% of which are for commercial production forestry. External customers include forest management companies, consultants and private woodland owners. Tree tissue samples can also be analysed for starch and soluble carbohydrates – a method developed to provide a quantitative measure of food stores for several research projects, including plant production and the effects of atmospheric pollution.

In the past, soil analyses have been limited to pH and electrical conductivity. However, new European Union statutory requirements for soil information under forests has led to the development of facilities and methods for a wide range of analyses. Similarly, water samples taken from surface waters and from the soil (using suction cup lysimeters or centrifugation) are now routinely analysed, usually for common anions and cations, hazen value and turbidity.

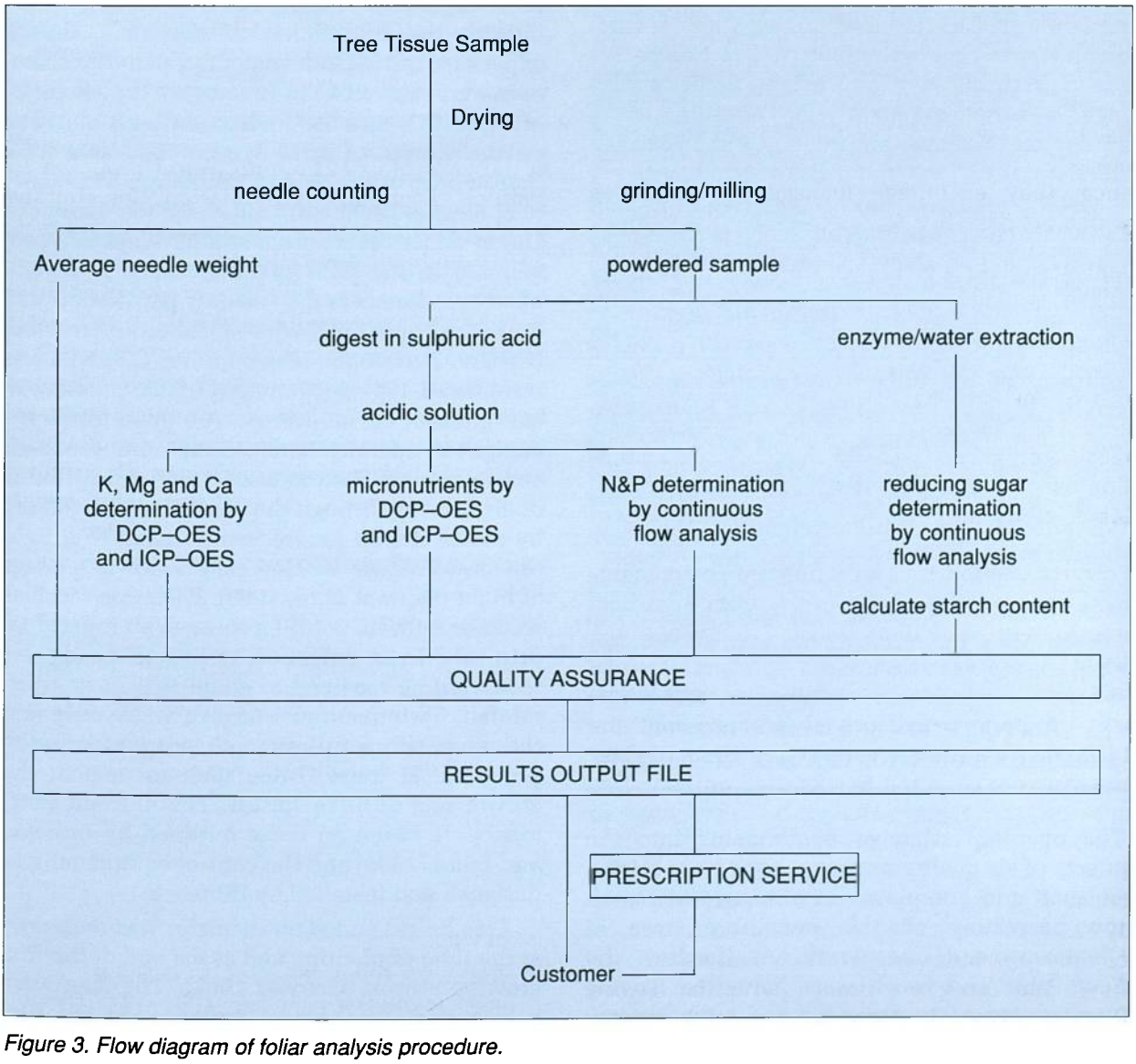


Figure 3. Flow diagram of foliar analysis procedure.

Investment in modern analytical equipment has been essential to carry out this work. For determination of nitrogen (as ammonium) and phosphorus (as orthophosphate) in plant tissue, continuous flow analysis has been used; a new automated system (Chemlab System 4) was used for the first time during 1993 (Plate 3). Gerhardt Kjeldatherm digestion and Vapodest 33 distillation equipment has been purchased for determination of soil nitrogen. Since 1978, macronutrients potassium, magnesium and calcium have been determined by direct current plasma optical emission spectroscopy using Spectrospan III equipment. This has now been replaced by an inductively coupled plasma optical emission spectrometer (Plate 4). This advanced analytical tool can determine all major and minor nutrients simultaneously. In addition, inorganic contaminants in water and soil will be more easily quantified.

Chromatographic methods of separation and quantification are well represented within the laboratory. Gas chromatography (Hewlett Packard 5880A) is used to separate volatile components such as monoterpenes in tree tissue. Ion chromatography using Dionex equipment is carried out mainly for determination of anions and cations, and mono- and di-saccharides.

Quality assurance has become very important in recent years. Methods of analysis have been clarified, and all analytical processes detailed in standard operating procedures. Certified reference materials are included in every batch of samples for foliar analysis. Regular checks of accuracy of the foliar macronutrient analysis service are made by taking part in interlaboratory sample exchange exercises run by the International Union of Forestry Research Organisations/United Nations Economic Commission for Europe and the Canadian Forest Service.

ANDY MOFFAT AND ERNEST WARD

AIR POLLUTION AND CARBON DIOXIDE ENRICHMENT: OPEN-TOP CHAMBER EXPERIMENTS

The open-top chamber experiments into the effects of air quality on tree growth were started in 1988 and completed in autumn 1993 with the harvesting of the remaining trees at Glendevon and Chatsworth. At Headley, the Scots pine and beech were harvested leaving Norway spruce to grow for one more season. Four species – Sitka spruce, Norway spruce, Scots pine and beech – had been grown in open-top chambers in either ambient (polluted) air or filtered air for six seasons. Provisional results indicate that there were no significant effects of air quality on height, stem diameter, and fresh or dry weights for any of the three species at Glendevon. At Chatsworth the result was similar, but height growth of both Norway spruce and beech had increased in filtered air during 1993. At Headley, Norway spruce and beech grew significantly better in filtered air. Continuous measurement and analysis of air quality at the three sites confirmed that ozone concentrations were highest at Headley. Overall, we can conclude from this major, long-term experiment that ambient air quality significantly affects the growth of trees in some parts of the U.K. Impacts range from clear adverse effects of ozone to subtle beneficial effects of sulphur and nitrogen compounds. Follow-up work is now being set up in oak, Sitka spruce and Scots pine stands to identify the response mechanisms occurring at specific forest sites.

With the completion of the air pollution experiment at Glendevon, the open-top chambers were converted to investigate the effects of elevated CO_2 and the interaction with nutrition on the growth of Sitka spruce. This is a joint Forestry Commission and Edinburgh University long-term experiment funded by the European Union under the research and development programme in the field of Environment. In eight open-top chambers the soil was partitioned into four equal quadrants with 40 cm moisture-proof barriers. A 16 tonne tank supplies CO_2 which is introduced at a concentration of 350 ppm above background, i.e. on average 700 ppm, through a computer operated monitoring and feedback control system (Barton *et al*, 1993). The volume of air flowing through the chambers is regulated by motor driven louvre vents linked to a light sensor, to reduce air flow and hence CO_2 usage at night (Durrant *et al*, 1993). Each tree receives water or nutrient solution through an individual drip tube in an irrigation system that regulates total volume received to equal that of incident rainfall. Two quadrants receive water only and the other two a full strength nutrient solution provided at rates calculated to match the growth rate of Sitka spruce. The nutrient treatments are based on those outlined by Ingestad and Lund (1986) and the control equipment was designed and installed by Biotronic.

Tree height and stem diameter was measured at the time of planting and at the end of the first growing season (October 1993). The data were subjected to analysis of variance. In the first growing season after planting out, nutrition has

had a significant effect on the diameter of the trees, with nutrient application resulting in increased diameter growth. This difference was larger in ambient CO_2 than in elevated CO_2. In a second experiment, aspect significantly affected tree height and diameter, with south-facing trees showing increased growth over the first growing season. This illustrates the importance of careful experimental design when using small plots or limited numbers of replicates.

The site at Headley has been equipped with the installation of improved fan/filter units providing increased airflow (Plate 5). A new experiment has been initiated (Project 712) to investigate the interacting effects of CO_2, ozone and water supply with a view to predicting changes in tree growth (ash, oak and Scots pine) in post climate-change England. A similar CO_2 control system to that described above for Glendevon has been installed providing treatments of ambient ($\approx$ 350 ppm) and elevated (700 ppm) CO_2. Ozone addition is also through a computer operated feedback and control system allowing ramping of ozone levels through the morning and afternoon, mirroring diurnal variation. The high ozone treatment (20–100 ppb) is based upon twice the mean concentrations for the 1991 growing season of 10 ppb overnight, rising to a maximum of 49 ppb during the afternoon. Potted seedlings of all three species have been acclimated to ambient or elevated CO_2 in a modified polytunnel since January 1994. The trees will be transferred to chambers for ozone/CO_2 fumigation in May 1994 and planted in October 1994 when the chambers currently occupied by Norway spruce (see above) are released. Water supply regimes of ambient and full field capacity will be imposed at this stage, resulting in the final experimental design as shown in Figure 4.

DAVE DURRANT AND MARK BROADMEADOW

REFERENCES

BARTON, C.M.V., LEE, H.S.J. and JARVIS, P.G. (1993). A branch bag and CO_2 control system for long-term CO_2 enrichment of mature Sitka spruce (*Picea sitchensis* (Bong.) Carr.). *Plant Cell and Environment*, **16**, 1139–1148.

DURRANT, D., LEE, H., BARTON, C. and JARVIS, P. (1993). *A long-term carbon dioxide enrichment experiment examining the interaction with nutrition in Sitka spruce.* Research Information Note 238. Forestry Commission, Edinburgh.

INGESTAD, T. and LUND, A.-B. (1986). Theory and techniques for steady state mineral nutrition and growth of plants. *Scandinavian Journal of Forest Research*, **1**, 439–453.

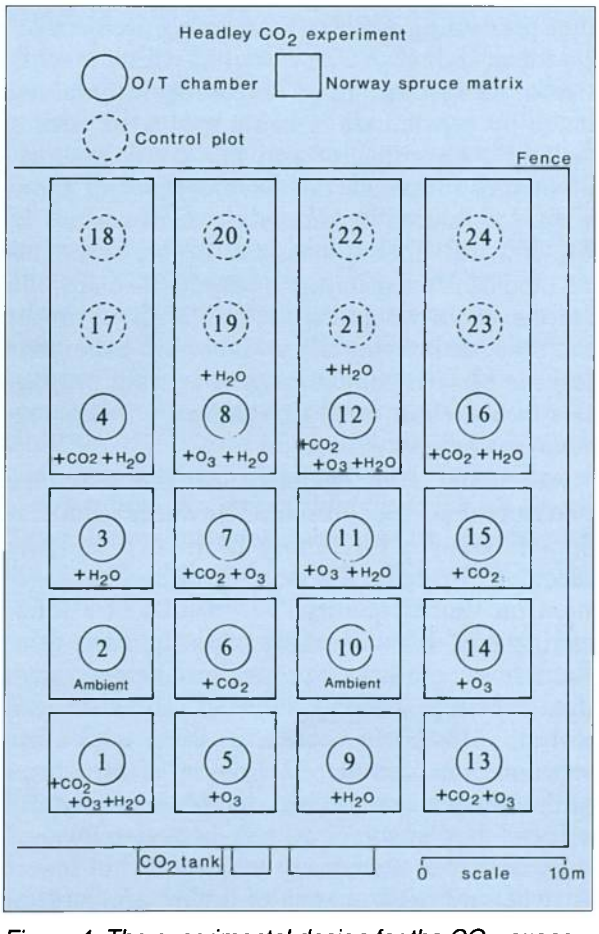


Figure 4. The experimental design for the CO_2, ozone and water availability treatments for ash, oak and Scots pine at Headley.

FOREST PRODUCTS

Over the past year a significant part of Forest Products' research has focused on factors influencing the deterioration of timber, both in the round and in sawn form, particularly as colonisation by sapstain fungi during harvesting and after processing remains a recurring problem for the forest industry. The extent to which mechanised harvesting may encourage increased attack by sapstainers is being evaluated and in particular how macro- and micro-environmental factors influence the development of these fungi. It has also become clear from studies in the sawmill that processed timber becomes infected with sapstainers largely through the actions of invertebrate vectors such as mites and flies, countering the widely held belief that degrade of sawn timber originates from propagules of bluestain fungi disseminated in air currents (see below).

As before, the majority of the Branch's resources has been directed towards commissioned research on timber properties and the effect of provenance and silvicultural management on timber quality. The results of a long-term study looking at spacing in 'non-thin' plantations of Sitka spruce (see below) have also recently been published (Brazier and Mobbs, 1993). In essence, this work has revealed that commercial yields of structural grade timber are likely to be significantly reduced if planting intervals between trees of more than two metres are employed, but losses in structural performance of timber are particularly marked as planting distances increase from 1.5 to 3 metres.

Forest Products staff also continue to represent the Forestry Commission on British Standards committees and play a central role in organising and contributing to the Technical Sub-Committee of the Home Grown Timber Advisory Committee. In addition, almost 200 enquiries were processed coming from the public, educational establishments and the forestry industry on a diverse range of subjects including residues, wood properties, fuel and preservation.

JOAN WEBBER

REFERENCE

BRAZIER, J.D. and MOBBS, A.D. (1993). The influence of planting distance on structural wood yields of unthinned Sitka spruce. *Forestry*, **66**, 333–352.

A PEAT ALTERNATIVE

With the current interest in identifying peat alternatives, a collaborative venture between Forest Products Branch and Forest Enterprise, New Forest, has evaluated the potential for using bracken as a horticultural medium. Traditionally, bracken was used successfully for both growing and mulching, although this practice has been largely discontinued. Trials have shown that composting the bracken produces a very versatile horticultural medium and has the added advantage of destroying the carcinogenic compounds generated by the plant. Following this work, significant quantities of bracken are being marketed on a commercial basis. Apart from the horticultural advantages, using bracken for this purpose would involve regular cutting and harvesting, a recognised method for controlling this pest species which is an established and encroaching problem in many woodlands and on uncultivated farmland.

JOAN WEBBER AND RONA PITMAN*

*Forest Enterprise, New Forest

FUNGAL DEGRADE OF TIMBER

Preservation of utility poles

In the case of homegrown pine harvested for utility poles, roundwoods are felled and then transported to a timber yard where they are debarked and air seasoned in preparation for pressure treatment with creosote. This seasoning period immediately after felling is when many decay basidiomycetes can become established. It is the objective of the current project to develop an on-site treatment which will prevent colonization by these decay fungi.

A prime consideration of any forest-based treatment is the labour involved in application. Incorporating the treatment into the harvesting machinery is an obvious way of keeping additional labour to a minimum and at the same time ensuring that treatment is immediate. Spores of a promising biocontrol treatment, *Trichoderma harzianum,* have been incorporated into the chain-oil of felling saws with encouraging results. Sapstain and decay are reduced in treated material and experiments indicate that application in chain-oil actually increases establishment of the *Trichoderma* compared with treatments where spores are applied in a water suspension. Trials are currently being conducted throughout the year to investigate how season affects the success of application by chain-saw.

Integrated control, the combined use of a biological control agent and a compatible chemical, is another area of interest. A field experiment run over an eight-month period has indicated that *Trichoderma viride* can be successfully applied to pine alongside borate salts. Significant control of decay was observed in the experiment whether or not the material was exposed to rainfall, countering the widely held view that borates are considered to be too highly leachable for effective outside use.

Laboratory studies have continued to yield insights into how biological control operates in the field. A particularly exciting area has involved the metabolites of *T. harzianum* and their effect on the interactions between target decay fungi. The outcome of interactions between basidiomycetes can be completely reversed in the presence of *Trichoderma*, indicating that the mould has the potential to markedly alter the structure of fungal communities in wood.

MAGNUS SCHOEMAN, JOAN WEBBER AND
DAVE DICKINSON*

*Department of Biology, Imperial College, London

Fungal stain and moulds on unseasoned timber

Dissemination of sapstain fungi by bark beetles is widely reported and accepted, but the extent to which both sapstain and mould fungi are transmitted by micro-arthropods onto freshly felled logs and sawn lumber is rarely considered. In an evaluation of the source of infection on freshly felled logs stored in the forest, logs protected from bark beetle attack but exposed to other micro-arthropods exhibited similar levels of internal sapstain to those exposed to all insects. The incidence of infection attributed to bark beetles was confined to periods of beetle emergence whereas infection in logs protected from bark beetles occurred throughout the year and showed much greater variation between individual logs, highlighting the importance of vectors other than bark beetles in the forest environment.

In order to understand the role of micro-arthropods in fungal infection of sawn and stacked lumber, a fourteen-week field trial was established at a sawmill in southern England during the summer. Defacement of boards sawn from the sapwood of freshly felled logs of Corsican pine (*Pinus nigra* var. *maritima*) was analysed at two time intervals for fungal sapstain, moulds and basidiomycetes. The boards used in the trial were close stacked to reduce moisture loss and increase the hazard to fungal infection. Individual stacks were constructed in a nest arrangement which enclosed experimental sterilised board samples contained in plastic tanks and positioned centrally in each stack (Plate 6). These experimental boards had previously been γ-irradiated inside the tanks and the open tank faces then either left uncovered or covered with a very fine (5μm) nylon mesh screen to prevent entry of micro-arthropods. In addition, the outer casing timbers in each stack were dip-treated with either a fungicide, a broad-spectrum insecticide/acaricide, a combined treatment containing the fungicide and the insecticide/acaricide, or with water which served as a control.

At the eight- and fourteen-week inspections basidiomycete infection was minimal in all the treatments, but the casing boards from the control stacks were severely sapstained and there was a little superficial mould growth. The fungicide treatment, either alone or in combination with the insecticide, prevented sapstain or mould development throughout the fourteen-week trial. Although boards treated with the insecticide were slightly sapstained and showed severe moulding after eight weeks, by the end of the fourteen-week trial the degree of sapstain had increased while the level of mould defacement was significantly reduced. Treatments including the fungicide were always effective in preventing fungal growth on the wood, while the insecticide treatment alone eliminated live micro-arthropods and reduced the incidence of sapstain. Significant numbers of dead micro-arthropods were recorded on these boards and their remains were often associated with discrete zones of sapstain in the wood (Plate 7).

The condition of the irradiated sample boards, was evaluated after eight weeks' expo-

sure. Boards which were accessible to arthropods – that is, placed in open tanks surrounded by non-insecticide treated casing timbers – exhibited a high level of sapstain. When protected from arthropod invasion by a mesh screen and/or insecticide treatment, sapstain on the experimental boards was minimal.

However, micro-arthropods were not only implicated as primary vectors of spores of sapstain fungi on green sawn lumber (Plate 8), but were also found to graze the moulds and therefore limit the intensity of defacement by these fungi. Mould spores appeared to be largely transmitted into and within the board stacks by air currents and, in the absence of live arthropods on the insecticide-treated casing boards, moulding was severe after eight weeks, but minimal on the other treatments. After fourteen weeks, however, the mould fungi declined and this was attributed to degradation of the insecticide treatment and re-establishment of the micro-fauna. The low incidence of moulding on the untreated casing timbers, where the micro-fauna was abundant and active, supports the view that fungivory is a major influence on the intensity of defacement.

Analysis of the irradiated boards in screened tanks where micro-arthropods were excluded showed significant moulding except when surrounded by untreated casing boards. In the latter situation, the screens were clean and moulds had been removed by grazing micro-arthropods in the stack. In the absence of micro-arthropods the screens were heavily moulded. Aerial dissemination of mould spores to the screens, followed by hyphal growth through the screen mesh and sporulation on the inner surfaces, resulted in mould infection of the experimental boards when arthropods are excluded. The lower incidence of moulding on experimental boards in open tanks surrounded by non-insecticide treated casing timber, and the higher incidence when insecticide was applied confirms the proposition that grazing micro-arthropods significantly reduce surface moulding on the boards. Fungivory by micro-arthropods, therefore, plays a dual role in the fungal colonisation of green sawn lumber by introducing sapstainers and also contributing to the removal of moulds.

ROD EATON AND MICHAEL POWELL

School of Biological Sciences,
University of Portsmouth

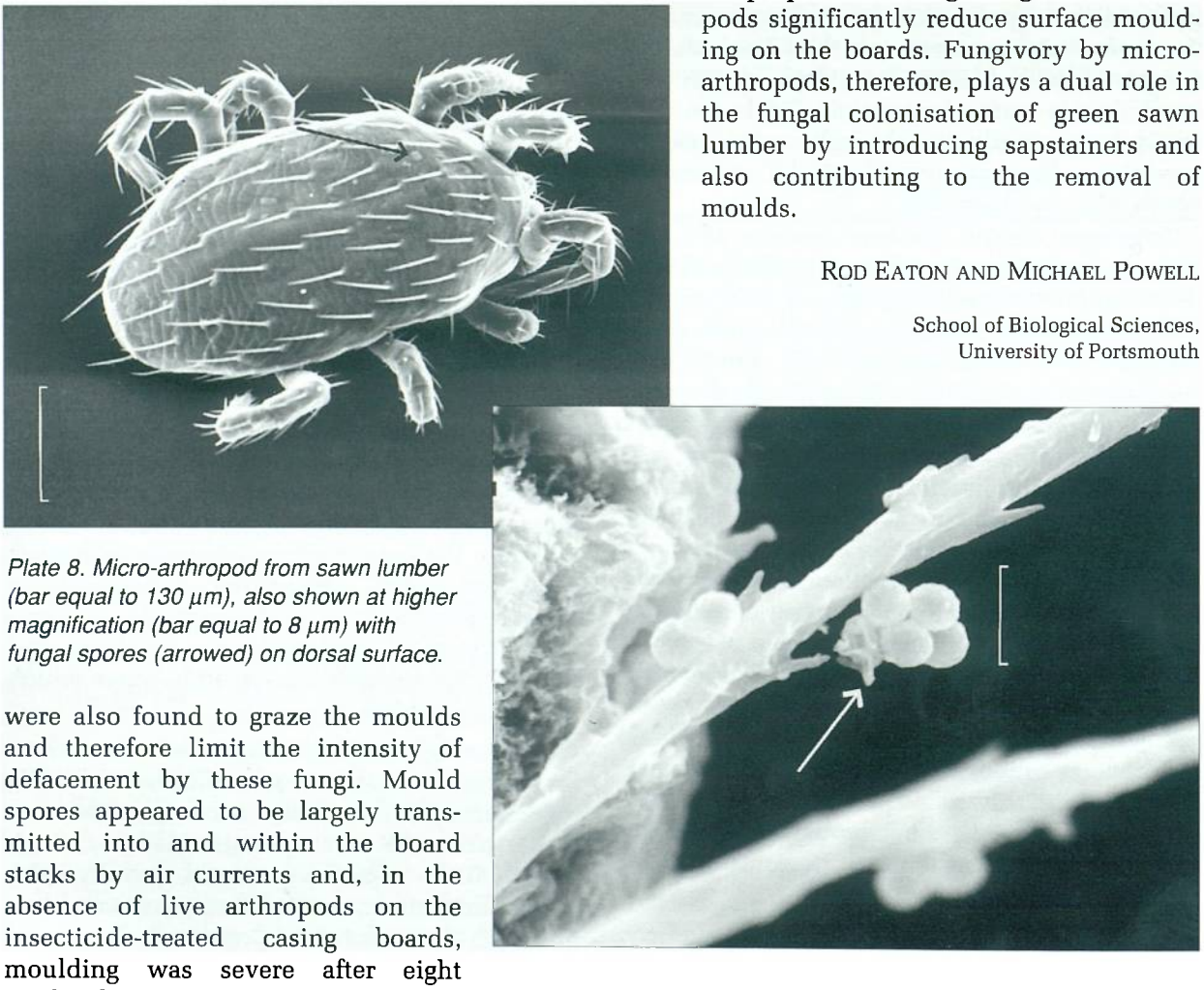


Plate 8. Micro-arthropod from sawn lumber (bar equal to 130 μm), also shown at higher magnification (bar equal to 8 μm) with fungal spores (arrowed) on dorsal surface.

TESTING BRITISH-GROWN TIMBER

Strength grading of British-grown oak

Currently there are no design properties in BS5268 and no British standard grading rules for temperate hardwoods. Work is being carried out at the Building Research Establishment (BRE) on two batches of British-grown oak to enable drafting of a visual grading standard comprising two or three grades, together with the strength properties for those grades.

The first draft of the standard will be applicable to all temperate hardwoods, although strength properties will only be given initially

for oak in BS5268; the standard is anticipated for September 1994. There are also plans to carry out testing on sweet chestnut in 1995 to permit mechanical properties to be added for that species. If the work can be completed in time, the grading standard and strength properties will be referenced in the European Standard currently being drafted on the assignment of grades and species to strength class.

All visual assessments of the four sides and whole lengths of the first batch of oak sections are complete as, too, are strength tests to determine modulus of elasticity and modulus of rupture on some 450 pieces of oak in three sizes (50 x 100 mm, 100 x 200 mm and 150 x 150 mm). Inspection of failure sections and data analysis are almost complete and provisional grade classification is progressing. Testing has been carried out at moisture contents higher than is typical for oak in structures, and higher than the 12% moisture content (mc) requirements of the relevant European Standard. The period necessary to kiln dry these sections to 12% mc would have been too lengthy and possibly would have resulted in unacceptable degrade.

Early test results on oak kiln-dried to around 35–65% indicated strength properties somewhat lower than expected and this looks likely to be confirmed by results from the subsequent testing, including some on freshly sawn 'green' timber with an even higher moisture content. When testing and data analysis is complete, appropriate combinations of strength and yield will be determined to enable decisions on the preferred grades to be included in the draft standard.

Drying of Sitka spruce

The output of British-grown commercial softwood is expected to reach four million m^3 by 2025. Much of this will be Sitka spruce which can differ in certain characteristics from imported sources of timber. One such difference is a somewhat increased tendency to distort, often visible as twist, when the material is dried to 'in service' moisture contents. This is particularly associated with faster grown material and with trees felled at a relatively early age which have a higher proportion of juvenile wood.

The amount of twist allowed in BS4978 (Softwood Grades for Structural Use) is based on measurements made at a maximum timber moisture content of 20%. On this basis, initial assessments carried out on two parcels of British grown Sitka spruce battens indicated that the percentage of battens which complied with the British Standard ranged from 45%–70%; similar results were obtained for imported timber.

It is known that the amount of twist in British-grown softwoods, in particular Sitka spruce, can be reduced by using modified kiln schedules and heavy restraining weights to restrict movement during the drying process. Indeed, much British-grown timber is already coming to the market in a suitably straight condition as a result of being dried under restraint. Although this material meets the requirements of BS4978, it cannot be distinguished from supplies dried by conventional air-drying and the extent to which current supplies of timber dried under restraint could subsequently distort in service under cyclic climatic conditions has not been quantified.

Preliminary results of the research currently being conducted in the Timber Division at BRE have already given a basis for re-assurance. Two sizes of four metre long Sitka spruce battens (47 x 150 mm and 47 x 100 mm) were specially selected for 'worst-case' studies as material likely to twist under the conditions of the investigation. Each batten was cross-cut into two to provide end-matched samples which were then kiln-dried either with or without restraint. After kilning the amount of twist was measured for each of the respective sizes. Results showed that on average only 38% of the 47 x 150 mm material and 32% of the 47 x 100 mm material complied with BS4978 when kilned without restraint (Table 1). This compared with 80% and 57% compliance respectively for the comparable battens dried under restraint. The very low values for the unrestrained battens confirmed that the quality of material selected for this investigation was indeed at the poorest end of the quality range.

Table 1. Effect of kiln-drying with and without restraint on distortion of British-grown Sitka spruce ('worst-case' sample)

Batten sizes (mm)	*Compliance (%) with BS 4978 after kiln-drying*	
	unrestrained	*restrained*
47 × 150	38	80
47 × 100	32	57

All material was subsequently subjected to cycled humidity conditions of 65%, 30%, 90% and 65% relative humidity, each for approximately 6–8 weeks. As expected, some increase in twist occurred after the first two humidity changes but the increases were identical for both methods of kilning. Thus the advantage of material dried under restraint was maintained and any extra induced drying stresses did not emerge as dormant twist on subsequent exposure to changes in humidity. Even at the end of

the complete cycle, although all battens showed more twist than at the start, the material dried under restraint maintained its advantage.

Research is continuing to confirm these early indications and to examine the effects of shorter humidity cycles, shorter kilning schedules at higher temperature, and optimising loading weight. Continuing work will include tests on better quality material more representative of normal construction grade Sitka spruce and also glue-jointed material.

TONY BRAVERY, TONY FEWELL AND KEITH MAUN

Building Research Establishment, Garston, Watford

WOOD QUALITY

Influence of site and silvicultural practice on wood quality of oak

The main aim of this project is to quantify the influence of site and silvicultural practice on wood structure and properties of oak. It is part of a larger European Union (EU) funded project which arose in response to the increasing level of interest in planting broadleaves in many parts of the EU, triggered by recent policies encouraging farm forestry on previously cultivated land. Although this type of favourable site can be expected to produce rapid growth, there is little information about the extent to which such growth rates will affect wood quality. For that reason, the present project gives particular emphasis to the influence of spacing, crown size and growth rate on wood structure and properties. Other EU partners (Scotland, Denmark, and Germany) have undertaken similar work on beech, ash, sycamore and poplar, each country contributing material on the different species from their own localities to the relevant partners.

Samples were collected from ten trees, selected from each of 16 sites (six sites from England and Wales, four from Scotland, four Danish and two German), grown at a range of stocking densities. The original intention was to sample from stands of known seed origin and silvicultural history, but such material proved impossible to obtain, so stands were selected on the basis of current site conditions. For each tree, measurements included total height, diameter at breast height, crown dimensions, and branch size and distribution below the spring of the crown. Discs were cut from each tree at breast height, bark and sapwood thickness recorded, and variations in ring width, earlywood and latewood proportions, density, spiral grain, and shrinkage measured from pith to bark. These data are still being analysed in relation to tree dimensions and site conditions.

From all sites, density (Figure 5, opposite Plate 10) and ring width tended to decrease from pith towards bark, while spiral grain (Figure 6, opposite Plate 13) increased. Longitudinal shrinkage tended to be higher towards the pith, but tangential (Figure 7, opposite Plate 14) and radial shrinkage showed no clear trends from pith to bark.

The analyses suggest that basic density, spiral grain and shrinkage (tangential, radial, and longitudinal) were all influenced by site, at a comparable ring number from the pith (Figures 5–7). Comparing stands with trees of a similar age, there also appeared to be significant differences in bark thickness, sapwood width and earlywood width. However, most of these site differences could not be related to silvicultural practice; multiple regressions suggested that only ring width and longitudinal shrinkage were significantly correlated with crown dimensions or stocking rate. Between trees within sites there were considerable differences in density, spiral grain, and shrinkage; again, these differences were not consistently related to crown dimensions. These between and within site differences in wood properties suggest there is potential for selection to improve such aspects of wood quality, independent of growth rate.

Between trees, mean ring width was significantly correlated with weighted density, but at a level which is surprisingly low (R^2=0.022) in the light of the commonly held assumptions about the influence of growth rate on density of oak wood. Density was significantly correlated with tangential shrinkage, and also with angle of spiral grain. These complex relationships between growth rate, density and other wood properties, are now being explored in greater detail using computer tomography and microscopic analyses of growth ring structure. Earlywood vessel dimensions, latewood fibre dimensions, and tissue proportions are being measured for comparison with maximum, minimum, and mean density of individual growth rings determined from computer tomography scans. These analyses should allow further interpretation of the influence of silvicultural management on density (and hence on other wood properties), and suggest the extent to which this relationship can be controlled by selection for particular aspects of wood quality between and within stands.

DEE AEBISCHER AND PAT DENNE

School of Agricultural and Forest Sciences, University of Wales, Bangor, Gwynedd

MENSURATION

Overview

A total of 124 permanent sample plots were given a full measurement, including thinning where required. Of these plots, ten were abandoned due to wind damage. A number of plots in the Elwy Sitka spruce line thinning experiment were also seriously wind damaged and this is likely to lead to early closure of this experiment. Twenty–three new permanent sample plots were established covering a range of unthinned Sitka spruce, mixture and hardwood crops. Training in sample plot methods was given to contractors and Forest Enterprise district staff involved in sample plot measurement and a number of collaborative yield studies.

Significant progress has been made on the second site yield research project jointly funded by the Forestry Commission and the Ministry of Agriculture, Fisheries and Food. Site yield models are being developed for ash, poplar, sycamore, hybrid larch and Norway spruce. Growth measurements have been collected from 142 temporary sample plots on a range of site types for the five species. Single tree volume functions have been produced for all five species and these are shown in Table 2. Confirmation of major soil group classifications, and improvement of estimates of accumulated temperature and potential soil moisture deficit to take account of altitude, has been necessary for all sample plots included in the study.

The Branch has dealt with a number of advisory tasks during the year including: four two-day seminars on the tariff procedure for Forest Enterprise staff and representatives of the private sector, carried out at the request of South Scotland, North and East England, and South and West England Forest Enterprise Regions; a training course in sample plot methods for five senior forest scientists from China; an increasing number of enquiries on measurement procedures and yield models requiring field visits and data analysis.

The longer-term research programme of the Branch, in particular yield model validation, has continued although advisory and contract commitments have inevitably disrupted progress. There was major involvement in the Forest Condition Monitoring Survey, and the Branch continued its representational role on the European Standards Committee concerned with the preparation of a standard covering methods of measurement of round timber. A collaborative project with the University of Wales, Bangor, to develop mathematical functions for tree profiles, and to simulate the effect of stem defects on product out-turn, started in November 1993. Three projects dealing with aspects of yield, timber quality and carbon storage are reported below.

JANET METHLEY

Table 2. Parameter estimates of single tree volume functions for ash, poplar,sycamore, hybrid larch and Norway spruce

Species	*Single tree volume function*
Ash	$v = - 0.020112 + (0.0000908 \times dbh^2 \times h^{0.7085})$
Poplar	$v = - 0.004298 + (0.0000435 \times dbh^2 \times h^{0.8908})$
Sycamore	$v = - 0.016828 + (0.0000968 \times dbh^2 \times h^{0.6660})$
Hybrid larch	$v = - 0.014706 + (0.0000833 \times dbh^2 \times h^{0.7360})$
Norway spruce	$v = - 0.015632 + (0.0001099 \times dbh^2 \times h^{0.6475})$

MORTALITY STUDY IN UNTHINNED SITKA SPRUCE CROPS IN SOUTH SCOTLAND REGION

Mensuration Branch was commissioned to investigate the mortality assumptions in the unthinned Sitka spruce yield models, and, in collaboration with Forest Enterprise staff and contract surveyors, established and measured 171 temporary and permanent sample plots in six Forest Districts. The sample plot data, representing a range of crop ages, spacings and yield classes, were processed using existing computer programs to produce stand level estimates of the yield model variables. The predictions made by the yield models were compared with the actual values obtained in sample plots. A range of tabulation and regression methods was employed to test for the presence of bias in prediction errors. Existing permanent sample plots have also been included in this investigation to determine how representative they are of South Scotland conditions. This study has helped to progress the longer term validation of the published Sitka spruce yield models.

JANET METHLEY, ROBERT MATTHEWS, JOHN PROUDFOOT, STAN ABBOTT, NIGEL FEARIS AND ADRIAN ELLIS

TIMBER QUALITY ASSESSMENT FOR PRODUCTION FORECASTING

In April 1993 the HGTAC Technical Sub-committee approved the formation of a Timber Quality Steering Group charged with the task of carrying out a pilot study to investigate the potential for developing a crop quality classification system and to demonstrate its relevance to sawmill out-turn. The Steering Group members are representatives of sawmillers, private growers, Forest Enterprise, the Forestry Authority and wood science. The study has proved to be a major undertaking, requiring commitment, cooperation and resources from the different sectors of the industry, although the bulk of project management and implementation has been undertaken by staff from Mensuration Branch and BSW Carlisle. The Steering Group and a sawmillers' sub-group agreed that straightness was the most important stem characteristic affecting quantity and quality of sawmill out-turn. Straightness was also considered to be the simplest measure of quality that could be studied in the time available, and the characteristic that could be assessed with a measure of consistency by different observers. Four log length categories, linked to different value products, were identified and included in the straightness assessment carried out on the first six metre butt portion of the tree. A Sitka spruce crop of relatively poor quality and a Norway spruce crop of relatively good quality were assessed for straightness by six trained observers. The assessed trees from both sites were felled, processed and measured in the mill. Preliminary analysis of the data included an investigation of a number of crop quality scoring systems, which were calculated using the observed combinations and numbers of different log lengths. Initial results have indicated that different crop qualities can be identified using straightness assessment scores and that these are meaningful in terms of product out-turn. Further research is required before the assessment method can be introduced to production forecasting.

JANET METHLEY, ROBERT MATTHEWS, JOHN PROUDFOOT AND ADRIAN ELLIS

JOINT ENERGY TECHNOLOGY SUPPORT UNIT/ FORESTRY COMMISSION PROJECT ON ENERGY AND CARBON BUDGETS OF WOOD FUEL PRODUCTION

Among the many methods of potentially sustainable energy generation, wood fuel has been receiving increasing attention. Indeed, biomass fuel farming is frequently proposed as a cheap, low-technology means of producing renewable energy. For any such bioenergy system to be worthwhile, the energy produced must be greater than the inputs of non-renewable energy required to establish and operate the scheme. Moreover, to be truly sustainable, establishment and operation of the bioenergy generation system must result in negligible net emissions to the atmosphere of greenhouse gases, principally carbon-based compounds such as carbon dioxide. In order to confirm that a bioenergy generation scheme meets these criteria, it is necessary to evaluate the energy and carbon budgets of the proposed system. The Department of Trade and Industry, through the Energy Technology Support Unit, has collaborated with Mensuration Branch on a research project to model the energy and carbon budgets of wood fuel production from short rotation coppice. A computer model has been developed which calculates the total energy and carbon benefits and costs of a bioenergy producing system based on the biomass productivity of the crop, a description of the activities carried out to produce the

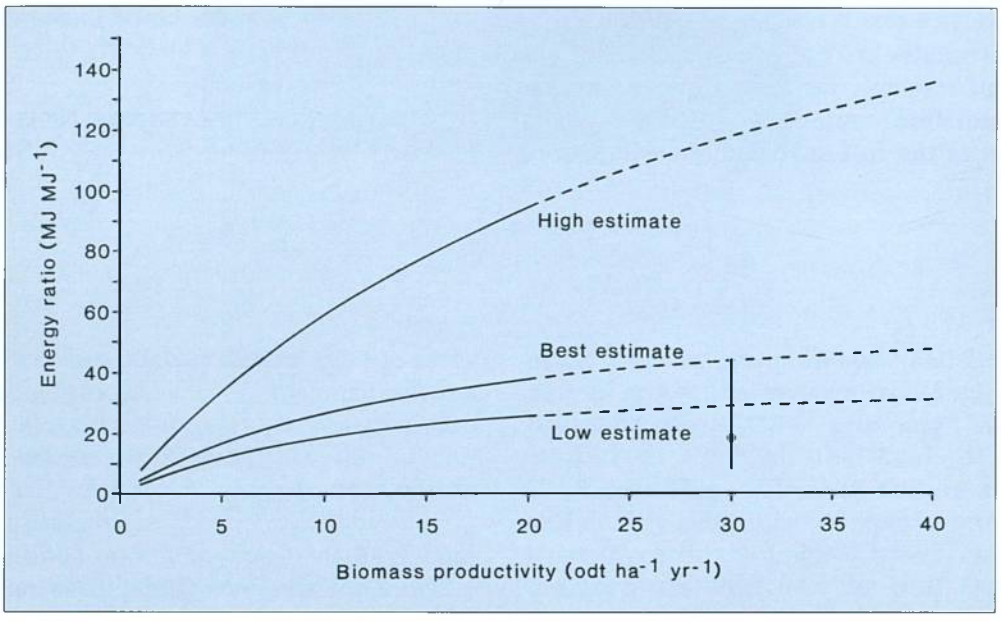


Figure 8. Relationship between predicted energy ratio and utilisable biomass productivity for wood fuel production from short rotation coppice. Dashed lines indicate extrapolations based on data for harvesting machines which cannot cope with high biomass yields. Large dot and vertical line: estimate and range for energy ratio, given 30 odt ha $^{-1}$ yr $^{-1}$, assuming conventional harvesting methods.

biofuel, and data on the energy costs of fossil fuels, materials and machinery.

It is impossible to make precise statements about the energy and carbon budgets of short rotation coppice crops for the production of wood fuel, due to uncertainties in the estimation of certain energy and carbon costs, and the wide variation in techniques of crop management, wood harvesting and fuel processing. The energy budget of a biofuel system may be summarised using statistics such as the energy ratio defined thus,

$$\text{Energy ratio} = \frac{\text{Total energy benefit}}{\text{Total energy cost}}$$

which indicates the number of units of energy produced for every unit of non-renewable energy expended in operating the system. For the biofuel producing system to be worth operating, the energy ratio needs to be significantly greater than one.

The computer model was used to investigate the sensitivity of the energy ratio to changes in the methods by which short rotation coppice is grown. Table 3 shows the variation in the estimated energy ratio with the cutting cycle and productive life of the coppice crop, while Figure 8 shows the variation in estimated energy ratio (in megajoules (MJ)) with the biomass productivity (in oven dried tonnes (ODT)) of the crop. Typically the energy produced in the form of wood chips from short rotation coppice is estimated to be 30 times greater than the energy expended in growing and harvesting the crop, giving an energy ratio of 30. The fossil-fuel carbon emitted in producing one MJ of energy in the form of wood from short rotation coppice is estimated to be typically 0.0013 kgC. Because wood fuel itself is 'carbon neutral', this represents the total emissions of carbon to the

Table 3. Dependence of predicted energy ratio on cutting cycle and productive life of coppice crops. (the estimates in the grey shaded region are relatively low, because only a single harvest is obtained from the crop)

Cutting cycle (yr)	*1*	*2*	*3*	*4*	*5*
Productive life (yr)					
3	8	7	–	–	–
4	10	–	11	–	–
5	12	14	–	13	–
6	13	–	–	–	16
7	14	18	19	–	–
11	17	22	–	–	27
13	18	24	27	28	–
16	19	–	29	–	32
17	19	26	–	31	–
25	20	28	32	35	–
26	20	–	–	–	37

atmosphere as a result of using wood fuel.

These estimates are based on the assumption that current methods for growing and harvesting short rotation coppice are sustainable. An assessment of the full environmental impact of short rotation coppice crops is required to test this assumption.

ROBERT MATTHEWS, NIGEL FEARIS AND
STAN ABBOTT

MYCORRHIZA RESEARCH UNIT

This Unit was established during 1993 to carry out research into aspects of mycorrhizas that might be relevant to forestry. It has two staff members, whose work continues the mycorrhiza project, formerly carried out within Physiology Branch.

Investigations on ectomycorrhizas have concentrated on establishing methods for inoculation of Douglas fir in the nursery with spores of mycorrhizal fungi. Nursery experiments showed that it was possible to inoculate with spores of fungi in the genus *Rhizopogon*, and guidelines for accomplishing such inoculations had been issued. However, continued research in the nursery failed to reproduce earlier success. Spores of *Rhizopogon* spp. from the Pacific Northwest were inoculated into soil around the roots of seedlings, but mycorrhizas failed to establish except with naturally-occurring fungi.

A European Union research project, in cooperation with research institutes in France, Germany, Denmark and Portugal, was started with Silviculture (North) Branch. The project examines inoculation of Sitka spruce cuttings with the fungus *Laccaria proxima*, and will investigate the effects of such inoculation on their rooting and future field performance.

The Unit Head, Dr Chris Walker, is chairman of the working group on systematics and taxonomy of arbuscular mycorrhizal fungi within the pan-European COST grouping which has worked to establish the Bank of European Glomales. This system of culture registration and quality assurance in experiments on arbuscular mycorrhizal fungi, is based on a database designed and written in the Unit. Data entry is now proceeding, and the bank will shortly be formally launched. Cooperative research is in progress with laboratories in Brazil, Canada, Denmark, Finland, France, Germany, India, Ireland, Italy, Kenya, Spain, Switzerland and The Netherlands, as well as several British institutes. In the Finnish work, with Dr M.Vestberg of the Agricultural Research Centre of Finland, Laukaa, a sealed system for culturing obligately symbiotic mycorrhizal fungi, has been developed (see Plate 9). A contract with the Food and Agriculture Organization was fulfilled when Dr Walker spent a month in India providing training and advice to establish mycorrhiza research units in two of the Indian Council for Forestry Research and Education institutes. Contracts in the U.K. include an investigation into the mycorrhizal status of a coal-mining spoil heap in Strathclyde Region.

CHRIS WALKER

PATHOLOGY

A substantial part of the Branch programme is concerned with monitoring the health of trees across Great Britain. In part this work is done through the Forest Condition Survey, which involves annual assessment of the crown density of over 8000 forest and plantation trees comprising five important species. Assessment is by comparison with photographs of ideal trees. The 1993 results showed that a marked two-year decline in the crown condition of Scots pine was reversed and a similar decline in oak was arrested. There was a continued recovery of beech following a decline in 1991. An additional element in the 1993 survey was a second assessment, conducted with reference to a local standard rather than an ideal tree. This will permit a more satisfactory comparison with the data produced in many other European countries (Redfern *et al.*, 1994).

A new programme, funded by the Department of the Environment on contract, involves the establishment over a two-year period of a system for monitoring the health of non-woodland trees in England. A report for 1993 (Gibbs, 1994) was based on *ad hoc* investigations and surveys, but in future these will be supplemented by observations made in a network of plots established in urban and rural areas.

Complementary to the above is work concerned with events aimed at raising awareness of tree health among foresters, arboriculturists and the general public. These events are arranged under the auspices of either the Forestry Authority conservancies or Forest Enterprise districts and in 1993 took place at eleven locations. Steve Gregory of this Branch leads the project and he draws on the services of other Branch members and of staff in Entomology, Environment and other branches, as appropriate.

The testing and evaluation of the computer programme ROTTERS, an expert key for the identification of wood rotting fungi in culture (*Report*, 1991) was completed by David Rose during the year. The programme is now being made available on a commercial basis to all interested parties. Upgrades in the form of additions to the fungi covered, particularly the *Agaricales*, are planned in the near future.

For many years research on the biology of Fomes root and butt rot, caused by *Heterobasidion annosum*, has been a major part of the Branch programme. In August, Derek Redfern and Jim Pratt attended an International Union of Forest Research Organizations conference which was held in Sweden and Finland. They presented papers which re-appraised the need for stump protection against *Heterobasidion annosum* in Britain, and on the use of borates and urea to control stump infection by the fungus (Pratt, 1994; Redfern *et al.*, 1994). These topics were particularly appropriate since there is now increased interest in the control of the disease in Scandinavia. The disease is well established in the natural forest there, and stump protection, which has been practised in British plantations since 1960, has generally been considered inappropriate in these circumstances. However, large areas of farmland afforested since the last war are now being thinned for the first time giving rise to serious outbreaks of disease. Our knowledge of the problem, and the particular papers which were presented on this occasion, aroused great interest.

Several scientists from abroad spent time working with members of the Branch during the year. Dr Stefania Tegli, from the University of Florence, spent the summer working with Clive Brasier on the genetic control of cerato-ulmin production (cerato-ulmin being the principal wilt toxin of the Dutch elm disease fungus), and Dr Esperanza Sanchez from the Instituto Nacional de Investigaciones Agrarias in Madrid conducted research with John Gibbs on the ecology of *Seiridium cardinale* on Monterey cypress and with David Lonsdale on the relationship between the beech scale *Cryptococcus fagisuga* and its parasitic fungus *Verticillium lecanii*. Dr Remigijus Ozolincius from the Lithuanian Forest Research Institute spent four months with Derek Redfern working on the effects of SO_2 pollution on Norway spruce.

JOHN GIBBS

REFERENCES

GIBBS, J.N. (1994). *The health of non-woodland trees in England, 1993.* Arboriculture Research and Information Note 121-94-PATH. Arboricultural Advisory and Information Service, Farnham.

REDFERN, D.B., BOSWELL, R.C. and PROUDFOOT, J. (1994). *Forest condition survey,* 1993. Research Information Note 251. Forestry Commission, Edinburgh.

REDFERN, D.B., PRATT, J.E. and WHITEMAN, A. (1994). Stump treatment against *Heterobasidion annosum*: a re-appraisal. *In:* M. JOHANSSON and J. STENLID, eds. *Proceedings of the eighth international conference on root and butt rots.* Swedish University of Agricultural Sciences, Uppsala. 656–661.

PRATT, J.E. (1994). Some experiments with borates and with urea to control stump infection by *Heterobasidion annosum* in Britain. *In:* M. JOHANSSON and J. STENLID, eds. *Proceedings of the eighth international conference on root and butt rots.* Swedish University of Agricultural Sciences, Uppsala. 662–667.

Disease Diagnostic and Advisory Services

Scotland and northern England

The year was characterised by a high number of enquiries in which climatic damage was believed to have been involved. In spring, widespread browning was recorded on conifers in several northern nurseries and, in Sitka spruce and Douglas fir, the foliage injury was frequently accompanied by dieback of shoot tips. The precise cause of these symptoms remains unknown but they may have been induced by a combination of wind and low temperature. Unusually severe spring weather was also probably responsible for some cases of damage to young broadleaves. At one exposed site in southern Scotland, oak and birch suffered substantial dieback, and went on to produce feeble shoots with exceptionally small leaves. In the oak, the leaves also exhibited a marked reddish discoloration. Autumn frosts caused browning of Sitka spruce in several plantations in southern Scotland and northern England. In a nursery fertilizer trial in northern England, Sitka spruce seedlings that had received high nitrogen treatments sustained foliage browning and shoot dieback that was also probably attributable to autumn frost. The shoot injuries were extended by *Botrytis* infection in many cases. In late summer, a north-easterly gale led to salt-spray damage to the foliage of trees on the southern shore of the Forth estuary. Reports suggest that this damage extended along the North Sea coast as far south as Northumberland.

A wide range of fungal diseases was recorded. Early in the season, severe foliage infection of hybrid larch and European larch by *Meria laricis* occurred at some nurseries. Japanese larch, a species that is normally highly resistant to this disease, was also infected, though not severely, in two cases. As in southern Britain, willows at many northern localities suffered serious damage from scab disease (*Venturia saliciperda*) and, in oak, mildew (*Microsphaera alphitoides*) was also severe and widespread in the north. A number of cases of needle browning in Scots pine caused by *Lophodermella sulcigena* were recorded in late summer and, in spring 1994, another needle pathogen, *Lophodermium seditiosum*, was responsible for dramatic browning in some plantations. Several unusual diseases were also recorded including *Marssonina betulae* on birch, *Gloeosporidium tiliae* and *Plectophomella concentrica* on lime, and *Gloeosporium nervisequum* on plane. The last of these, though a common cause of dieback in southern Britain, is rare in the north. In one of the cases in which *M. betulae* was identified, the fungus, which is normally a leaf pathogen, was found fruiting on shoot lesions. *G. tiliae* was found to be responsible for significant defoliation of lime at three localities; in one instance, this was associated with infection of petioles as well as leaf blades. *P. concentrica* was also found on lime at three locations. It is a common cause of canker and minor dieback in elm but it is less well known on lime. Following the unusual record of *Pseudonectria rousseliana* in last year's *Report*, another case of dieback in box caused by this fungus has been diagnosed. Browning and dieback in yew were investigated on a number of occasions. Though the cause of damage was not clearly established in any of these cases, one fungus was consistently found on symptomatic needles and shoots. Its precise identity and possible role in the damage are still under investigation.

Steve Gregory, Grace MacAskill, Derek Redfern and Jim Pratt

Wales and southern England

The generally cool and damp spring gave rise to a number of leaf and shoot diseases. Most noticeable were scab diseases – *Venturia inaequalis* on apple species, particularly some cultivars of crab apple, and *Venturia saliciperda* on willows, particularly Golden willow (*Salix alba* var. *vitellina*). Damage to flowering cherries by blossom wilt, caused by the fungus *Monilinia* (=*Sclerotinia*) *laxa*, was particularly severe in

the south of England. The cultivar *Prunus* 'Sargentii' was most commonly involved and often suffered severe dieback. Wilting leaves on a 22-year-old rowan in the grounds of Alice Holt Research Station, Surrey, were found to be infected with *Monilinia aucupariae*. This is apparently the first British record for this fungus.

During the summer a number of cases of leaf spot, followed by reddening or yellowing of affected leaves and premature defoliation, were reported on wild cherry. The causal fungus, *Blumeriella jaapii*, has not been recorded by this Service before and only a handful of records are known from other sources. It was somewhat of a surprise, therefore, to receive eight records in this year including two from south Scotland and one from Northern Ireland. In addition there were further reports of cherry leaf scorch, caused by the fungus *Apiognomonia erythrostoma*, first reported last year (*Report*,1993). The year was also notable for the number of reported cases of root killing by *Phytophthora*. Species affected included wild cherry, sweet chestnut, lime, sycamore, yew, Douglas fir, noble fir, larch and cedar. Only two species were positively identified – *P. cinnamomi* on Douglas fir and sweet chestnut and *P. citricola* on yew. *Phytophthora* root disease of alder is covered later in this report.

Oak mildew, caused by *Microsphaera alphitoides*, was widespread and exceptionally severe in some parts of England making some trees almost white in appearance. A severe leaf spot on sycamore in early September was identified as being caused by the fungus *Phleospora aceris* (=*pseudoplatani*), a fungus only recorded once before in this area (in 1955) but on three occasions more recently in Scotland and northern England (*Report*, 1973, 1981, 1987).

DAVID ROSE, BOB STROUTS AND JOAN ROSE

AN ENDEMIC DUTCH ELM DISEASE FUNGUS IN THE HIMALAYAS

Two highly destructive pandemics of Dutch elm disease have occurred in the Northern Hemisphere in this century, the first caused by *Ophiostoma ulmi*, and the current pandemic by the more aggressive *O. novo-ulmi*. However, Dutch elm disease was unknown before 1900, and the origins of both fungi are a mystery. A series of Forestry Commission sample surveys aimed at elucidating the origins of the disease have established the recent history of spread of both species across Europe, North America and south-west and central Asia (Brasier, 1990). The survey across China in 1987 (*Report*, 1988) indicated that China was probably not the source of the disease. This led to the hypothesis that either introduction from the Himalayas, a major unsurveyed region with unique elm and bark beetle species, or one or more unusual evolutionary events may have been involved in its origins (Brasier, 1990).

During September and October 1993 a further research survey was carried out in parts of Himachal Pradesh, western Himalayas, with the assistance of the Forest Research Institute (FRI), Dehra Dun (Plate 10). No wilt disease symptoms were seen on elms in the area, but typical beetle feeding wounds (the point of entry of Dutch elm disease) were found on some trees of *Ulmus wallichiana*. In addition, a Dutch elm disease-like *Ophiostoma* was obtained from bark around scolytid beetle breeding galleries on *U. wallichiana* at high altitude in two Himalayan valleys.

This is the first report of an apparently endemic form of Dutch elm disease fungus. The Himalayan fungus appears to be a separate species from *O. ulmi* and *O. novo-ulmi* (Plate 11), but shares a number of important biological properties with *O. novo-ulmi*, including the production of high levels of cerato-ulmin, the principal protein toxin implicated in the disease. Its discovery promises to shed new light on their origins. One possibility is that it is unconnected with this century's two pandemics, and is of solely ancient affinity to *O. ulmi* and *O. novo-ulmi*; in this case, the Himalayan fungus may present a further threat to the elms of the Northern Hemisphere. Another is that it may be a recent evolutionary precursor of *O. novo-ulmi*. A third, suggested by the preliminary results of sexual crosses, is that the Himalayan *Ophiostoma* may have hybridised with *O. ulmi* to give rise to *O. novo-ulmi* via a secondary speciation event (*cf.* Brasier, 1990). Indeed, if more than one hybrid genotype was favoured by selection, or if the Himalayan fungus was introduced separately into Europe and North America to give rise to the EAN and NAN in independent hybridisation events, such hybridisation could account for the many unexplained differences between EAN and NAN *O. novo-ulmi* (see Brasier, 1991).

The discovery of an endemic form of the disease may also open up new opportunities for its biological control elsewhere in the world. Detailed studies on the behavioural, physiological and molecular properties of the Himalayan fungus are now in progress. Investigations of the

ecology and population biology of the disease system in the Himalayas are planned in collaboration with scientists at FRI, Dehra Dun, with a view to establishing the biological constraints on the disease under natural conditions.

CLIVE BRASIER

REFERENCES

BRASIER, C.M. (1990). China and the origins of Dutch elm disease: an appraisal. *Plant Pathology*, **39**, 5–16.

BRASIER, C.M. (1991). *O. novo-ulmi* sp. nov., causative agent of current Dutch elm disease pandemics. *Mycopathologia*, 115, 151–161.

DIFFERENTIAL RESISTANCE OF ELMS TO INFECTION VIA BEETLE FEEDING WOUNDS

Studies on resistance to Dutch elm disease have concentrated almost exclusively on the spread of the fungus once it is within the xylem vessels. However, initial infection commonly occurs via wounds (known as feeding grooves) made by the bark beetle vectors. Elms are resistant both to beetle feeding (Webber and Kirby, 1983) and to penetration of the fungus into the xylem via such feeding wounds (Webber, 1987) but these aspects of resistance have remained largely unexploited in elm breeding.

Previous studies simulating natural insect transmission via artificial feeding grooves have shown that a minimum 1000 spores of NAN *O. novo-ulmi* are required to infect English elm, *Ulmus procera* (Webber, 1987). Using similar tests, three elm species with different levels of resistance to the spread of *O. novo-ulmi* within the xylem – *U. procera* (moderately susceptible), Commelin (*Ulmus glabra x U. carpinifolia*, moderately resistant) and *U. pumila* (immune) – were compared. The wounds were inoculated with spore concentrations of *O. novo-ulmi* ranging from 50 to 100 000. They were then scored for persistence of the fungus in the feeding groove and for xylem infection one month after inoculation. Although *U. pumila* is highly resistant to wilt disease, entry of the fungus into the xylem via the feeding wounds was readily achieved. With 10 000 spores, infection occurred successfully in 70% of tests and was always associated with strong internal symptoms of tylosis and streaking. However, no external symptoms of wilt were ever visible. In contrast, entry was strongly restricted on the moderately wilt-resistant Commelin elm; 10 000 spores resulted in only 30% infection, but some external symptoms did develop. The level of infection obtained in English elm was identical to *U. pumila*, but external symptoms of wilting and leaf yellowing were always observed. The minimum spore threshold resulting in any infection in the three species was 500, 1000 and 5000 spores for *U. pumila*, English and Commelin elm respectively.

Apparently, the immunity of *U. pumila* to Dutch elm disease does not necessarily preclude successful entry by *O. novo-ulmi* or its partial establishment in the xylem. However, despite its more moderate level of resistance, Commelin elm may have an active resistance mechanism expressed in the bark surrounding the beetle feeding groove, perhaps derived from its *U. glabra* parentage. The existence of such a mechanism requires investigation, since it might be exploitable for use in resistance breeding.

JOAN WEBBER AND CLIVE BRASIER

REFERENCES

WEBBER, J.F. and KIRBY, S.G. (1983). Host feeding preference of Scolytus scolytus. *In:* D.A. BURDEKIN, *ed. Research on Dutch elm disease in Europe.* Forestry Commission Bulletin 60. HMSO, London. pp. 47–49.

WEBBER, J.F. (1987). Influence of the d^2 factor on survival and infection by the Dutch elm disease pathogen, *Ophiostoma ulmi*. *Plant Pathology*, **36**, 531–538.

AN UNUSUAL *PHYTOPHTHORA* ASSOCIATED WITH DISEASE OF COMMON ALDER

During the summer of 1993 we investigated two cases of damage to common alder, *Alnus glutinosa*, which involved the characteristic symptoms of *Phytophthora* root disease – death of bark on roots and at the stem base accompanied by a tarry exudate (Plate 12). At one site, near Droitwich in the west Midlands, some 20 affected trees were distributed along the banks of a small stream. At the other, near a nature reserve in Kent, two affected trees were found. Here damage to alder from other causes was probably also present. Following the dissemination of a press release by the nature reserve authorities, a number of additional reports of diseased alder were received, and on investigation *Phytophthora* symptoms were found at a further site. This involved young (five years old) trees in Gwent that had been planted on land formerly used for the production of hardy ornamental nursery stock.

Isolation attempts were made from necrotic bark tissue and from soil at the base of affected

trees at all three locations. An unusual *Phytophthora* was isolated from the west Midlands and Gwent sites. It shows a close similarity to *P. cambivora*, a known pathogen of hardwoods in Britain, in terms of the morphology and size of sporangia and gametangia (asexual and sexual spores). However, it also exhibits important differences from this species. Whereas colonies of *P. cambivora* are normally fast growing with dense woolly aerial mycelium, those of the alder fungus are slow growing and 'flat-frosty' in appearance. They sector readily, suggesting a genetic instability. Whereas *P. cambivora* colonies grow well at 30°C, the alder fungus fails to grow at this temperature. Also, whereas *P. cambivora* is classically heterothallic, requiring its two mating types for gametangial production, the alder fungus produces gametangia and oospores profusely in single culture, and is therefore intrinsically homothallic.

Research is in progress on the biological affinities and pathological potential of this *Phytophthora*. A programme of fieldwork is also required as little is known about the pathology of common alder and we need to know whether these cases represent the norm or are a departure from it.

JOHN GIBBS, ROBERT STROUTS, JOAN ROSE AND CLIVE BRASIER

SCREENING OF POPLAR CLONES FOR DISEASE RESISTANCE

With the current interest in poplars for use in roundwood and biomass crops, a number of new clones of enhanced growth potential are being evaluated for disease resistance in the U.K. These clones have been kindly supplied for our trials by the Belgian Instituut voor Bosbouw en Wildbeheer, where they were bred and where disease resistance screening has already been carried out. Further screening in the U.K. is advisable because of the possible existence of more aggressive variants of the fungi and bacteria that cause the major poplar diseases. The diseases of greatest concern in both countries are bacterial canker, rust and Marssonina leaf spot, of which bacterial canker, caused by *Xanthomonas populi* is the most damaging in roundwood crops.

The first year's results of screening for resistance to bacterial canker have been obtained for the first batch of 29 new clones received from Belgium. The test was done using a leaf-scar inoculation technique which has been standardised throughout most of Europe, and which requires 3–4 years for full assessment following inoculation. For comparison with the test clones, six reference clones of known performance in Belgian trials were also tested. The selected results in Table 4 show the ranking of these reference clones, together with seven of the new clones, which are identified by code numbers. These seven clones have all been proposed for possible registration in Belgium. One additional Belgian clone has also been thus proposed, but results for its first year's screening are still awaited. It is interesting to note that five of the seven clones are of very high resistance to English isolates of the canker pathogen. The rather poor performance of the registered clone 'Ghoy', ranked 29th out of 35, is of some concern, although it must be emphasised that the final data, which will be obtained in 1995 or 1996, may show a different result. This longer-term testing is likely to differentiate more strongly between clones which recover from initial infection and those which develop perennating cankers.

DAVID LONSDALE AND JOAN ROSE

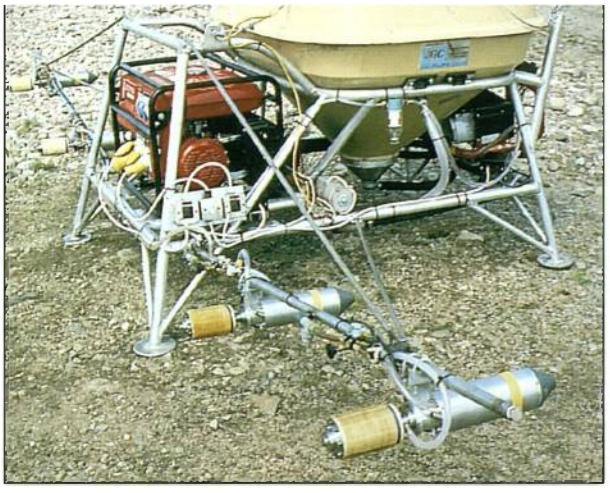


Plate 1. *The self-contained, ultra low volume application system developed by Entomology Branch for controlled droplet application of pesticides to forests.*

Plate 2. *View of the spray rig in action during an operation to control pine beauty moth in Scotland.*

Plate 3. *Continuous flow systems for analysis of nitrogen and phosphorus.*

Plate 5. *The Headley open-top chamber site.*

Plate 6. *Freshly sawn close-stacked pine lumber constructed in a nest arrangement, just before the addition of plastic tanks containing sterilised board samples to the central part of the stack.*

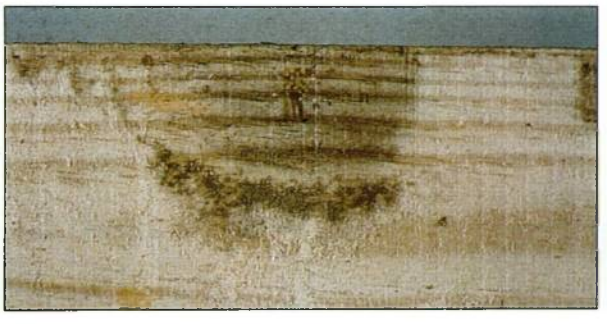


Plate 7. *Dead fungus fly surrounded by an area of sapstain on the surface of a casing timber previously dip-treated with an insecticide. This suggests spores of staining fungi are regularly transferred onto sawn lumber by arthropod vectors.*

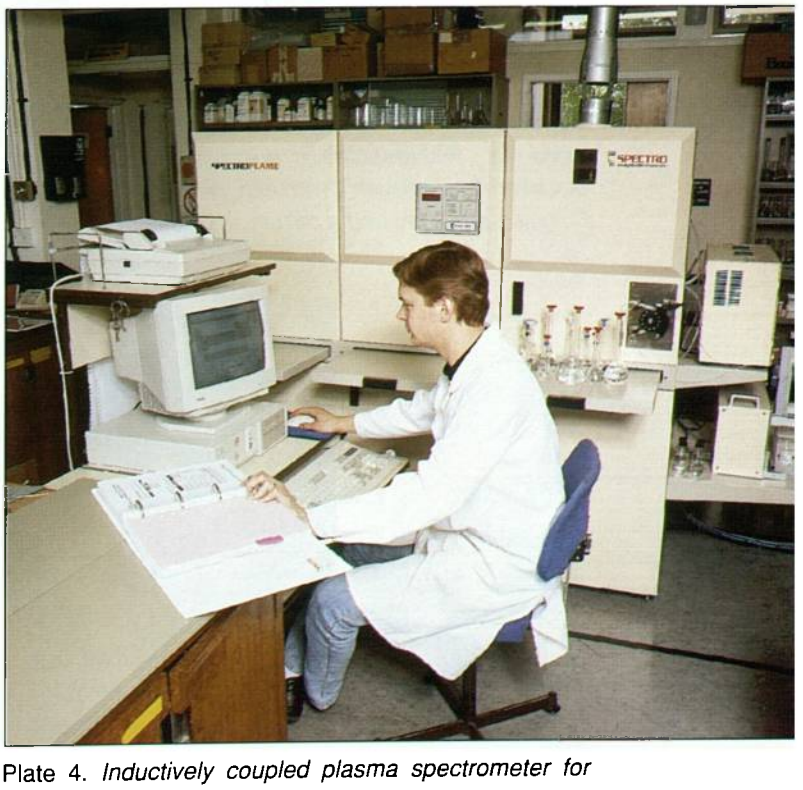


Plate 4. *Inductively coupled plasma spectrometer for analysis of major and minor nutrients.*

Plate 9. *The sealed bag system, developed for growing obligate symbionts free from contaminating organisms, being used to produce pure cultures of arbuscular mycorrhizal fungi. The potted plants in the bags can be seen placed close to each other without danger of cross-contamination.*

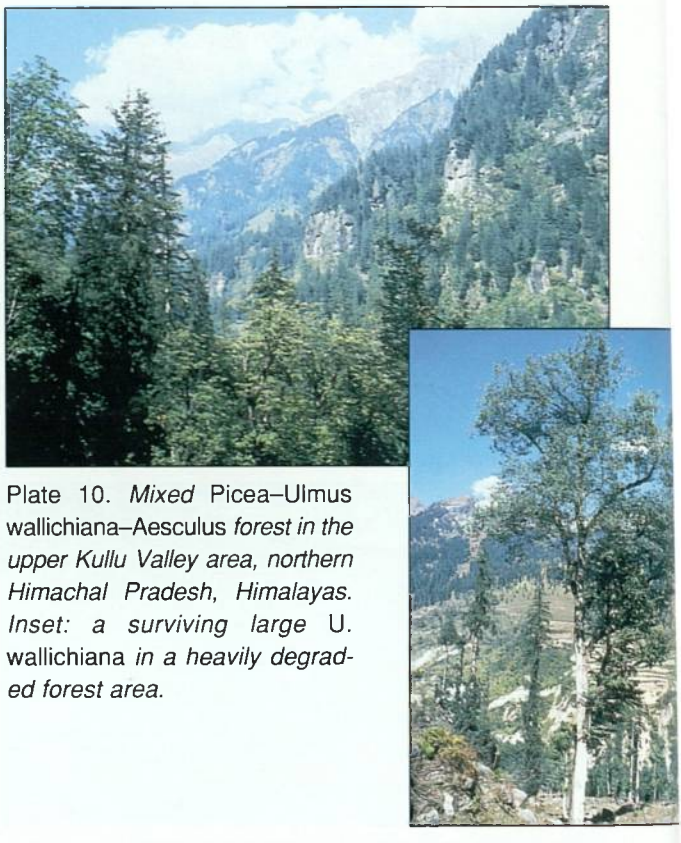


Plate 10. *Mixed* Picea–Ulmus wallichiana–Aesculus *forest in the upper Kullu Valley area, northern Himachal Pradesh, Himalayas. Inset: a surviving large* U. wallichiana *in a heavily degraded forest area.*

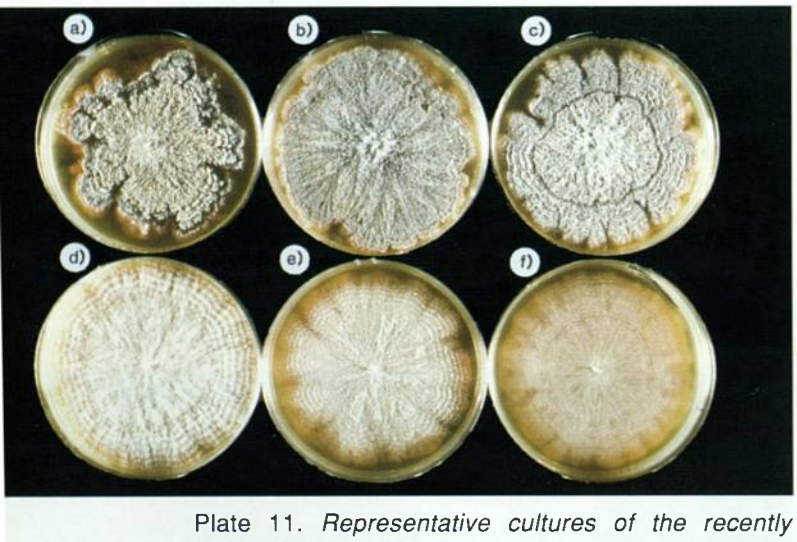


Plate 11. *Representative cultures of the recently discovered Himalayan Dutch elm disease fungus (a – c)* O. novo-ulmi *(d,e) and a culture of* O. ulmi *(f).*

Plate 13. *Delegates of the 1993 IUFRO* Wind and wind related damage to trees *conference preparing to board a cruise of Kielderwater at the end of the field visit.*

Plate 12. *Phytophthora symptoms at the base of common alder.*

Plate 14. *A long-eared owl chick just recently out of the nest. A new project is investigating the ecology of this species in coniferous forest.*

Table 4. Ranking of some of the poplar clones assessed for resistance to bacterial canker in 1993

Ranking (1–35)	*Clone*	*Parental origin*	*Status in testing*	*Mean canker index (0–5 scale)*
1	71.015/1 §	D × T	New clone under test	0.966 †
2	71.009/1 §	D × T	New clone under test	1.000 †
3	Beaupré *	T × D	Registered 'UNAL' clone	1.004 †
4	71.009/2 §	D × T	New clone under test	1.016 †
5	60.038/6 §	T × D	New clone under test	1.174 †
6	69.039/4 §	T × D	New clone under test	1.376 †
16	Donk ***	D × T	Unregistered older clone	2.268 ††
19	Boelare **	T × D	Registered 'UNAL' clone	2.382 †
29	Ghoy **	(D × N) × N	Registered 'UNAL' clone	2.786 ††
30	S.681–84 §	D × N	New clone under test	2.856 ††
31	S.683–24 §	D × N	New clone under test	2.865 ††
34	Regenerata ****	D × N	Unregistered older clone	3.114 ††
35	Androscoggin ****	M × T	Unregistered older clone	3.821 ††

§ Proposed for registration in Belgium

† Mean value for five different bacterial isolates from England

†† Mean value for two different bacterial isolates from England

Asterisks denote reference clones of known performance in Belgian trials as follows:
* highly resistant, ** moderately resistant, *** relatively susceptible, **** very susceptible

Abbreviations for species of *Populus* used as parents:
D = *deltoides*, T = *trichocarpa*, N = *nigra*, M = *maximowiczii*

PLANT PRODUCTION

Plant Production Branch is a team of five scientists with responsibilities divided between statutory matters related to the Forest Reproductive Material regulations, such as seed testing and advisory work, and scientific research to improve woody plant propagation.

In June 1993 the work of the branch was subjected to external scrutiny by a Visiting Group. Its report applauded the quality of the current programme and recognised the 'considerable synergy which exists between the testing, advisory and research roles of the branch'. This linkage is crucial to the development of relevant research programmes.

Two notable achievements were the winning of a three year, European Union sponsored project, in collaboration with five other countries, on temperate broadleaved tree seed dormancy, and a one year Overseas Development Administration contract on seed pretreatment of tropical legumes.

The Branch hosted visitors from across the world, from Australia to Zimbabwe. In particular, Dr Ciccarese from Italy collaborated on several months' research comparing the pretreatment and germination of temperate and mediterranean pines. And Mr Balcha from Ethiopia spent several weeks learning seed testing techniques and investigating germination and viability assessments on the seeds of native Ethiopian trees.

PETER GOSLING

SEED AND NURSERY RESEARCH

The effects of 5°C (prechill) or 10, 20 or 30°C (invigoration) on dormant Sitka spruce seed germination.

Sitka spruce seeds (*Picea sitchensis* (Bong.) Carr.), like many temperate conifer seeds, exhibit shallow or conditional dormancy. They only germinate slowly and over a narrow range of temperatures. A common way to overcome this type of dormancy is to incubate moist seeds at 1–5°C for 3–6 weeks, referred to as prechilling. A similar method termed invigoration incubates moist seeds at 15 or 20°C for periods up to two weeks. Both methods increase the rate of germination of seeds at optimal temperatures, and prechilling widens the range of temperatures over which Sitka spruce seeds germinate. But the effect of invigoration on germination at sub-optimal temperatures is unknown. This is important information because Sitka spruce seeds are sown in the spring when U.K. soil temperatures are sub-optimal (often 5–10°C).

Moist Sitka spruce seeds were incubated for periods between 0 and 23 weeks at 5°C (prechill) or 10, 20 or 30°C (invigoration treatments) then moved to germination conditions at 10°C for up to 42 days. Data showing maximum germination (%) reached by the end of the test are presented in Table 5.

Table 5. Germination (%) achieved by the end of a 42 day test at 10°C. Means are based on 4 × 100 seeds

Treatment temperature	*Temperature duration (weeks)*						
	0	*2*	*5*	*6*	*14*	*18*	*23*
30°C (invigoration)		4	23	19	0	0	0
20°C (invigoration)		11	19	24	35	17	1
10°C (invigoration)		0	1	1	28	39	79
5°C (prechill)		2	3	26	90	98	93
Untreated	1						

Only 1% of the control (untreated) seeds germinated at 10°C, while treated seeds reached 98% (5°C), 79% (10°C), 35% (20°C) and 23% (30°C). The best treatment was the 5°C (prechill). Even the longest invigoration treatments did not bring about those benefits but this was probably due to the increasing number of seeds killed by fungi during such treatments.

STEVE JONES AND PETER GOSLING

Imbibition by cherry (Prunus avium) stones

Wild cherry is an increasingly important broadleaved species for lowland planting, but current nursery practices give erratic germination. Cherry stones are deeply dormant and require pregermination treatments for 12 or more weeks. Recommendations range from incubating moist stones at about 20°C for two weeks followed by 12 weeks at 4°C (Gordon and Rowe, 1982), to a sequence of warm followed by cold treatments (Suszka, 1976). The first stage of pretreatment involves soaking seed in water for a period of time, since seed must be fully imbibed to respond to the pretreatment temperature regime. However cherry seeds are surrounded by a hard endocarp which may significantly delay the rate of imbibition. A study was carried out to determine the length of time required for seed in intact stones to become fully imbibed, and to investigate the effects of the endocarp on water entry into stones.

The process of imbibition by whole stones was followed by determining the change in moisture content of whole stones, and the constituent endocarps and seeds over time during soaking. Results showed that the process of water uptake was rapid with stone moisture content increasing from about 10% to nearly 25% after 48 hours of soaking (Figure 9). The endocarp reached its maximum moisture content of 23% after only five hours, while seed moisture content began increasing after about two hours and then increased at a more steady rate, reaching about 33% after 48 hours. This pattern of change in moisture content with time indicates that the endocarp becomes rapidly saturated and then water continues to pass through the endocarp to the enclosed seed.

Removal of the endocarp before soaking resulted in seed moisture content reaching its maximum after 24 hours compared with 48 hours for seed soaked inside intact stones.

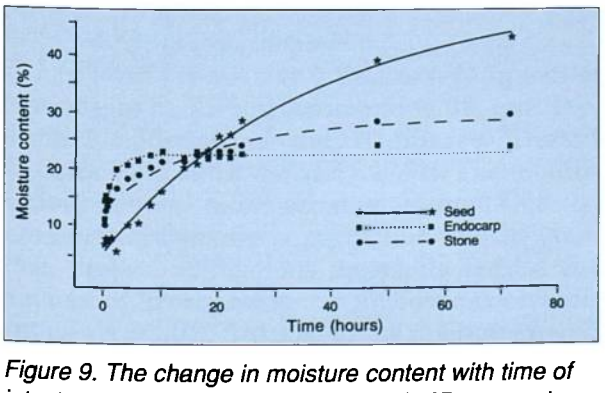


Figure 9. The change in moisture content with time of intact stones, the endocarp, and seed of Prunus avium *stones.*

These results show that although the endocarp delays the rate of water uptake by the seed, a two day soak is all that is required to achieve full imbibition of cherry seed.

In a further study it was shown that soaking in water, before stones are transferred to the stratification medium, was not necessary since a comparison of moisture content of seed in stones either soaked in water or placed in moist peat and sand showed an identical pattern of water uptake (Table 6).

RICHARD JINKS AND JANE BREARLEY

Table 6. Seed moisture content (%)

	Time (h)			
Treatment	*0*	*24*	*48*	*72*
Water soak	6	23	41	41
Peat : sand	6	27	37	41

REFERENCES

GORDON, A.G., and ROWE, D.C.F. (1982). *Seed manual for ornamental trees and shrubs.* Forestry Commission Bulletin 59. HMSO, London.

SUSZKA, B. (1976). Increase of germinative capacity of mazzard cherry (*Prunus avium* L.) seeds through the induction of secondary dormancy. *Arboretum Kornickie*, **21**, 257–270.

Pretreatment of multipurpose tropical legume tree seeds

Current recommendations for breaking hard seed coated dormancy in multipurpose tropical legume trees are never reliable and often ineffective. Hence valuable seed is wasted and plant supply is rarely sufficient. The Overseas Development Administration is funding a systematic investigation of tropical legume tree seed pretreatment and germination.

Leucaena leucocephala is one of the most widely planted multipurpose tropical legume trees and there is a lot of scientific, technical and anecdotal literature on the germination and pretreatment of this species. However, it appears that optimal germination conditions have yet to be established and even within recent literature there remain numerous fundamental anomalies and contradictions including some authors who maintain that pretreatment is unnecessary!

Figure 10 shows the results of an experiment to determine the optimum germination conditions of *L. leucocephala* seeds which were either untreated or pretreated by chipping with a scalpel. One obvious feature is that germina-

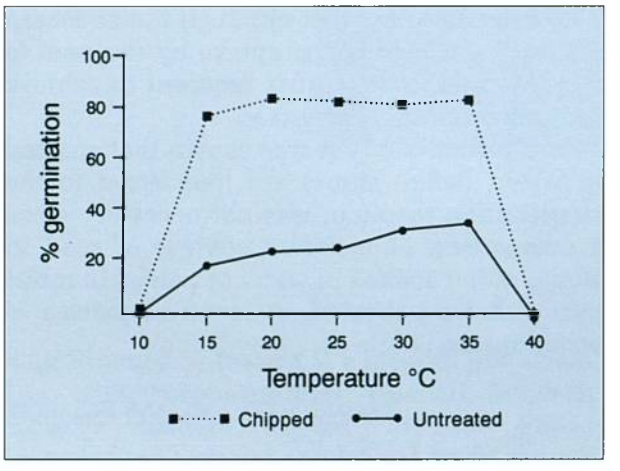


Figure 10. Germination capacity at different temperatures of untreated and chipped Leucaena leucocephala.

tion was completely prevented at 10°C and 40°C, but was otherwise extremely consistent between 15 and 35°C. An interesting contrast between the ungerminated seeds remaining at 10°C and 40°C was that seeds at the former germination temperature remained alive but those at the higher temperature had been killed.

Another obvious feature is that chipped seeds germinated significantly better than untreated seeds at all temperatures at which germination occurred. At temperatures of 15–35°C inclusive the germination of chipped seeds reached ca. 80% and was consistently 60% higher than untreated seeds.

It can be concluded, firstly, that a chipping pretreatment does stimulate the germination of *L. leucocephala* and, secondly, that laboratory seed tests could be carried out over a relatively wide range of temperatures because the germination capacity of untreated and chipped seeds is not significantly affected at constant incubation temperatures in the range 15–35°C.

PETER GOSLING, YVONNE SAMUEL AND STEVE JONES

OFFICIAL SEED TESTING STATION

In 1993–94, we tested 180 Forestry Commission seed lots, 233 lots from the Oxford Forestry Institute, and 73 seed lots from seed merchants and nursery managers.

A contract to perform additional tests for the Oxford Forestry Institute was carried out with help from a biology graduate on a temporary contract.

YVONNE SAMUEL AND PETER GOSLING

SILVICULTURE (NORTH)

Overview

Following a review of the branch structure in the Division, we were joined in October 1993 by Helen McKay, Bruce Nicoll, Colin McEvoy, David Clark and Joyce Harrower from Physiology Branch. We have worked closely with them in the past, especially on aspects of plant stock quality and root development, and look forward to developing integrated programmes that will build on their physiological expertise and our silvicultural skills.

Windthrow has long been recognised as a major constraint on British silviculture, particularly on the shallow-rooting acid soils of northern and western Britain. Research into the silvicultural, physical, physiological and ecological aspects of windthrow has understandably been a major component of our work. 1993 saw a number of important developments in this field. Firstly, a major and very successful international conference on *Wind and wind-related damage to trees* was held in July at Heriot-Watt University under the auspices of the International Union of Forestry Research Organizations (Plate 13). The organising committee was chaired by Chris Quine, and staff from the Northern Research Station were major contributors to and organisers of the five day meeting. The meeting attracted international interest with over 100 people attending. Speakers from Europe, Australasia and North America provided a very valuable account of research and its application.

Earlier in the year, two Research Information Notes were published representing the first substantial updating of the Windthrow Hazard Classification since the early 1980s. The modifications give a more accurate estimate of the windiness scores for a particular site. In practice, these modifications appear to reduce the amount of forest area in the highest risk classification (WHC VI). Because of the investment and planning implication of these changes, we held a one day briefing for members of the Timber Growers Association in October 1993 and undertook a contract for Forest Enterprise, providing revised windiness scores for all their forests in upland Britain, calculated using a geographical information system.

James Simpson organised a European Union (EU) sponsored workshop on *The establishment of farm woodlands* in conjunction with colleagues from Institut National de la Recherche Agronomique in France. The workshop was attended by researchers from throughout the EU and provided recommendations on topics in this field requiring future research.

Besides these aspects, staff were involved in a range of research initiatives related to the Government's sustainable forestry programme, including natural regeneration, nutritional implications of whole-tree harvesting, farm woodlands and community forestry. Research into the development of site-specific silvicultural regimes and systems is essential if multipurpose forest management is to become a reality.

BILL MASON

Physiological quality of planting stock

Two years' experiments investigating survival and growth of directly planted bare-root stock have shown major species differences in outplanting performance. Sitka spruce of Queen Charlotte Islands origin could be planted over the widest period (November to March) with good survival and growth, whereas survivals of greater than 80% with Douglas fir were achieved only when planted in February and March. Both Corsican and Scots pine had poor survival when planted immediately after lifting in October; survival improved as lifting was delayed, reaching 95% in mid-November. Pine survival fluctuated during November and December but was >85% throughout January, February and March. The pattern of survival for Sitka spruce, Douglas fir, Scots pine and Corsican pine was closely related to the condition of their fine roots, which was assessed by electrolyte leakage.

The response of both hybrid and Japanese larch to direct planting was different to that of the evergreen conifers. Freshly lifted larch had two distinct times (one in autumn and one in spring) when >80% survival was achieved; there was poor survival (50–60%) in mid-winter. These fluctuations were closely related to seasonal changes in larch root growth potential but not to electrolyte leakage – in mid-winter the roots were in excellent condition but did not elongate even when given good conditions for growth. The autumn lifting window was narrow and varied from year to year, whereas survival of >80% was achieved throughout March. The results from these experiments were combined with those from cold-storage experiments to make recommendations on the best management strategies for larch: direct planting of larch lifted during the last twoweeks in October and during March, and cold storage of stock lifted between November and mid-March with planting in early April.

Seasonal trends in the physiological condition of oak, ash, beech and Norway maple have been examined by measuring root growth potential, electrolyte leakage from the fine (<2 mm diameter) and tap roots, root and shoot moisture content, shoot water potential, and tolerance to frost, desiccation and rough-handling. In general, the species showed the same patterns of electrolyte leakage and stress tolerance as conifers (decreasing electrolyte leakage during October to December before stabilizing at a low over-winter level, and increasing stress tolerance during autumn with maximum tolerance during winter). There were marked and consistent differences among the species. Ash, for example, had the lowest fine root electrolyte leakage. Both ash and oak had much greater shoot water potentials during winter (30 and 20 bars respectively) than maple and beech (<5 bars). This work has been funded by the Department of the Environment.

Morphological and physiological differences among seedlings of four native Scots pine origins (Loch Maree, Glengarry/Glen Moriston, Glen Affric, and Abernethy), from a British seed orchard and of a provenance from middle Sweden were examined. Several consistent differences have been noted. The plants from seed orchard seed were largest but had the poorest root:shoot ratio. The Loch Maree provenance seems to allocate the greatest proportion of its biomass to fine roots and needles and the smallest proportion to the stem and woody roots. Plants raised from Swedish seed are slightly more root frost hardy. This work has been funded by the Scottish Forestry Trust.

HELEN MCKAY, COLIN MCEVOY AND MIKE PERKES

INFLUENCE OF FERTILIZATION ON FOREST PERFORMANCE OF SITKA SPRUCE PLANTING STOCK

Nursery regimes

A large number of Sitka spruce plants are produced using precision sowing and undercutting techniques rather than traditional methods of broadcast sowing and transplanting. Undercut stock is associated with better physiological condition and root:shoot ratios than transplants of the same age (Deans *et al.*, 1989; McKay and Mason, 1991). Recent experiments at the Forest Enterprise nursery at Wykeham have demonstrated that the process of undercutting is associated with a reduction in the nitrogen content of foliage even when trees are given high rates of fertilizer to compensate for root regeneration (Figure 11). To ensure that trees achieve size specifications and high nutritional status, nurseries now repeat top dressings with compound fertilizer to redress nitrogen, phosphorus and potassium deficiency. In some cases high fertilizer input regimes are not appropriate due to environmental or managerial concerns, particularly where there is a risk of losses to groundwater. It is therefore important to specify optimum fertilization regimes for crop growth and subsequent forest performance. Experiments suggest that rates of fertilizer equivalent to 150 kg nitrogen ha^{-1} yr^{-1} are optimum for plant growth in the nursery (Figure 12), while higher inputs are unlikely to be justified in height growth terms.

Forest performance

The influence of nutrition on forest performance of Sitka spruce transplants has been extensively researched by Benzian *et al.* (1974). The main findings from her work suggested that optimum nutrition was not important to survival but did benefit subsequent height growth of trees. Recent outplanting experiments with Sitka spruce undercuts given different nutritional regimes in the nursery did not show a consistent response (Table 7). Foliage nutrient analysis has suggested that trees achieve similar, satisfactory, nutrient concentrations after one growing season despite contrasting nutritional status at planting (Table 8). The implication of these findings is that foliar nitrogen status may be less critical for planting stock establishment than other aspects of plant quality. Physiological assessments of frost hardiness and root electrolyte leakage did not indicate any differences between trees grown with different

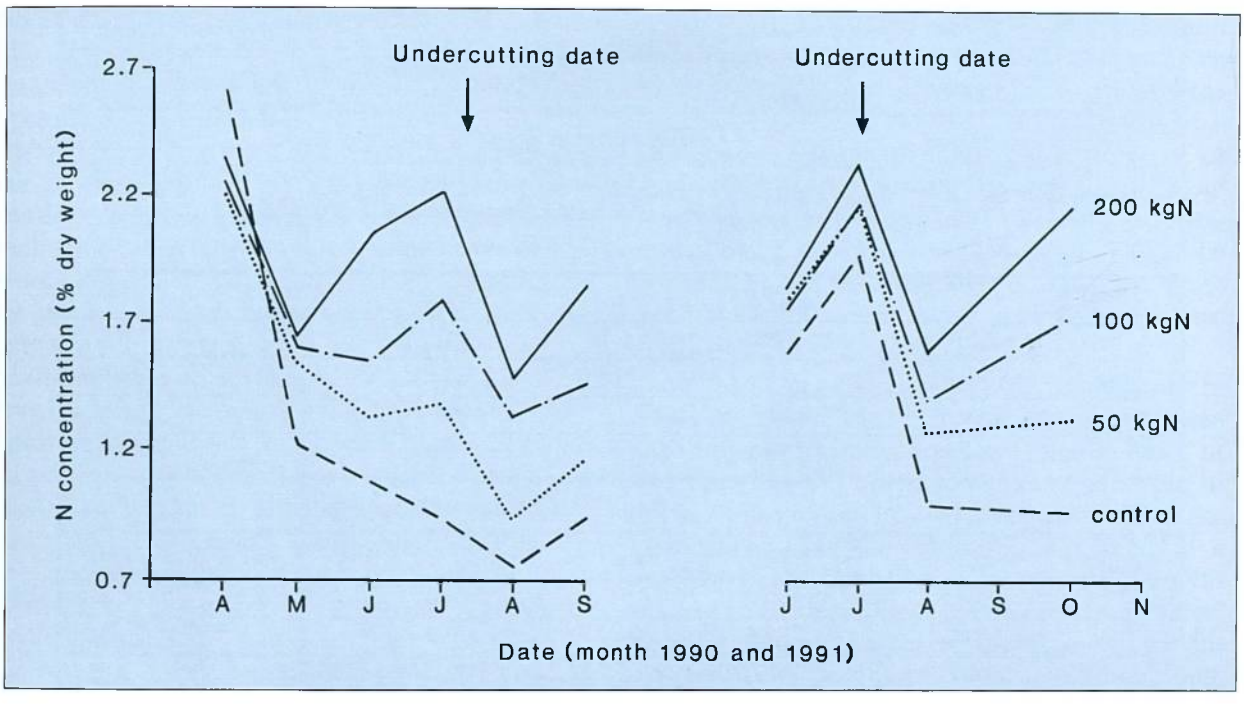


Figure 11. Foliar nitrogen concentrations of Sitka spruce undercuts with different nitrogen regimes.

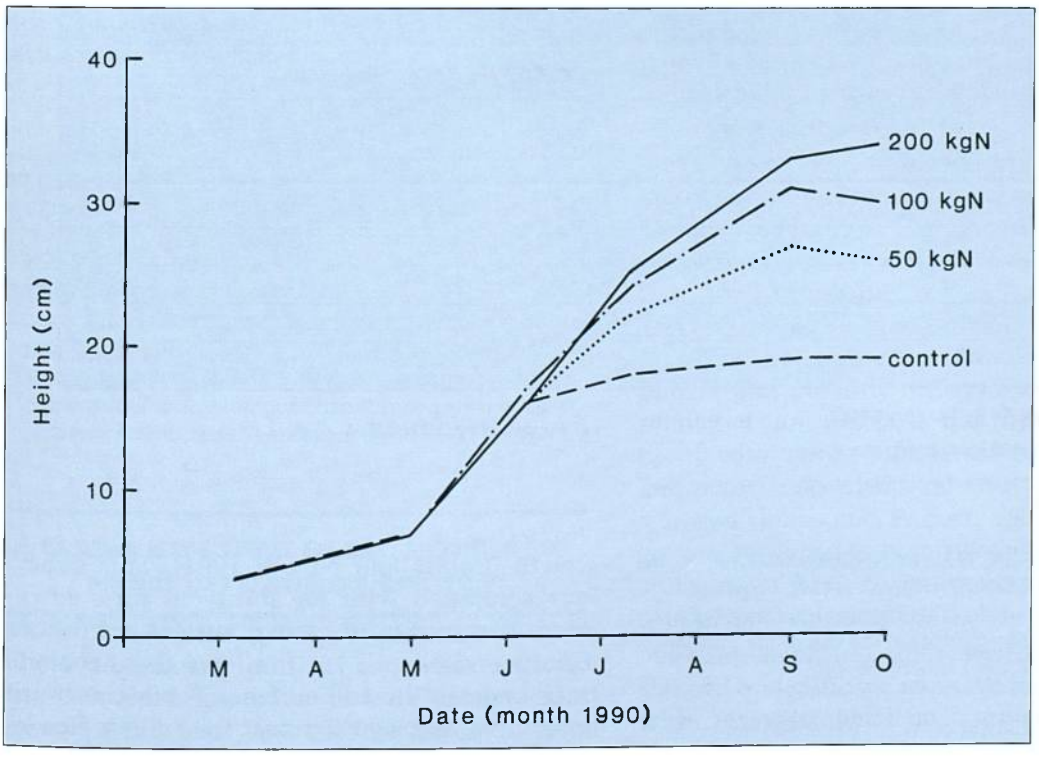


Figure 12. Height growth of Queen Charlotte Islands Sitka spruce 1u1 undercuts in response to different top dressings.

levels of nutrition. However, high rates of fertilizer top dressing may even be detrimental to forest performance where root:shoot ratios are adversely affected.

JOHN MORGAN AND BOB HOWES

REFERENCES

BENZIAN, B., BROWN, R.M. and FREEMAN, S.C.R. (1974). Effect of late-season top-dressings of nitrogen (and potassium) applied to conifer transplants in the nursery on their survival and growth on British forest sites. *Forestry*, **45**, 151–184.

Table 7. Survival and first year increment of Sitka spruce undercuts planted with different nutritional status

Treatment (quantity of fertilizer applied in nursery, kg N ha^{-1})		*Experimental site (1992 planting season)*		
		Brecon 39	*North Yorks Moors 67*	*Moray 26*
		Survival (%)		
Control –	0	97	97	94
	50	96	91	99
	100	97	97	98
	200	94	98	98
LSD @ 5%		ns	5.0	ns
		Height increment (cm)		
Control –	0	13.2	5.7	8.2
	50	9.2	4.9	4.8
	100	7.5	6.0	5.3
	200	12.3	9.1	5.5
LSD @ 5%		3.3	2.2	1.6

Table 8. Foliar nitrogen concentrations at the end of the first growing season

Treatment	*Initial nitrogen level (% oven dry weight)*	*Experimental site (1992 planting season)*		
		Brecon	*North Yorks Moors*	*Moray*
Control	0.97 *	2.49	2.82	2.74
50 N	1.33 **	2.35	2.86	2.75
100 N	1.74 **	2.11	2.77	2.68
200 N	2.17***	2.18	2.70	2.81
LSD @ 5%	0.26	0.22	ns	ns

* Deficient levels for nursery stock

** Marginal levels for nursery stock

*** Satisfactory levels for nursery stock

DEANS, J.D., MASON, W.L., CANNELL, M.G.R., SHARPE, A.L. and SHEPPARD, L.J. (1989). Growing regimes for bare-root stock of Sitka spruce, Douglas fir and Scots pine. I: Morphology at the end of the nursery phase. *Forestry*, **62**, Supplement, 53–60.

McKAY, H.M. and MASON, W.L. (1991). Physiological indicators of tolerance to cold storage in Sitka spruce and Douglas fir seedlings. *Canadian Journal of Forestry Research*, **17**, 787–793.

Surface root development of urban trees

Previous work on conifer species showed that roots originating from the upper part of tree root systems have an innate tendency for upward growth (Coutts and Nicoll, 1991). This behaviour combined with an ability to turn downward in response to certain surface conditions (Coutts and Nicoll, 1993) allows these roots to track beneath the soil surface. The better nutrient supply and aeration near the soil surface let surface roots thicken faster than other deeper roots and, as a result, they develop into the tree's main structural roots. These are important for tree stability, but can cause damage in urban areas when growing under pavements or other structures.

Experiments are now under way to find the basic patterns of root development in four species of broadleaved trees. This work is funded by a Department of Environment contract, and is directed towards understanding the

development of surface roots in amenity areas. The direction of growth and allocation of biomass between main lateral roots is being investigated using seedlings and transplants of Norway maple, wild cherry, hawthorn and silver birch. Trees are grown both in controlled conditions and also outdoors in large containers that allow relatively unrestricted root development. Basic patterns of growth are determined by excavation and measurement of coordinates using methods developed on conifers. Analysis of diameters will provide information for these species on whether biomass is allocated predominantly to a few large surface roots or to a larger number of small roots. Such differences would be useful in selecting trees for planting in urban areas. Other experiments will identify the responses of roots to barriers in the soil. Barriers are sometimes used in an attempt to avoid the damage caused by surface roots to pavements. These experiments will examine if roots can be permanently deflected or if they return to their original growth direction after negotiating a barrier. Work in both parts of this study is at an early stage, but an initial assessment indicates large differences in root system development between species.

BRUCE NICOLL

REFERENCES

COUTTS, M.P. and NICOLL, B.C. (1991). Orientation of the lateral roots of trees. I: Upward growth of surface roots and deflection near the soil surface. *New Phytologist*, **119**, 227–234.

COUTTS, M.P. and NICOLL, B.C. (1993). Orientation of the lateral roots of trees. II: Hydrotropic and gravitropic responses of lateral roots of Sitka spruce grown in air at different humidities. *New Phytologist*, **124**, 277–281.

A COMPARATIVE STUDY OF TWO METHODS FOR PREDICTING FERTILIZER RESPONSE

Where significant growth responses can be obtained, the application of fertilizer late in a forest rotation can be economically attractive. However, past research has shown that it is difficult to predict where crops more than 15 years old will respond to fertilizers. This is especially true for Sitka spruce crops, where it has proved difficult to establish any relationship between foliar nutrient concentrations and growth responses to fertilizer applications in pole-stage crops (McIntosh, 1984).

A root bioassay technique has been developed at the Institute of Terrestrial Ecology for assessing the nitrogen, phosphorus and potassium nutrient status of trees (Harrison and Helliwell, 1979; Dighton and Harrison, 1983; Jones, *et al.*, 1987; Jones and Poskitt, 1991). This technique is based on the rate of uptake of a labelled element (phosphorus, nitrogen, or rubidium as an analogue for potassium) from solution by excised roots. The technique integrates plant and soil conditions, and could be potentially more effective than foliar analyses for predicting nutrient deficiencies and hence fertilizer response.

A fertilizer experiment was established in south Wales in 1991 to investigate which nutrient (nitrogen, phosphorus or potassium), or combination of nutrients, was most effective in promoting growth in a late thicket stage Sitka spruce crop planted in 1968. This allowed a comparison of the root bioassay technique with standard foliar analysis. Samples of top whorl foliage were collected and analysed using standard procedures (Taylor, 1991) in autumn 1990. Root samples were collected in May 1991 for root bioassay assessment. Fertilizer applications of nitrogen, phosphorus and potassium were made to the plots in a factorial design in July 1991. Both the foliar and root sampling assessments were carried out one and two years after the initial assessments, and basal area growth was assessed annually.

The foliar concentrations prior to fertilizer application indicated marginal to deficient nitrogen levels, deficient phosphorus levels and potassium levels well above the marginal threshold. Threshold values were those identified for younger crops (Binns *et al.*, 1980). From these foliar analyses a growth response to phosphorus and possibly nitrogen would have been predicted. Results from the root bioassay indicated very strong uptake of both phosphorus and potassium, with a relatively low uptake for nitrogen (Jones and Poskitt, 1991), suggesting a growth response to both phosphorus and potassium might have been expected, while one to nitrogen would seem unlikely.

Foliar sampling after fertilizer application showed a significant increase in nitrogen levels with nitrogen fertilizer application, in both 1991 and 1992. Phosphorus and potassium levels only showed a significant response to, respectively, the phosphorus and potassium fertilizer in 1992. By comparison, the root bioassay results showed significant reductions in uptake as a result of all fertilizer applications (nitrogen, phosphorus and potassium) in 1992, although in 1993 this effect was only significant in the case of phosphorus.

Analysis of basal area increment during 1992 and 1993 shows that the only element to which

there has been a positive growth response has been phosphorus. There is no indication of either a response to the other two elements or an interaction between the elements.

In conclusion, neither foliar analysis nor the root bioassay technique have proved reliable guides as to which fertilizer to apply in a 26-year-old Sitka spruce crop.

JANET DUTCH AND NEVILLE DANBY

REFERENCES

BINNS, W.O., MAYHEAD, G.J. and MACKENZIE, J.M. (1980). *Nutrient deficiencies of conifers in British forests.* Forestry Commission Leaflet 76. HMSO, London.

DIGHTON, J. and HARRISON, A.F. (1983). Phosphorus nutrition of lodgepole pine and Sitka spruce stands as indicated by a root bioassay. *Forestry*, **56**, 33–43.

HARRISON, A.F. and HELLIWELL, D.R. (1979). A bioassay for comparing phosphorus availability in soils. *Journal of Applied Ecology*, **16**, 495–505.

JONES, H.E., HARRISON, A.F. and DIGHTON, J. (1987). A ^{86} Rb bioassay to determine the potassium status of trees. *New Phytologist*, **107**, 695–708.

JONES, H.E. and POSKITT, J.M. (1991). *A preliminary assessment of the nutrient status of Sitka spruce in an area affected by bent top in the south Wales coalfield.* Contract report, project no. T01062B5. Institute of Ecology, Grange-over-Sands. Unpublished.

McINTOSH, R. (1984). *Fertiliser experiments in established conifer stands.* Forestry Commission Forest Record 127. HMSO, London.

TAYLOR, C.M.A. (1991). *Forest fertilisation in Britain.* Forestry Commission Bulletin 95. HMSO, London.

NATURAL REGENERATION OF SITKA SPRUCE

The majority of Sitka spruce stands are currently managed under a patch clear-felling silvicultural system which relies upon artificial regeneration. However, heavy seed years can result in the occurrence of very dense natural regeneration on receptive sites. This creates a number of problems for forest managers in planning the restocking of forest areas.

The deliberate fostering of Sitka spruce natural regeneration would offer an opportunity not only to reduce the costs of restocking but also to increase the diversity of the forest. In order to help identify the site and crop factors which influence the success of Sitka spruce natural regeneration on the characteristic site types of the Border country, a survey of 47 sites was carried out during the summer of 1993, on contract to Forest Enterprise (FE).

Seven FE forest districts were included in the study with the highest mean level of regeneration (60% of full stocking) being found at sites in the Forest of Ae, Dumfries and Galloway Region. In general, greater densities of seedlings were recorded on sites with peat and peaty gley soils. This trend was also associated with the rate of site re-invasion by vegetation. Grasses and rushes were found to be particularly competitive to young seedlings, and their presence greatly reduced the final density of established regeneration. Mosses appeared to provide a very good medium for seed germination on moist sites which were not prone to droughting. The reduced vigour of vegetation on high elevation sites (>250m a.s.l.) also provided a better opportunity for Sitka spruce seedling establishment.

The influence of good seed years was evident throughout. Particularly high seedling densities were evident on sites which had been supplied with abundant seed at a time when the ground conditions were receptive to seed germination and seedling establishment. If, as suggested by the literature (e.g. Isaac, 1940; Scarratt, 1966), Sitka spruce seed remains viable for only one year, then the timing of felling of trees in relation to the seed production cycle appeared critical to successful promotion of natural regeneration.

The results of this study will enable future monitoring work to concentrate in more detail on the most relevant factors such as vegetation competition, seed production cycles, and soil and site conditions. The work has also provided a very useful stimulus to the consideration of managing natural regeneration in a deliberate and planned way. A workshop to discuss the management of Sitka spruce natural regeneration within Forest Enterprise is now being arranged.

CHRIS NIXON, PETER OLIVER AND COLIN EDWARDS

REFERENCES

ISAAC, L.A. (1940). *Life of seed on the forest floor.* Research Note 31. United States Department of Agriculture Forestry Service.

SCARRATT, J.B. (1966). *Germination, early growth and survival of Sitka spruce seedlings.* Ph.D. Thesis, University of North Wales, Bangor.

THE AGE STRUCTURE OF THE NATIVE PINEWOODS OF SCOTLAND

Pine dominated forests, once widely distributed across the Scottish Highlands, are now reduced

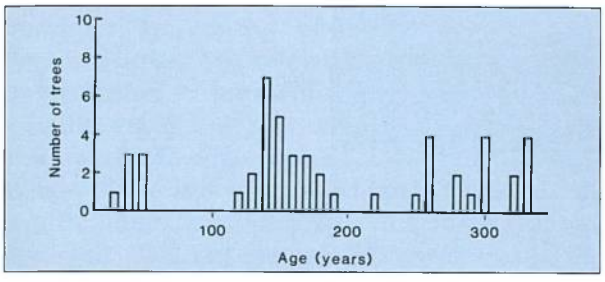


Figure 13. Age distribution of trees at Glen Loy.

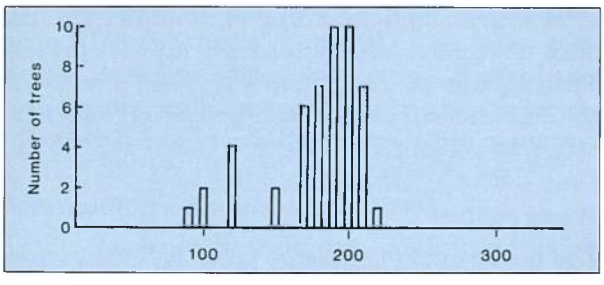


Figure 14. Age distribution of trees at Glengarry.

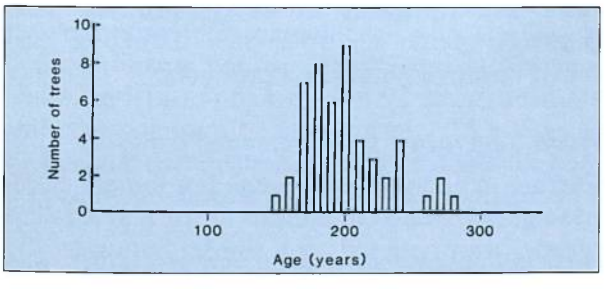


Figure 15. Age distribution of trees at Loch Arkaig.

to remnant populations. In order to manage and extend these woodlands we need more information about their natural composition and structure. A study was carried out during the summer of 1993 of the age structure of three pinewoods in west Scotland at Glengarry, Glen Loy and Loch Arkaig (Highland Region). All three study sites were representative of the south-western biochemical region of the native pinewoods, thereby complementing earlier work carried out within the east central region at the Mar Lodge Estate in Deeside (*Report*, 1993; Nixon and Cameron, 1994).

The mean tree age at the three study sites was 185 years with a range from 27–323 years. At Glen Loy, three distinct age classes were apparent (Figure 13), while at Glengarry the majority of trees were found to be within a range of 160–210 years (Figure 14). The Loch Arkaig woodlands also had a compact age range of 149–271 years (Figure 15). All three woodlands lacked young trees as a result of restricted regeneration over the last 100 years. The structure of the mature trees was semi-irregular in nature with the oldest trees being scattered throughout areas of younger individuals, suggesting that previous regeneration had occurred in relatively small pockets rather than as a result of catastrophic wind or fire damage.

The range of tree ages present in the three pinewoods was similar to that found in the three Mar Lodge pinewoods. The distribution of tree ages seen in each woodland appears to be largely a function of variations in the exploitation and management history of each area rather than inherent site-based variation.

The study has illustrated the fundamental changes in the structure of the native pinewoods brought about by man's intervention and exploitation. In some cases, the lack of young trees may put the regenerative capacity of the woodlands in doubt unless, in future, management acts to address the problems associated with the lack of regeneration. Further work is needed to study the seed viability, and the periodicity of seed production of the older trees to help to assess the urgency of the situation.

More detailed and wider ranging studies are still needed. An increased understanding of the structure and dynamics of these woods will make it possible to manage and extend the existing remnant woodlands in an ecologically appropriate manner, thereby helping to satisfy the objectives of the Forestry Authority's guidelines for the management of the native pinewoods.

CHRIS NIXON, TIM GOUCHER AND COLIN EDWARDS

REFERENCE

NIXON, C.J. and CAMERON, E. (1994) A pilot study on the age structure and viability of the Mar Lodge pinewoods. *Scottish Forestry*, **48**(1), 22–27.

SILVICULTURE (SOUTH)

OVERVIEW

Silviculture of broadleaves

Handbook 9, *Growing broadleaves for timber* by Gary Kerr and Julian Evans, was published during the year and launched by the Forestry Authority on the occasion of the Centre of Excellence award ceremony at Workmans Wood near Birdlip, Gloucestershire.

Experiments on the silviculture of walnut were written up by Gary Kerr and published in *Forestry*.

Poplars and short rotation coppice

A well attended conference was held at the National Agriculture Centre at Stoneleigh entitled *Poplar – a profitable farm and woodland crop*, and selected papers from the conference were published in the *Quarterly Journal of Forestry* (Tabbush, 1993a). Poplar research concentrated on the European Union contract working towards European site yield predictions for poplar as an alternative use for land surplus to agricultural requirements. Four new clonal trials were set up to include 60 new clones received from Belgium since 1990, and a set of Dutch and Italian clones which are being planted in similar experiments in the other European countries.

A final report on an Energy Technology Support Unit (ETSU) contract, *Coppiced trees as energy crops*, was presented to ETSU and published by them (Tabbush, 1993b). New experiments were established under two new contracts: *Initial spacing* (ETSU) and *The effects of sewage sludge* (Southern Water Services).

Arboreta and dendrology

The hunt for native black poplar trees (*Populus nigra* subsp. *betulifolia*) has been pursued through the press and radio, and 1046 trees verified so far. A Research Information Note has been published (White, 1994). A collection of authentic native black poplar accessions is being established at two forest sites (one in South Wales and one in Norfolk), as part of a strategy to ensure the conservation of the genetic variability of the species.

Measuring and recording of notable trees has been continued largely through support for the Tree Register of the British Isles, and a revision of *Champion trees* has been prepared for publication as a Technical Paper.

Weed control

The heavy load of advisory work on forest weed control has continued. A revised version of Field Book 8, *The use of herbicides in the forest*, has been finalised and presented for publication. In the meantime, Research Information Note 246 (Edwards *et al.*, 1994) has been released, giving an up-to-date listing of currently approved herbicide products.

Avon Vegetation Research contract

Further experiments investigating the effectiveness of herbicides to control forest and nursery weeds were carried out, under contract, by David Clay and Fiona Dixon of Avon Vegetation Research, with joint funding from The Forestry Authority and Forest Enterprise.

As part of the search for more effective foliar-acting herbicides for forest nurseries, crop tolerance was evaluated by testing the effect of seven herbicides at three doses and two application dates on birch, Japanese larch and Sitka spruce. Simulated rain was applied to half the pots 24 hours after spraying to assess potential for root uptake. Fluroglycofen-ethyl and pyridate were generally safe except on birch at the first application date. Desmetryn, metamitron and thifensulfuron-methyl were generally safe on larch. Post-spraying rain increased the toxicity of cyanazine on all species, but reduced that of desmetryn.

Heather can be a serious problem on some nurseries; candidate herbicides were evaluated for pre- and post-emergence control. Pre-emergence applications of chlorthal dimethyl, napropamide, oxadiazon and propyzamide were effective at low doses. Metazachlor gave promising results as a post-emergence treatment.

Previous work has shown the effectiveness of

imazapyr for control of *Rhododendron ponticum*. Further experiments have shown that translocation of herbicide from sprayed shoots is quite rapid but root exudation of imazapyr and transfer to adjacent plants was not detected. Where the foliage of sprayed bushes was cut off two or more days after spraying there was no regrowth from cut stumps. Where untreated *R. ponticum* or spruce trees were grown in the same pots as treated plants there was no evidence of imazapyr damage.

Cycloxydim was shown in the 1992 work to be very effective for the control of wavy hair grass (*Deschampsia flexuosa*). This was confirmed in a new experiment where it gave control superior to fluazifop-butyl or glyphosate on plants grown under different moisture regimes.

Arboriculture and urban forestry

The Arboriculture Advisory and Information Service became free-standing with finance through the Tree Advice Trust and was launched by Lord Strathclyde in March 1993.

The demonstration plot concept has developed through the success of the demonstrations at Wednesbury (in association with the Black Country Urban Forestry Unit), and at Thames Chase and the Forest of Mercia in association with the community forest teams. This year, a 19 hectare demonstration was planted on colliery spoil in association with Nottinghamshire County Council.

A final report was presented to the Department of the Environment (DoE) on the Arboriculture V contract, and on the basis of this a new contract has been obtained, in part to pursue the idea of a plant quality index. The work on planting stock has been written up by Gary Kerr for publication in *Forestry*.

DoE funded work on the use of steel rods to assess soil aeration has been published by Simon Hodge in three peer-reviewed journals and as an Arboriculture Research Note (ARN). Conference presentations were made in the U.K. and U.S.A. and more than 50 enquiries received from around the world. Similarly, DoE funded work on compressed-air soil injection and stem nutrient injection has been published in *The Arboriculture Journal* and in three ARNs.

PAUL TABBUSH

REFERENCES

EDWARDS, C., MORGAN, J. and WILLOUGHBY, I. (1994). *Approved herbicides for use in forestry*. Research Information Note 246. Forestry Commission, Edinburgh.

TABBUSH, P.M. (1993a). Poplar husbandry. *Quarterly Journal of Forestry*, **87**, 203–205.

TABBUSH, P.M. (1993b). *Coppiced trees as energy crops*. Energy Technology Support Unit B 1291. Department of Trade and Industry, London.

WHITE, J.E.J. (1994). *Black poplar: the most endangered native timber tree in Britain*. Research Information Note 239. Forestry Commission, Edinburgh.

RESEARCH AND DEMONSTRATION IN THE NATIONAL FOREST

The Branch is establishing three large-scale demonstration and research woodlands in the National Forest, in consultation with the National Forest Team, and with part-funding from the Department of the Environment. The aims of these woodlands are:

- to demonstrate cost effective techniques of woodland creation; and
- to investigate alternative methods of establishing a range of multiple-use woodlands.

The sites have been selected to represent the type of land that is likely to be planted within the National Forest. The largest site extends to 13 hectares (ha) of newly restored spoil at the former Desford colliery in Leicestershire. The other two sites comprise eight ha of good quality arable land at Barton-under-Needwood, Staffordshire, and 11 ha of low grade pasture near Swadlincote, Derbyshire. Each woodland combines a number of demonstration areas, showing a range of establishment systems, with research experiments investigating topics such as mixtures, direct seeding, spacing and species trials. Figures 16, 17 and 18 (with plates) show planting plans for the three areas. Incorporated in the three demonstration woodlands are five ha of open space, water features, existing copses and hedgerow, all of which are being actively managed.

Successful establishment on newly restored colliery spoil

One of the major challenges is to establish trees on the newly restored colliery spoil at Desford. Detailed site analysis revealed several obstacles to successful woodland establishment. The mound of colliery spoil was covered with between 15 and 40 cm of topsoil which was unstable on some of the steeper slopes; the spoil was also very compacted. In addition, a very high level of pyrites was found in the colliery spoil, which on contact with air would result in extreme soil acidity. These problems are being alleviated by the addition of coarse lime, to ensure controlled buffering of acidity, and con-

tour ripping to alleviate compaction and improve soil stability on slopes.

A range of tolerant species has been grouped for planting depending on site conditions. On the north facing slope a mixture of mainly oak (*Quercus* spp.) and birch (*Betula pendula*) was planted; on more drought stressed areas grey alder (*Alnus incana*), Corsican pine (*Pinus nigra* var. *maritima*) and silver maple (*Acer saccharinum*) were planted. To broaden our understanding of species choice on difficult sites, two species trials have been established to investigate exotic and native species. The former includes 17 species which have potential on any combination of dry, acid or compacted sites and are considered robust; examples of these include *Robinia pseudoacacia*, *Ginkgo biloba* and *Catalpa speciosa*. Other elements of the robust establishment package were: high stocking density (between 3100 and 4500 stems per hectare) to ensure that woodland conditions are established as quickly as possible; fertilizer application; careful planting using high quality stock; and effective weed control.

Creation of new native woodland

On each of the three sites a large area of new native woodlands has been established using the design principles outlined in Forestry Commission Bulletin 112 *Creating new native woodlands* (Rodwell and Patterson, 1994). The aim is to plant native trees and shrubs based on the composition of semi-natural woodlands on similar sites within the framework of the National Vegetation Classification (Rodwell, 1991). Different methods of establishment have been used to form woodlands on similar sites with the objective of comparing the costs of each system with the structure and form of the resulting woodlands.

Growing trees for profit

The subject of the eight ha demonstration area at the Barton-under-Needwood site is *Silviculture for profit,* which shows how to maximise the economic return from forestry on good arable land. The area contains: poplars (grown at one and three metre spacings for chips and pulp, and eight metre spacings for veneer) with or without understorey plantings; pure fast growing conifers such as Corsican pine and Norway spruce (*Picea abies*); Norway spruce and ash (*Fraxinus excelsior*) in different types of mixture; and pure ash and sycamore (*Acer pseudoplatanus*).

Growth of native tree species

An experiment on the Desford colliery site compares the survival and growth of 17 native tree species to obtain information on how this range of species performs on a difficult site. The experiment has also been replicated on the good arable site and the poor quality grazing site, to compare the performance of these species on sites of varying quality.

Direct sowing of tree seed

Direct sowing of tree seed as a low cost method of establishing trees on former agricultural land has recently generated a lot of interest. The methods currently being used involve the direct sowing of tree seed at high densities at the same time as an agricultural crop such as linseed or oilseed rape. The seedlings are protected by the agricultural crop which is removed during or at the end of the first growing season to allow the trees to grow on. Similar systems can be traced back to recommendations made by John Evelyn in his classic work *Sylva, or a discourse of forest trees*, first published in the seventeenth century. The main potential benefit of the system is that it uses techniques which are familiar to farmers, but this must be balanced against the unpredictability of emergence of dormant tree seed and the difficulties in controlling arable weeds near young tree seedlings. Two experiments have been established, to examine the direct sowing of oak and Scots pine (*Pinus sylvestris*) tree seed and subsequent vegetation management strategies, on the colliery spoil and the good quality arable site.

The areas contain much that is relevant to the expansion of forestry in lowland Britain and have already attracted large numbers of visitors since planting began in January 1994.

GARY KERR, SIMON HODGE, IAN COLLIER AND NICK RYLANCE

REFERENCES

RODWELL, J.S. (ed.) (1991). *British plant communities, Vol. 1: Woodlands and scrub.* Cambridge University Press, Cambridge.

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

SURVEY OF NATURAL COLONIZATION

Natural colonization is the process of woodland creation on previously unwooded sites by natural dispersal of seeds. It has long been recognised as a method of establishment and a recent survey within the West Midlands Borough of Sandwell has shown that 35% of the woodland

present arose in this way. Although it is probably the closest method to a natural succession that can be achieved it is very unpredictable and it is difficult to control either the speed of the process or the character of the woodland which develops. A survey of natural colonization was carried out in 1993 to associate site characteristics with the presence of seedlings and help managers identify sites where natural colonization is likely to be successful.

The survey covered a total of 47 sites which had been abandoned for between 10 and 41 years, situated in Avon, south Staffordshire and the West Midlands. Sites varied between one and seven hectares (ha) in size, and sufficient 4 x 4 m quadrats were assessed at each to cover 2.1% of the area. The following characteristics were assessed within each quadrat: numbers and mean height of each woody species present; predominant vegetation type (e.g. weak grass sward, herbs); nature of the substrate (e.g. colliery spoil, top soil, rubble); texture of the substrate (e.g. clay, sand); penetrability; damage; and aspect. The species of parent trees surrounding the site were also recorded.

Species

In all, 25 species were found as seedlings but their frequencies and abundances varied considerably. The species which were found at the greatest number of sites – hawthorn (25), willow (22), birch (17), oak (17) and ash (12) – were generally the most abundant with the largest total numbers of seedlings in the order: ash (705), birch (673), willow (515), hawthorn (398), and oak (104). Some species, such as alder and beech, were present as parents but not found as seedlings, whereas others such as dogwood and wayfaring tree were found as seedlings but not seen as parents. The distribution of colonising species differed between the three areas (Figure 19, with plates). In relatively rural Avon, 17 species were recorded, with ash and hawthorn dominating, but in south Staffordshire and the West Midlands, 13 and 11 species were found respectively with birch and willow the predominant species.

Distribution

The type of vegetation had a marked effect on the occurrence of colonising seedlings. The most common vegetation type was a densely matted grass sward, and only 14% of these were colonised to an acceptable woodland standard (defined as a 4 x 4 m plot containing at least four trees of any size or two trees >1 m). Weak, open sward was the vegetation type most frequently associated with seedlings and 33% of quadrats with this type of sward were colonised to an acceptable level (Figure 20).

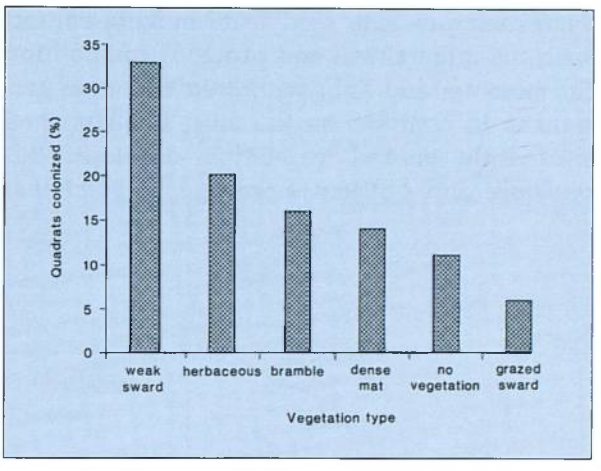


Figure 20. The effect of vegetation type on number of quadrats colonised in a survey of abandoned urban sites.

Eight different substrates were recognised; top soil was the most frequent and pulverised fuel ash the least. There was a strong positive association between the presence of colonization and either sub-soil or small-sized soil-less substrates such as gravel, ballast and clinker, where approximately 50% of quadrats were colonised. In contrast there was a negative association with pulverised fuel ash where no seedlings were found.

Texture of the substrate also had an influence on the occurrence of colonization. There were significant negative correlations between the presence of seedlings and either sand or impervious substrates such as rock and concrete. In contrast the presence of seedlings was positively correlated with loam and clay.

The relationships between colonization and other factors are less clear. Too little damage was observed to allow useful analysis. There was some evidence which suggested that sites of low penetrability (high compaction) were less readily colonised than those where penetrability was high. Although most quadrats were flat, aspect did have some effect; north and west facing slopes tended to be most frequently colonised.

For woody colonization to occur there must be a suitable seed supply, and species with poor powers of dispersal are least likely to colonise urban sites. The survey found the frequency of colonization of most species to be closely linked to the presence of parent trees and site conditions conducive to the germination and establishment of woody seedlings. In the absence of ground vegetation, fertile, moist sites will be colonised most quickly and by the

widest range of species. However, these sites are also most favourable to rank ground vegetation. Rapid invasion of coarse grasses and other vegetation prevents seed from making contact with the mineral soil and provides competition for moisture and light with seed that does germinate. In contrast, on the most impoverished sites little ground vegetation develops, but moisture and nutrient stress are so great that woody colonization cannot establish either. Woody colonization is most likely on sites that are sufficiently infertile and moisture stressed to prevent the rapid dominance of rank vegetation, but not so stressed as to prevent the establishment of woody seedlings.

SIMON HODGE AND RALPH HARMER

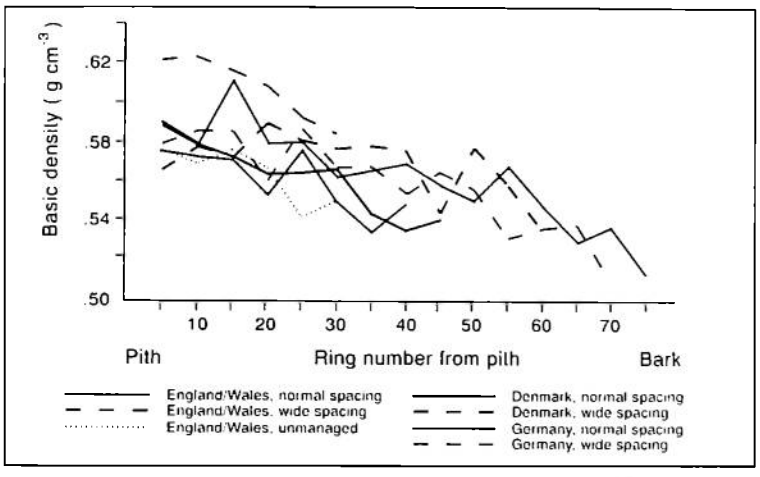


Figure 5. *Changes in basic density of oak wood (g cm^{-3}) measured from pith to bark. Points are means of ten trees from each stand.*

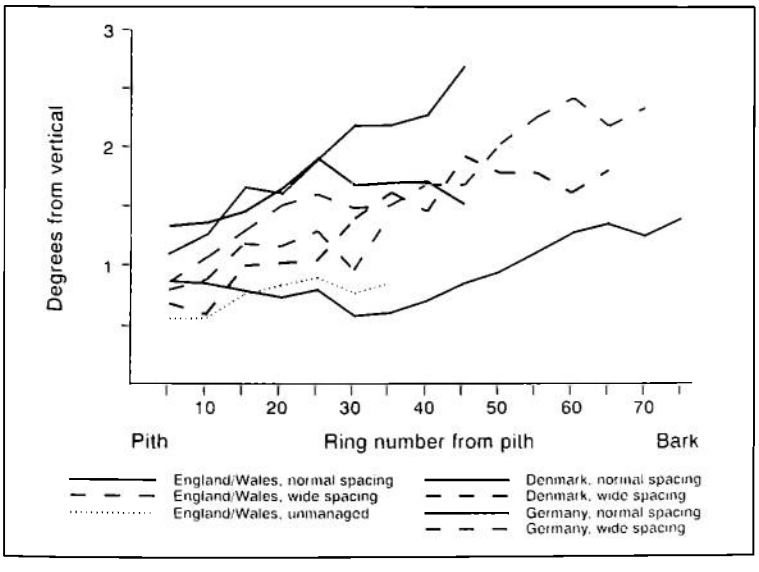


Figure 6. *Angle of spiral grain measured on vertically split oak discs using an angle gauge (positive or negative direction of grain angle has been ignored). Points are means of ten trees.*

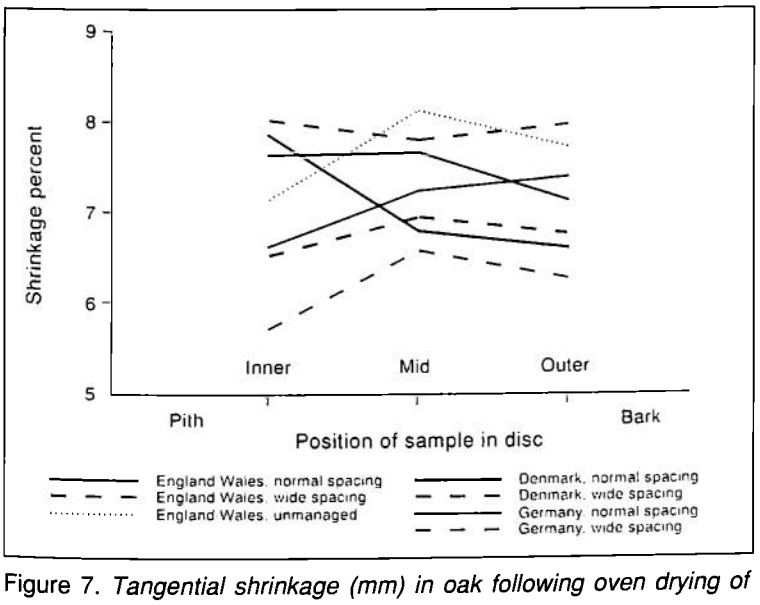


Figure 7. *Tangential shrinkage (mm) in oak following oven drying of green oak, variation at three positions across a disc. Points are means of ten trees.*

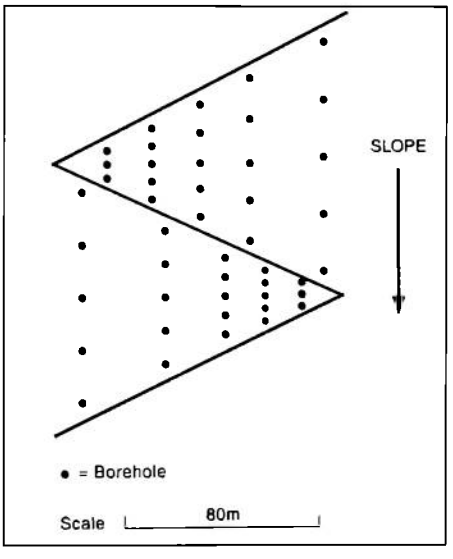


Figure 23. *Schematic of the layout of drain and boreholes in the drainage demonstration at Kielder Forest.*

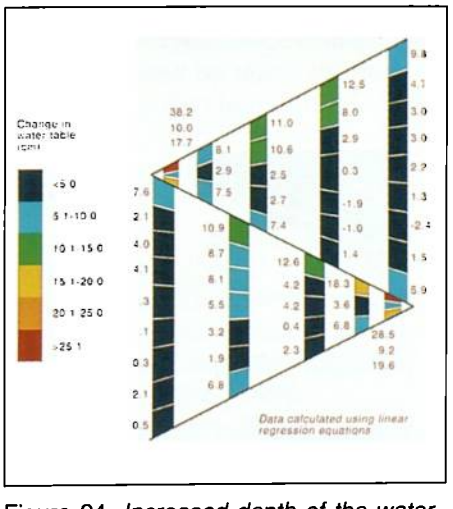


Figure 24. *Increased depth of the water-table (cm) following drainage for a week with 30 mm rainfall.*

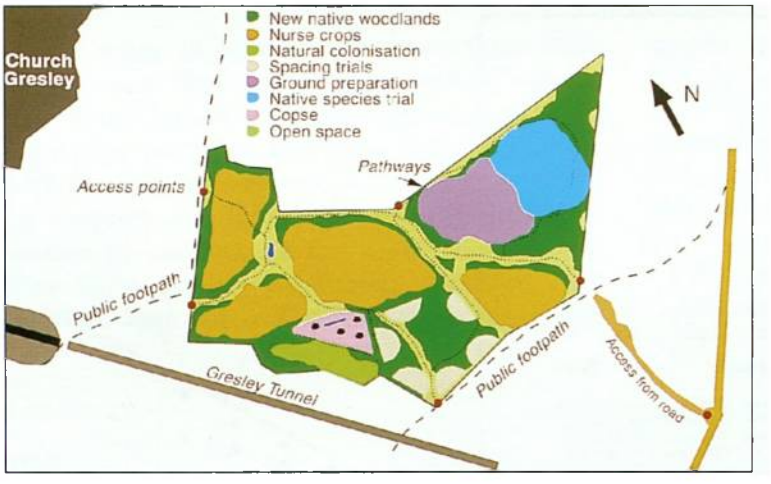


Figure 16. *Research and demonstration in the National Forest: Church Gresley site.*

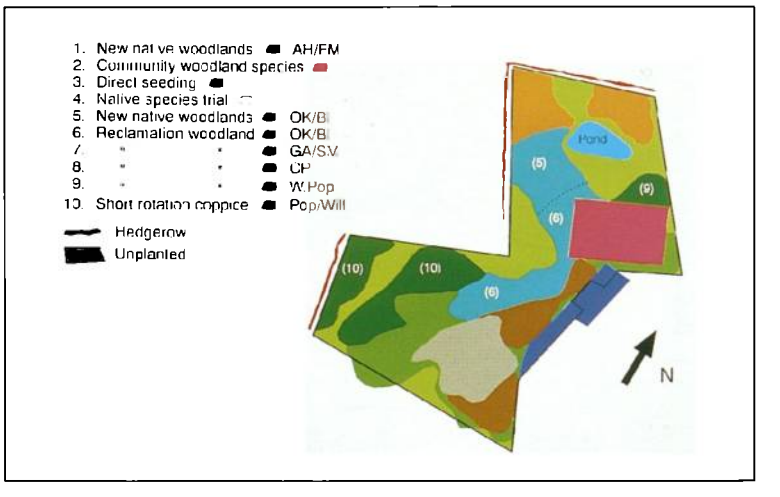


Figure 17. *Research and demonstration in the National Forest: Desford Lakes site.*

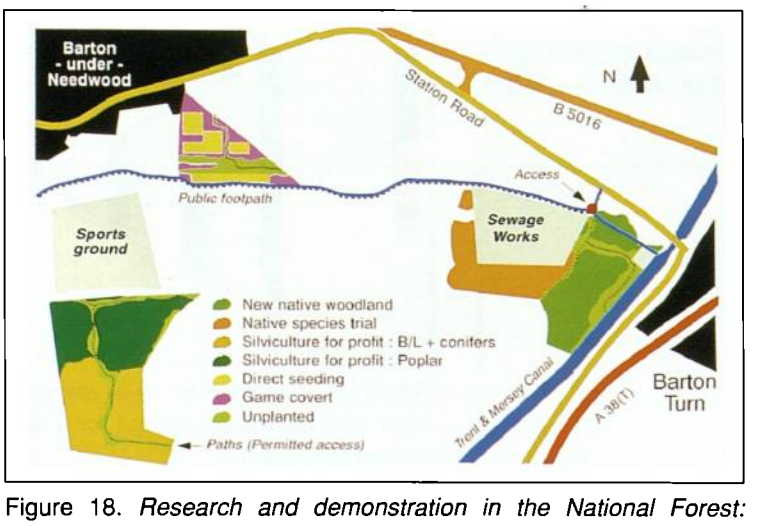


Figure 18. *Research and demonstration in the National Forest: Barton-under-Needwood site.*

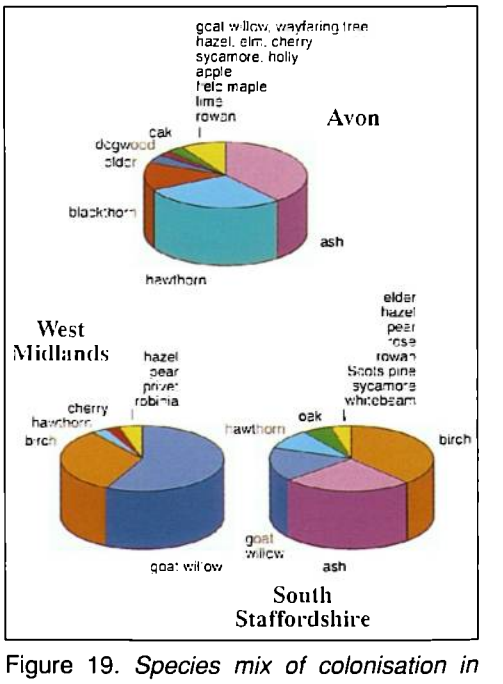


Figure 19. *Species mix of colonisation in the three regions.*

TREE IMPROVEMENT

Overview

A number of significant changes took place within the Branch during the 12 months under report. At the start of the year, David Rook was appointed Chief Research Officer (North) at the Northern Research Station. Alan Fletcher took over as Head of Branch, but his previous position was not filled so a reorganisation of project responsibilities was needed. Dr Christine Cahalan, who was responsible for the Ministry of Agriculture, Fisheries and Food/Forestry Commission (MAFF/FC) funded project on genetic improvement of broadleaves for farm forestry, resigned to take up a post at the University College of North Wales. Dr Ned Cundall has been appointed as a replacement to complete the five-year project and to initiate new work on improvement in broadleaves.

The current and previous reductions in staff have meant the reprioritising of projects and species. There has been a slowly decreasing effort on provenance of conifer species and a closure programme for older and fringe species has been initiated. Efforts on conifer provenances are now concentrated on the main International Union of Forestry Research Organizations' experiments with Sitka spruce, Douglas fir, grand fir, noble fir and Pacific silver fir. As regards broadleaves, new provenance experiments have been planted with *Quercus robur*, *Q. petraea* and *Q. rubra*.

Flowering in the major commercial species was light in spring 1993 which lessened the demand for registration of new seed stands. This Branch is now responsible for the inspection and registration of poplar stool beds, involving a substantial work load in summer 1993. The database for all Forest Reproductive Material was completed and the *List of basic material* in abbreviated, bound form was published for the first time. This includes seed stands, seed orchards and poplar stool beds, and will be updated and reprinted annually. The Register of Native Pinewood Seed Collection Areas was also updated and a similar list was published.

Increasing proportions of time and resource are being spent on contract research, now amounting to almost 25%. The Branch is involved in two major contracts, namely the MAFF/FC project on genetic improvement of broadleaves for farm forestry and secondly a European Union (EU) funded project on *Fast growing northern conifers*. The latter involves the evaluation of Douglas fir families from the Pacific North-West of America in collaboration with colleagues in France, Belgium and Italy. A second part of this contract concerns flowering and seed production in larch and Sitka spruce.

A further EU project involves selection and propagation for increased production of aescin in horse chestnut (HCH) in conjunction with research teams in Germany and Italy. Three populations of HCH have been sampled in the U.K. and the chemical level in the nuts analysed. This shows that there are significant between-tree differences in the concentrations of aescin. Attempts will now be made to establish the high yielding individuals in clonal banks and cutting hedges.

A three week workshop for four scientists from the Chinese Academy of Forestry was held in spring 1994 as part of the Overseas Development Agency project on the improvement of Japanese larch and other larch hybrids. This proved to be very successful and the Chinese scientists will continue the improvement programme in China during 1994.

The University of Edinburgh instituted a new M.Sc. course in Tree Improvement during 1993/94. This involved a considerable lecture workload for several members of the Branch, who are also involved in supervising and assisting with dissertations.

The Branch was host for the annual meeting of the Nordic Tree Breeders. Two topics were discussed – progeny testing and breeding strategies. Twenty papers were presented on these topics and the proceedings of the meeting have been published.

The breeding of Sitka spruce is still the largest single project but, with the increasing emphasis on broadleaves and contracts, the time being devoted to the species is diminishing. Nevertheless,

following on from a review of the breeding strategy, a general breeding population was identified using an index selection method (see below). Because of competition for resources, the next phase in the project on breeding of Sitka spruce will not begin for another 12 months.

The biochemical work of the Branch has developed with work starting on the use of the random amplified polymorphic DNA technique to characterise (fingerprint) the clones in the Sitka spruce breeding population. The technique will be extended to identification of poplar and willow clones. Studies in a Sitka spruce seed orchard using isozyme genetic markers, as reported later, have shown that a very high percentage of outcrossing is being achieved.

In 1991 the Forestry Commission placed a research grant with Nottingham University to fund work on the possibilities of producing transgenic plants of Sitka spruce. Although the project encountered problems in the early days, these have largely been overcome to the extent that the ß-glucuronidase reporter gene has been successfully inserted into embryogenic cell lines of Sitka spruce (see below).

ALAN FLETCHER

DEVELOPING TRANSFORMATION SYSTEMS FOR SITKA SPRUCE

This project was initiated to develop systems for introducing foreign genes into Sitka spruce with the ultimate aim of producing genetically transformed plants. Development of such a system requires the investigation of a range of techniques, such as the establishment of the plant material in the correct condition for transformation, insertion of the genes, establishment and testing of completely transformed cell lines, and regeneration of transformed whole plants from the cell lines.

A system has been developed where somatic embryogenic cell lines can be initiated from mature zygotic embryos. The frequency of initiation of cell lines is low but at rates comparable to other conifer species that have been investigated. Plantlets have been generated from the embryogenic cell lines by maturation and germination of the immature embryos. The rapid rate of growth of the embryogenic cell lines and the ability to obtain whole plants from them offers an ideal system for obtaining completely transformed plants following the insertion of the selected foreign gene.

The ß-glucuronidase reporter gene has been inserted into embryogenic cell lines by *Agrobacterium tumefaciens* mediated gene delivery and into mature zygotic embryos by particle bombardment. This gene has been used to optimise the conditions needed for transformation to be successful in the two delivery systems. Success of the delivery system was measured by assay of the products of the transient expression of this gene.

The npt-II gene has also been inserted into embryogenic cell lines using the *Agrobacterium* delivery system. This gene confers resistance to aminoglycoside antibiotics such as kanamycin sulphate. The *Agrobacterium* treated cell lines have been grown on a medium containing the antibiotic, and putative transformed cell lines have been established from those cells that were formed. Experiments are now in progress to regenerate whole plants from these cell lines. The whole plants will be analyzed at the molecular level for the presence and expression of the inserted gene.

The genes inserted into the Sitka spruce embryogenic tissue to date will not confer any benefit to the whole plants developed from it. They have been used to optimise the delivery system and to allow selection of transformed cells. The system that has been developed will allow genes for beneficial characters such as herbicide or insect resistance to be inserted into somatic embryogenic tissue and expressed in the growing tree.

PASCAL DRAKE

THE USE OF ISOZYME GENETIC MARKERS TO ESTIMATE THE RATE OF OUTCROSSING IN A SITKA SPRUCE SEED ORCHARD IN SCOTLAND

Seed orchards are the means by which the end product of a breeding programme is produced for commercial use. In order to function effectively outcrossing rates must be high, as selfing leads to an increased proportion of empty seeds as well as to inbreeding depression. To maximise the opportunity for outcrossing, conventional seed orchards generally comprise large numbers of superior clones with wide separation between ramets of each clone. Such a design is expected to produce a seed crop which reflects both the genetic superiority and the broad genetic base of the parental clones. However, despite such efforts to optimise design, factors outwith the control of the tree breeder, such as variation between clones in the

timing and intensity of their male and female flowering, may prevent the seed orchard from functioning effectively. There is, therefore, a need for quantitative information on flowering and outcrossing rates in our seed orchards.

Isozyme markers are ideally suited to the study of outcrossing rates. Isozymes are the multiple molecular forms of proteins, enzymatically active and catalysing the same reaction. Variant enzymes produced by different alleles at the same locus are termed allozymes. Stains which produce a non-diffusible, chromogenic precipitate at the site of enzyme activity are used to locate the multiple forms of enzymes with common catalytic activity after they have been resolved by means of electrophoresis in a solid matrix. The inheritance of the isozymes makes them suitable markers for studying mating systems. In conifers, it is possible to identify the genotype of the mother clone by analysis of the haploid gametophyte in the seed and, by further analysis of the associated diploid embryo, to determine the paternal contribution to the embryo. Using this information it is possible to obtain an estimate of the outcrossing rate in the seed orchard.

Isozyme markers were used to study the outcrossing rate in a grafted seed orchard at Ledmore, Perthshire during 1990, six years after planting. A survey of flowering in the orchard during that year showed that all the clones flowered, with 95% of the ramets of each clone producing female cones and 95% of the ramets producing male cones. Most clones produced more than 50 male and 50 female cones per ramet. Female flowers were receptive at the same time in nearly all the clones, and pollen shedding peaked a few days before the female flowers were at their most receptive.

Gametophytes and embryos were separated, ground in extraction buffer, applied to commercially prepared cellulose acetate plates and subjected to electrophoresis. The plates were stained for the following isozyme systems; glutamate-oxaloacetate transaminase (GOT), glutamate dehydrogenase (GDH), phosphoglucose isomerase (PGI) and phosphoglucomutase (PGM). GOT and GDH were polymorphic at one locus and PGI and PGM each produced two loci which were polymorphic. Single locus estimates of outcrossing rates ranged from 0.94 to 1.00 and did not differ significantly from 1. The multilocus estimate, based on data from the six polymorphic loci was 0.98. The proportion of empty seeds and the percentage of seeds which failed to germinate were not recorded, so these estimates of outcrossing are based solely on seeds which successfully germinated. These results indicate that, of the seeds which germinated, a negligible proportion were the product of selfing during the 1990 season. These high estimates of outcrossing rates were probably partly due to the prolific and synchronous flowering of all ramets of all the clones. A season in which there was poorer flowering might have produced a very different result.

JOAN COTTRELL

BREEDING GENETICALLY IMPROVED DOUGLAS FIR

Douglas fir is a species with a great potential in western Europe. As part of a collaborative project, partially funded under the European Union/AAIR programme, the genetic testing of superior phenotypes selected by the United States Forest Service in natural stands in Washington and Oregon has begun in Britain and France. The general objective of the programme is to identify superior Douglas fir clones, for vigour and form, which can be included in both pan-European and U.K. based breeding populations.

Plants of 250 open-pollinated families, collected from candidate trees growing in origins within the state of Washington known to be well adapted to this country, will be established over three forest sites and one farm field site (FFS). A further 70 families of Oregon origins, constituting a sub-sample of more comprehensive testing work in France, will also be established on the same sites.

The first 160 open-pollinated families from Cowlitz and Snoqualmie (Washington origins) were planted in Huntly, Marches, and South East Wales Forest Districts and in a specially selected FFS near to the Northern Research Station in the spring of 1994. The balance of families from Skagit (Washington), Mapelton, Gold Beach and Powers (Oregon) will be planted in the spring of 1995.

Intensive measurements from the FFS over the first three years will be correlated with later assessments in forest-based experiments to investigate whether selection could be made at an earlier age in the more uniform and fertile FFS. If this proves possible, the cost of future forest progeny tests could be reduced considerably by screening out poorer families based on early test results.

The opportunity will be taken to compare family performance for vigour and stem form amongst Britain, France and the United States. If the same families are found to be superior,

then improved seed can be imported into Britain from the more advanced clonal seed orchards already established in the U.S.A. The first data to be correlated between Britain and the U.S.A. will become available in 1997.

STEVE LEE

MULTI-TRAIT SELECTION OF SITKA SPRUCE CLONES FOR THE GENERAL BREEDING POPULATION

Introduction

Breeding value estimation of Sitka spruce (*Picea sitchensis* (Bong.) Carr) plus-trees, based on measurement of half-sib progeny in comparative trials, began regularly in 1967 and continued until 1993. A review of the Sitka spruce breeding strategy showed that the time was opportune to identify all the clones that will constitute the F_0 general breeding population and move forward into the next generation of breeding and selection.

Composition of the general breeding population

A complete re-analysis of all progeny tests planted between 1967 and 1977 for 15-year or greater (up to 22-year) diameter, wood density and stem form (combination of stem straightness and branching quality; see Lee, 1992) led to the ranking of all plus-trees in test using a selection index. From this, a breeding population of the top 240 index-ranked plus-trees has been constructed.

Re-selection for the breeding population based on index value was restricted to those tests greater than 15 years old, since this is the earliest age at which selection for wood density can be carried out. Other high index-ranked plus-trees, subsequently identified following 15-year assessment of diameter, wood density and stem form in progeny tests planted after 1977, will enter as bottom-ranked clones in the F_1 breeding population.

Analysis of the data available for the index calculation was not straightforward due to the complicated nature of the half-sib tests established. Factors which had to be considered in the analysis of the data included: varying number of sites by year; variation in quality of site both within and across years; and use of weighted performance data and standard indices (Cotterill and Dean, 1990).

Number of sites

The number of sites over which a progeny test was replicated varied from eight in 1967 to three in 1977. In this exercise the number of sites analysed was limited to a maximum of three although often only two survived to 15 years and beyond. If 15-year data were available from more than three sites, attempts were made to select one site from Wales, one from the Borders and one from North Scotland, i.e. typical Sitka spruce growing areas.

Variation in site quality

The family heritability calculated at each test site was used to weight family mean trait value. Thus in the combined analysis of data from a number of sites, those with a high family heritability (e.g. 0.8) would be given greater weight than a variable site with low heritability (e.g. 0.4). This is roughly equivalent to the 'best linear predictor' equation adopted by White and Hodge (1989, Equation 5.3) which serves to weight observations in proportion to the ratio of additive to phenotypic variance. It also relates to the multi-site index selection suggested by Burdon (1979).

Weighted performance data and standard indices

Data from all years were combined into one large data set. This involved weighting family mean performance relative to the overall mean Queen Charlotte Islands control. Standard parameter estimates for family mean heritability and phenotypic and genotypic correlations were calculated by averaging values across years. In this way a standard index was created (Table 9).

Table 9. Standard family mean heritabilities and phenotypic and genetic correlations used in the index calculations

	Diameter	*Density*	*Stem form*
Heritabilities	*0.70*	*0.80*	*0.70*
Phenotypic correlatons			
Diameter	1.00		
Density	0.58	1.00	
Stem form	0.11	0.04	1.00
Genetic correlations			
Diameter	1.00		
Density	0.66	1.00	
Stem form	0.04	0.00	1.00

Moving into the next generation

The 240 top-rated clones have been divided into four sub-lines of equal index value and an amended form of assortative mating will now be employed in the next generation. Each sub-line has been further divided into thirds; all clones in the top third will be employed in five crosses; the middle third in three crosses; and the bottom third in two crosses (Figure 21). In this way more breeding effort will be spent on those clones believed to be of greatest breeding value as suggested by Lindgren (1986) and White *et al.* (1993).

Controlled pollinations within the first of the sub-lines is programmed to begin in spring 1995.

STEVE LEE

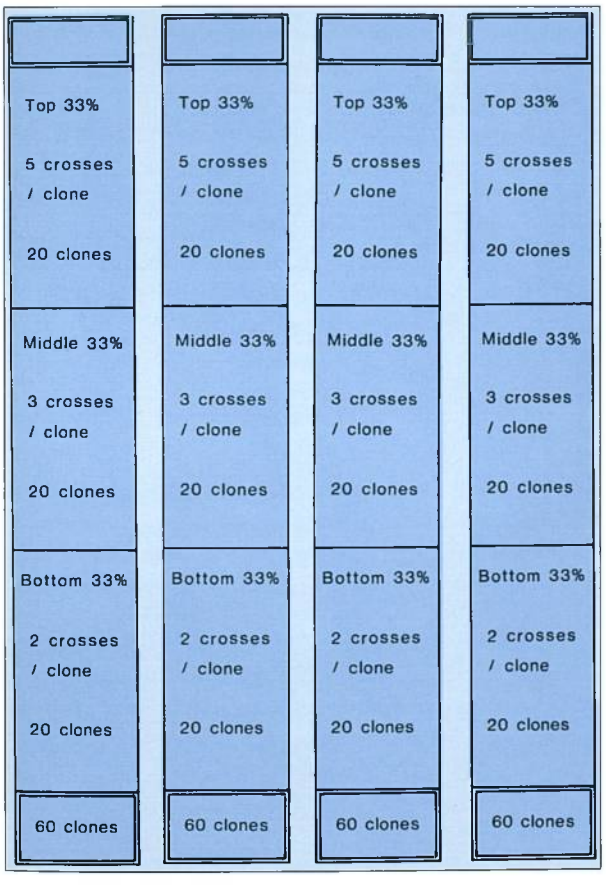


Figure 21. Sub-line structure of the Sitka spruce general breeding population.

REFERENCES

BURDON (1979). Generalisation of multi-trait selection indices using information from several sites. *New Zealand Journal of Forest Science*, **9(2)**, 145–152.

COTTERILL, P.P. and DEAN, C.A. (1990). *Successful tree breeding with index selection*. CSIRO, Australia.

LEE, S.J. (1992). Likely increases in volume and revenue from planting genetically improved Sitka spruce. *In:* D.A. ROOK, ed. *Super Sitka for the 90s*. Forestry Commission Bulletin 103. HMSO, London.

LINDGREN, D. (1986). How should breeders respond to breeding values? *In: Proceedings of IUFRO conference on tree breeding theory, progeny testing and seed orchards*. October 13–17. Williamsburg, Virginia.

WHITE, T.L. and HODGE, G.R. (1989). *Predicting breeding values with applications in forest tree improvement*. Klewer Academic Publishers, The Netherlands.

WHITE, T.L., HODGE, G.D. and POWELL, G.L. (1993). An advanced-generation tree improvement plan for slash pine in the southeastern United States. *Silvae Genetica*, **42(6)**, 359–371.

WILDLIFE AND CONSERVATION RESEARCH

The Branch was reorganised in mid-year. Staff at Wildlife and Conservation Research Branch Ardentinny and the Northern Research Station were amalgamated with Site Studies (North) to form Wildlife Ecology Branch. The Wildlife and Conservation Research Branch remains at Alice Holt.

A successful one day conference, *The biology, impact and management of Muntjac deer*, organised jointly with the British Deer Society and Forest Enterprise, was held at New Hall, Cambridge in October 1993. This was the first conference devoted entirely to the status of muntjac deer in the U.K. The proceedings will be published in 1994.

In Thetford, the joint English Nature and Forestry Commission red squirrel conservation study has been remarkably successful, with red squirrels appearing in the designated conservation area in reasonable numbers. The conservation strategies of supplementary feeding, grey squirrel removal, squirrel releasing and habitat design are all being evaluated.

The application for approval for grey squirrel poisoning in red squirrel areas was not granted until February 1994, which prevented the planned trials in summer 1993.

A major review of damage by mammals was published in 1993 which highlighted areas in need of further research, one important topic being the long-term effects of browsing by deer on tree growth and timber quality. This year an experiment was established to investigate the long-term responses of eight tree species to browsing by roe deer. The experiment will provide a better understanding of to what extent growth loss and deformity relate to early damage and how much they differ between tree species.

As deer populations continue to increase concern is growing about the effects of browsing on forest vegetation structure and diversity. A monitoring experiment is revealing how the succession of ground flora on a restocked site is modified by the effects of browsing by hares and deer (Figure 22). The experiment will provide evidence of the loss of diversity and changes in structure that arise from the impact of browsing mammals.

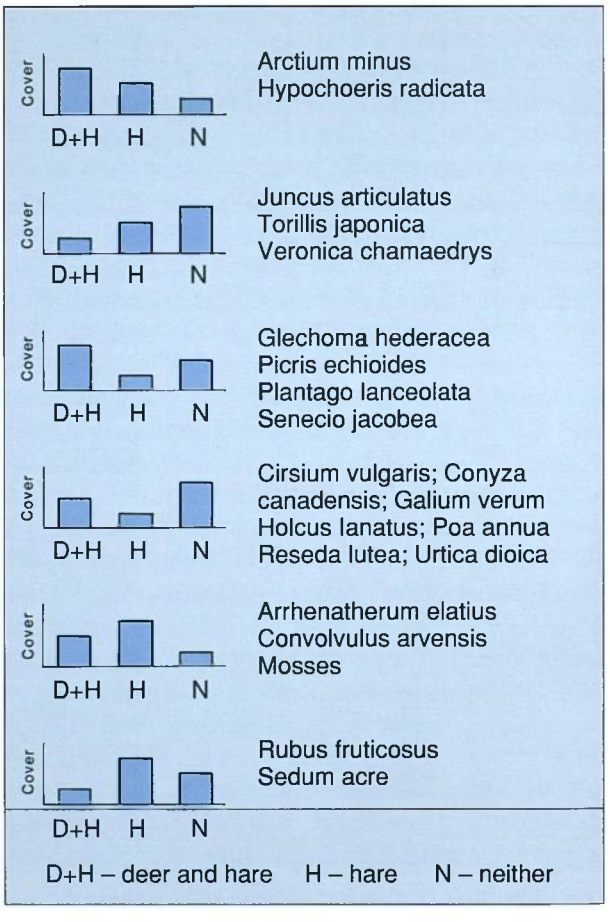


Figure 22. Preliminary results on the effect of browsing by deer and hares on the cover of different ground flora species in Thetford Forest, East Anglia. Changes in relative cover of ground flora species in response to grazing by hares, or deer and hares in combination. Each species has been scored as being more abundant, intermediate or less abundant under each grazing regime, and then grouped with the other species showing a similar response.

GREY SQUIRREL DAMAGE PREDICTION: INDEX TRAPPING

A collaborative study involving The Forestry Authority Research Division, Queen Mary and Westfield College (London University), and Forest Enterprise is in progress to formulate a damage risk prediction index. The aim is to

help forest managers target warfarin control of grey squirrels more cost-effectively. The rationale, based on previous research studies, is as follows: the severity of grey squirrel damage to broadleaved woodland is positively associated with the number of squirrels, particularly young animals, present during the main damage period of April to July. This, in turn, is directly related to the availability of tree seed in the autumn. If seed supplies are abundant, overwinter survival and the spring recruitment of young are high. A good measure of seed availability is the trappability of grey squirrels in baited live capture traps. High trappability indicates food scarcity, low numbers during the damage period and therefore a low damage risk. Low trappability indicates food abundance, high numbers of both adults and juveniles during the damage period, and a high damage risk.

The study started in 1990 in three Forest Enterprise districts in southern England and was extended to seven districts in 1994. A standardised trapping procedure using multi-capture traps was carried out in January/February in two selected woodlands within each forest district. Additional information, on the breeding condition of trapped animals and seed availability at the time of trapping, has also been obtained and will be incorporated into the index. Follow-up surveys of bark-stripping damage have been carried out at some sites. Differences in numbers of captures among sites and years have been found (Table 10), with generally good trapping success in 1993 and 1994, intermediate in 1992 and no captures in 1990. The results for 1991 were affected by a heavy fall of snow causing the trapping to be discontinued early. The damage assessment and breeding data will be analyzed in 1994 and the precise index formulated. The study will be continued for a further five years to validate the index.

HARRY PEPPER, JACKIE DAGNALL AND JOHN GURNELL

VEGETATION MANAGEMENT (LOWLANDS)

One of the objectives of managing forest edges, such as roadsides and rides, is to provide a variety of habitat conditions across a structurally graded edge or *ecotone*. Successional processes, if unhindered, result in the eventual dominance of scrub and woodland. Intervention is needed to halt this process. Intervention is commonly by mechanical cutting of herb and scrub belts, although alternative techniques such as scarification, to create bare ground for recolonisation, may also be considered. A series of experiments have been set up, in collaboration with Forest Enterprise, at Llandovery and Northamptonshire Forest Districts, to examine how these operations influence vegetation succession. Detailed monitoring programmes using permanently marked quadrats have been undertaken at each site.

These studies have shown that plant species diversity may be increased in the short term by scarification of the ride or roadside vegetation, with many species regenerating from buried seed. Severe scarification can lead to colonisation by common non-woodland species of low conservation status, and it is suggested that light scarification of irregularly spaced patches of vegetation may be preferable.

Cutting without removal of cuttings may lead to a build-up of nutrients in the long term, with a consequent suppression of some plant species by others which are more competitive and able to exploit high soil nutrient conditions. No evi-

Table 10. Number of grey squirrels captured (n) and number of sites where traps were laid (s, each site with six traps) in different forest districts over a five year period

	1990		*1991*		*1992*		*1993*		*1994*	
Forest District	n	s	n	s	n	s	n	s	n	s
West Downs	0	2	15	2	7	2	32	2	44	2
South Downs	0	2	0	2	1	2	7	2	1	2
Wilts & Avon	0	6	7	4	8	3	20	4	17	5
Dorset			5	4	1	1	21	4	37	4
Cornwall & S. Devon			2	4	2	4	6	3	–	–
Somerset & N. Devon			2	4	1	7	26	3	8	4
Dean					3	2	0	2	8	3
Totals	0	10	31	20	23	21	112	20	115	20

dence of this is so far available from these studies, although the non-removal of cut plant material does have a mulching effect, with physical smothering of smaller herbaceous species.

There is also evidence that the expected vegetation succession on many forest edges is interrupted by the actions of vertebrate herbivores, especially deer. Where deer pressure is high, there may be little or no woody regeneration along forest roadsides or at ride margins. Research studies of vegetation succession on edges have incorporated fenced exclosure plots, in order to assess better the impact of deer, rabbits, and other small mammals. These have demonstrated clear effects on natural regeneration of broadleaved trees and shrubs, leading to gross changes in vegetation structure. The removal of valuable invertebrate food-plants, such as bramble (*Rubus fruticosus* agg.), may have indirect effects on the abundance of other species such as violet (*Viola* spp.), which have been found to flourish in the bare ground conditions beneath the bramble. The loss of a shrubby fringe at forest edges, often comprising goat willow (*Salix caprea*), ash (*Fraxinus excelsior*), and smaller shrubs such as blackthorn (*Prunus spinosa*), can greatly reduce their value for wildlife.

Monitoring of vegetation change following windthrow of a lowland pine plantation has continued over three years, in parallel with mapping studies of fallen and standing dead wood. This has shown small, but discernible, changes to the relative abundances of plant species, but little indication of recovery of the original pre-afforestation heathland plant community. The detailed recording of the fate of the dead-wood resource may provide a useful insight into the dynamics of decay and colonisation of this vital component of natural forest ecosystems. Monitoring continues.

RICHARD FERRIS-KAAN

WILDLIFE ECOLOGY

Wildlife Ecology Branch was formed on 1 October 1993 by joining Site Studies (North) Branch with the Northern Research Station and Ardentinny members of Wildlife and Conservation Research Branch. Dr Philip Ratcliffe, Head of Wildlife and Conservation Research Branch, was seconded to Headquarters for most of the year, a move that has since been made permanent. This has curtailed progress with the Biodiversity Project Team formed during summer 1993.

The then Site Studies (North) Branch received a Visiting Group in July 1993. Support was received for the two themes reviewed, drainage and ecological site classification. The series of six 'Z' drainage demonstrations will continue and be completed in 1996. So far the fieldwork for three has been completed and analysis of the results is in progress.

Commissioned research on the flora of recently established broadleaved woodlands in upland Britain provided important information for the major publication *Creating new native woodlands* (Rodwell and Patterson, 1994).

Carnivore ecology work continued at Cowal Forest District with the range and habitat use of ten foxes being studied by radio telemetry. The study of sympatric populations of foxes and wildcats could not proceed at this locality because too few wildcats were found.

We are continuing to give financial and/or technical support to outside research on goshawks, capercaillies and songbirds in conifer forests.

GRAHAM PYATT

REFERENCE

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

ECOLOGICAL SITE CLASSIFICATION

There is a need for an ecologically based site classification if forest managers are to respond adequately to the demands of multiple-use forestry. By focusing attention on forest ecosystems we shall be better able to develop sustainable practices and have a sound basis for wildlife conservation and other aspects of forest planning. This new approach should also benefit the educational and recreational uses of forests.

Development of the classification has progressed to the stage where all the proposed components are in place. Ecological Site Classification (ESC) uses many of the ideas of the British Columbian Biogeoclimatic Ecosystem Classification (BEC), but has also been able to benefit from major recent publications in plant ecology and forest soils within western Europe (Rameau *et al.*, 1989, 1993; Brethes *et al.*, 1992). Much effort has also been given to integrating ESC with the National Vegetation Classification of Britain (Rodwell, 1991).

ESC can be applied at various scales: at the national level, for regions or Forestry Authority conservancies, for forests, or at the subcompartment level. The classification is being tested in a series of case studies using forest design plan areas. The first such study has suggested that there is a value in recognising a larger, broad-brush, mapping unit at a hierarchical level above that of the traditional soil type/phase unit normally found in pieces of one to several hectares. This larger unit may extend to one hundred or several hundred hectare pieces, and encompass soil variation equivalent (in the new classification) to several site types. The larger unit has been provisionally termed a landscape site unit. Mapping of such large units is much faster and therefore cheaper than traditional site mapping. Greater detail can be added for locations of special interest, such as forthcoming felling coupes or other areas of intensive management.

ESC is essentially three-dimensional with the variables being climate, soil moisture regime and soil nutrient regime. Britain is divided into eight climatic zones according to a combination of wetness and warmth factors. Two of the zones are above the tree line. Further division

into subzones based on the same two factors would be appropriate at regional and forest levels. A third climatic factor, oceanicity, can be introduced to represent climatic trends not already covered. Within each climatic zone or subzone, variation in soil quality is depicted by a grid made up of eight classes of soil moisture regime and six classes of soil nutrient regime.

Site diagnosis consists therefore of assessing the climatic zone/subzone, from appropriate maps, and locating the site in question on the soil quality grid. This can be done by one or more methods. The traditional approach through soil type/phase is considered insufficiently precise, but would be an obvious start. An additional or alternative approach would be through ground vegetation where sufficient exists (all species are now considered to have some indicator value). An assessment of the form of humus (e.g. mull, moder, mor) is a third alternative, particularly where ground vegetation is lacking.

It is intended that silvicultural and other interpretations would be linked to climatic zone/subzone and the respective soil quality grid. Each of the 48 cells of the grid could be considered as a potentially different site type (if sites of all qualities occur in the subzone), but prescriptions would be made for groups of cells as appropriate in a particular context. As a simple example, drainage prescriptions would be linked to classes of soil moisture regime irrespective of nutrient regime, subdivided as at present by soil texture classes. The climatic zonation would, however, provide a useful refinement in respect of the risk of soil erosion in the drains.

GRAHAM PYATT

REFERENCES

BRETHES, A., BRUN, J.J., JABIOL, B., PONGE, J.F. and TOUTAIN, F. (1992). *Humus form reference base: excerpts from Referentiel Pelologique.* Association Francaise pour l'Etude du Sol, Paris.

RAMEAU, J.C., MANSION, D. and DUME, G. (1989). *Flore forestiere Francaise: guide ecologique illustre. Vol 1: Plaines et collines.* Institut pour le Developpement Forestier, Paris.

RAMEAU, J.C., MANSION, D. and DUME, G. (1993). *Flore forestiere Francaise: guide ecologique illustre. Vol 2: Montagnes.* Institut pour le Developpement Forestier, Paris.

RODWELL, J.S., ed. (1991). *British plant communities I: Woodlands and scrub.* Cambridge University Press, Cambridge.

CLAY SOILS

The 'Z' drainage demonstration on a clayey peaty gley at Kielder Forest (*Report*, 1991, 1992, 1993) has been completed (Figure 23, opposite Plate 11).

The relationship between water-table depth in each borehole and weekly rainfall was modelled by linear regression, separately for the year before drainage and the year after drainage. From the models the difference in water-table depth due to drainage for an average week with 30 mm rainfall is illustrated in Figure 24 (opposite Plate 11). At a distance 2.5 m downslope of the ditch the change in water-table depth was 16 cm. At 5 m downslope the change was 7 cm, and at 10 or 20 m downslope it was 3 cm. A similar pattern of change was found using a more complex model developed by Rennolls *et al.* (1980). The smallness of the drainage effect was not unexpected in such a clayey soil.

Although the effect on mean water-table depth is small, drainage also speeds up the rate of fluctuation, thereby reducing the length of periods of flooding of roots. Since roots can survive short periods of flooding (Coutts and Philipson, 1978), the increased depth of the woody root system may exceed the change in water-table depth. Current tree-pulling work will investigate this possibility.

DUNCAN RAY

REFERENCES

COUTTS, M.P. and PHILIPSON, J.J. (1978). Tolerance of tree roots to waterlogging. 1: Survival of Sitka spruce and lodgepole pine. *New Phytologist*, **80**, 63–69.

RENNOLLS, K., CARNELL, R. and TEE, V. (1980). A descriptive model of the relationship between rainfall and soil water table. *Journal of Hydrology*, **47**, 103–114.

DEEP PEATS

The experiment at Rumster Forest, Caithness on the soil and hydrological effects of afforesting blanket peat (*Report*, 1989, 1990) has been running for five years. The height of the ground surface along a transect across each treatment plot has been measured twice each year relative to a benchmark (the top of a metal rod hammered through the three metres of peat into the mineral substrate). The annual rate of subsidence has decreased over the period. The unploughed, unplanted control treatment has subsided by 4 cm over the five years. This can be ascribed to the effect of the deep ditch

around the perimeter of the 42 x 20 m plots which lowered the water-table by 6 cm in the first year. The ploughed and planted treatments have subsided by 11 cm. The extra subsidence is probably due to the intensive drainage of the furrow ploughing – which, in combination with the perimeter ditch, lowered the water-table by 14 cm in the first year – rather than to any drying effect of the trees. Depth markers installed at 25 cm intervals down to 1.5 m depth have revealed that subsidence of the surface is due not only to shrinkage of the drained surface layer, but also to compression of the peat at greater depth.

RUSSELL ANDERSON

VEGETATION

The joint project with Scottish Natural Heritage on the wildlife benefits of birch in second generation Sitka spruce forests continued with commissioned surveys of the invertebrate fauna associated with different sizes of birch clumps in restocks of different ages. Over 100 species of Lepidoptera were recorded and there was a trend of increasing diversity from the older, more pure spruce towards younger spruce with a higher proportion of birch.

The effects of cultivation on ground vegetation in upland conifer forests were studied in three long-running silvicultural experiments in north Scotland. Vegetation surveys were commissioned and the results compared with records from before planting. Cultivation appears to have an indirect effect on vegetation through the improvement in crop performance, which in turn causes a reduction in ground flora diversity and a shift towards more shade tolerant species. There were no discernible effects of different methods of cultivation.

In collaboration with Wildlife and Conservation Research Branch at Alice Holt we have prepared two project plans concerned with biodiversity. The first concerns the effects of stand manipulations on the biodiversity of plantations. The second attempts to develop a methodology for the depiction, measurement and monitoring of stand-level biodiversity in unmanaged and near-natural forests. In this we hope to collaborate with other European countries. The overall theme is to compare the biodiversity of managed and natural forests.

JONATHAN HUMPHREY

FERTILITY OF SIKA DEER IN SCOTLAND

Knowledge of fertility is necessary for the management of sika deer populations, in the manner pioneered by the Red Deer Management Package.

Female reproductive tracts and jaw bones were collected between 1984 and 1991, mainly by Forestry Commission Rangers during normal non-selective culling, from most Scottish populations including: Shin in the north; Torrachilty, Inchnacardoch and Farigaig in the Great Glen area; Kintyre in the west; and Peeblesshire in the south. Pregnancy was determined by the presence of an embryo or a developed ovarian corpus luteum. Age was determined by tooth eruption and wear and animals classified as calf, yearling or adult. Sika female fertility was

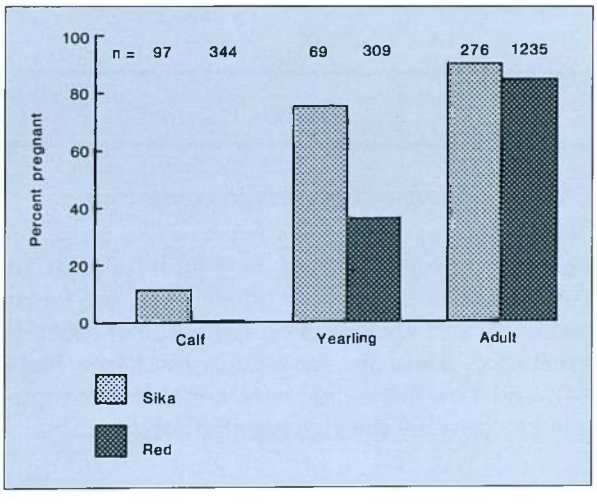


Figure 25. Fertility of woodland sika and red deer in Scotland.

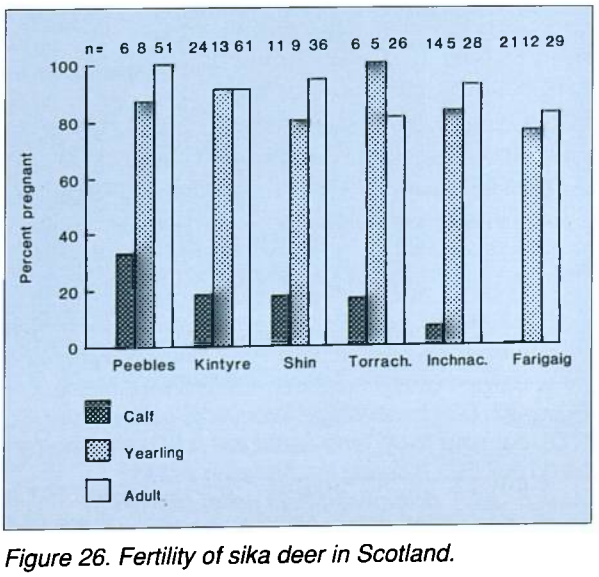


Figure 26. Fertility of sika deer in Scotland.

related to age as a measure of reproductive performance and compared with that of woodland red deer, data from Ratcliffe (1987).

Sika were more productive than red deer in all age classes (Figure 25). Most Scottish sika populations exhibited some calf pregnancies (Figure 26) but for red deer, at 0.6%, they were rare (Figure 25). Sika yearling fertility varied little, being above 70% for all populations (Figure 26). In contrast, red populations varied greatly, from 0% in Glen Crippesdale to 90% in Galloway (Ratcliffe, 1987), resulting in mean yearling fertility about half that of sika. Adults of both species performed at a high level in the amenable forest environment (Figure 25).

ANDREW CHADWICK

REFERENCE

RATCLIFFE, P.R. (1987). *The management of red deer in the commercial forests of Scotland related to population dynamics and habitat changes*. Ph.D. thesis. University of London, London.

BIRDS

Ecology of long-eared owls in coniferous forests

This new project started in Kielder Forest in 1993. It aims to provide information for forest managers and ecologists on the value of second-generation forest for long-eared owls (see Plate 14), and how forest habitats might be manipulated to provide the right configuration of hunting and breeding areas. It will also add another piece to the jigsaw of the ecology of owl communities in coniferous forests.

During the late winter and early breeding season all four species of owl in upland Britain feed largely on small mammals, particularly field voles (Figure 27). Field voles are abundant on restocked areas that develop grassy vegetation (Petty, 1992; Petty and Peace, 1993). In Kielder Forest around 1000 ha are being restocked each year which, over a 12–15 year period, provide a vast resource for field voles and their predators.

In upland areas devoted to sheep rearing, long-eared owls traditionally bred in shelterbelts and this habit persisted when many areas were afforested. Village's (1981 and 1992) study on long-eared owls in Eskdalemuir provides the only information for first-generation forests. As forests mature many nest sites in retained shelterbelts are abandoned and the status of long-eared owls then becomes obscure.

Work on raptor communities in Kielder Forest suggested that, prior to extensive restructuring of the forest, long-eared owls were confined to the forest/moorland edge. Here they bred mainly in old crow nests and hunted over adjacent open ground. During the late 1980s, long-eared owls started colonizing the interior of the forest and are now breeding successfully where tawny owl density is highest (Petty, unpubl. data). Therefore, one aim of the project is to study how tawny and long-eared owls differ in their foraging ecology. This will be achieved by radio tracking both species in adjacent territories. A Ph.D. student, funded by the Hawk and Owl Trust, will start work on this aspect in 1994.

STEVE PETTY

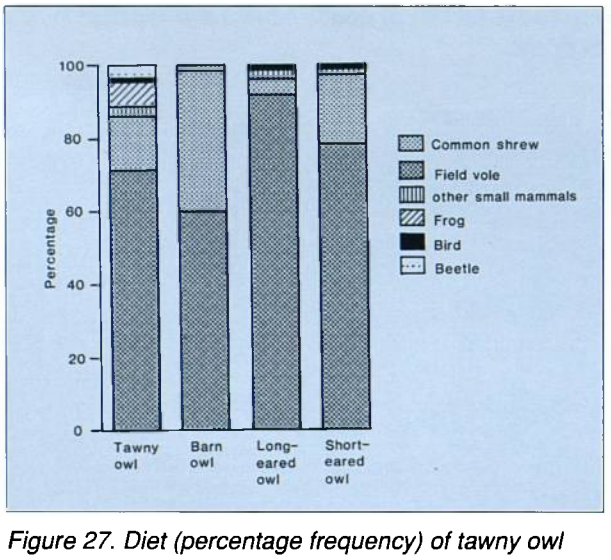


Figure 27. Diet (percentage frequency) of tawny owl (TO), barn owl (BO), long-eared owl (LEO) and short-eared owl (SEO) during the breeding season (March–July), determined from pellet analysis in Kielder Forest. Sample sizes of prey items are: TO = 2324, BO = 976, LEO = 157, SEO = 68.

REFERENCES

PETTY, S.J. (1992). *Ecology of the tawny owl, Strix aluco, in the coniferous forests of Northumberland and Argyll*. Ph.D. thesis. The Open University, Milton Keynes.

PETTY, S.J. and PEACE, A.J. (1993). Temporal and spatial fluctuations in field vole abundance in a predator/prey study. *In: Report on forest research, 1992*. HMSO, London. pp. 40–42.

VILLAGE, A. (1981). The diet and breeding of long-eared owls in relation to vole numbers. *Bird Study*, **28**, 215–224.

VILLAGE, A. (1992). Asio owls and kestrels in recently planted and thicket plantations. *In:* C.A. GALBRAITH, I. TAYLOR and S. PERCIVAL, eds. *The ecology and conservation of European owls*. Joint Nature Conservation Committee, Peterborough.

Golden eagle ranging behaviour in relation to land cover

Since July 1991, the Forestry Authority has commissioned the Royal Society for the Protection of Birds to study the ranging behaviour of territorial golden eagles in Argyll using radio telemetry. The aims are to determine the size of the eagle territories and to identify any preferred areas or habitats within those territories. The study also examines the relationship between eagle productivity and land cover. To date, ten birds have been fitted with transmitters and tracked.

Three sets of prey transects have been walked in different habitats. The numbers of encounters with potential prey or carrion have been few, but the relative value of these habitats, in terms of prey, is becoming clearer.

Information on the reproductive success of golden eagles has been collected and is being analysed in relation to the Macaulay Land Use Research Institute Land Cover Map for Scotland using a geographical information system.

The project has two more years to run.

MICHAEL MCGRADY AND JUSTIN GRANT
Royal Society for the Protection of Birds

COMMUNICATIONS

Both research stations continue to attract several hundred visitors each year. Student groups are welcomed from forestry, woodland management and environmental science courses at universities and agricultural colleges. Visitors from professional and vocational interest groups included members of the National Small Woods' Association, the Royal Institution, the Timber Growers' Association and the Edinburgh Branch of Rotary International. A two-day training course was held at Alice Holt for MAFF Plant Health and Seeds Inspectors. Staff at the Northern Research Station organised and hosted a number of national and international conferences and seminars. Overseas visitors included senior government forestry officials, foresters and forest scientists from Albania, China, Finland, France, India, Indonesia, Malawi, New Zealand, Poland, Romania, Slovakia, South Africa and Zimbabwe.

JOHN PARKER

RESEARCH ADVISORY SERVICE

Following the introduction of charging for research advice, an Oracle database for handling advisory information was designed and set up for access over the Alice Holt local area network. Since April 1993, information from all enquiries has been entered by individual branches. The objectives of the database are (a) to provide summary data and statistics for the effective management of the Research Advisory Service on a Divisional basis; and (b) to provide a facility for central invoicing.

During the year over 3000 enquiries were completed by research advisers. Of these, 21% were from The Forestry Authority, 13% from Forest Enterprise, 19% from private individuals, 10% from private forestry, and the remainder were split between categories such as local authorities and education.

MARTIN JUKES

LIBRARY AND INFORMATION SERVICE

The Library at Alice Holt Lodge has seen continued demand for its services by Research Division staff, the rest of the Forestry Commission and outside users. The weekly current awareness listing on electronic mail generated over 4600 requests from the Department of Forestry, The Forestry Authority and Forest Enterprise. A new information technology area has been created in one of the reading rooms. It provides a convenient and central area for access to the CD-ROMs and to the Library catalogues on adjacent terminals, which are now linked to the Alice Holt local area network. Personal visits to the Library were received from about 180 individuals and groups who made use of the range of our stock and the databases available on CD-ROM.

The Library at the Northern Research Station has seen improvements to its reference collection in the past year and further additions are planned. During the year, Mrs Margaret Plews took over the day-to-day responsibility for the NRS Library from Mrs Cathie McIlwhan.

CATHERINE OLDHAM

PHOTOGRAPHY

The Photographic Officer at the Northern Research Station has continued to provide a much needed service for the Station and plans are in hand to increase the computer graphics output facility at that location.

The Graphics Officer at Alice Holt successfully completed a computer training course, as a consequence of which the output of computer-generated graphics for presentations and publications has increased. A computer-aided design facility is now available.

The Forestry Authority exhibit at the Royal Show was designed and produced jointly by Photography Section and Artisan of Bristol, and was awarded the Silver Medal.

The photographic library has expanded its service to external publishers. Security mounts have been introduced to protect transparencies and ensure no improper use.

GEORGE GATE

PUBLICATIONS

The Section began the year with a new administrative support team; the staff settled in quickly and have made significant contributions to the rolling programme of system reviews. They have maintained a high standard of service to our customers throughout the year, particularly in the prompt fulfilment of orders.

Fewer than usual new priced publications were issued during the year, which meant that less income was generated than had been expected. Output in the unpriced Research Information Note series returned to normal with 17 new titles issued.

The year saw the launch of a new series, Technical Papers, which superseded the Occasional Paper series. This series will cover a broad spectrum of research findings of interest to other scientists, as well as to technical and professional staff in the forestry industry.

First steps have been taken to improve our publications promotion and marketing strategy, with the setting up of a review group.

The following titles were published during the year ending 31 March 1994:

Report

Report on forest research 1992 (£16).

Bulletins

109 The value of birch in upland forests for nature conservation (£5.95).

112 Creating new native woodlands (£8.95).

Guidelines

Forests & water (3rd edtn) (£5.75).

Field Books

9 Classification and presentation of softwood sawlogs (2nd edtn) (£2).

13 Invertebrate animals as indicators of acidity in upland streams (£11.95).

Technical Papers

1 Black grouse and forestry: habitat requirements and management (£3).

2 Deterioration of fine tree roots during cold storage in two contrasting winters (£3).

3 Forest nursery herbicides (£3).

4 The carbon content of trees (£3).

Miscellaneous

Research Advisory Service leaflet (free).

Research Information Notes

230 Revised windiness scores for the windthrow hazard classification: the revised scoring method.

231 The effects of revised windiness scores on the calculations and distribution of windthrow hazard classes.

232 Grey squirrel control using modified hoppers.

233 Rhododendron control by imazapyr.

234 Root growth in Sitka spruce grown in filtered and unfiltered air.

235 Red squirrel supplementary food hopper.

236 Forest condition 1992.

237 Using household surveys to estimate forest visitor numbers.

238 A long-term carbon dioxide enrichment experiment examining the interaction with nutrition in Sitka spruce.

239 Black poplar: the most endangered native timber tree in Britain.

240 The marketing of British grown hardwood as dimension stock.

241 The conservation management of deadwood in forests.

242 Setting up tree planting and woodland demonstrations.

243 The quality of Sitka spruce at the time of planting.

245 Sitka spruce genetic gain trials.

246 Approved herbicides for use in forestry (1994).

247 Fertilization regimes to produce different size classes of cell-grown birch.

KATHY DAVIES

STATISTICS AND COMPUTING (NORTH)

The local area network is now linked to Alice Holt Research Station, allowing e-mail and file transfer between Northern Research Station (NRS) and Alice Holt. Various improvements have been made to network security. Links are also established with the Forestry Commission wide area network and work continues on ironing out teething problems.

Programs have been written to simplify database interrogation. The main databases have been reorganised to make it easier to handle problems on one database without affecting others. A Plan of Operations database has been produced for outstations. To support these activities, training courses in the Oracle database management system have been mounted in-house for NRS and outstation staff, and these will be repeated and extended as necessary.

The tatter flag work for Silviculture (North) Branch continued; all stages of the handling and processing of tatter flag data are now computerised.

WAYNE BLACKBURN

Innovative methods to address non-standard problems continue to be developed. Areas of tree stumps colonised by *Heterobasidion annosum* do not follow any well-known distribution and there are typically many zero values. Several methods for analysing such data have been tried. A relatively simple method is to treat zero and non-zero values separately. Ideally, both zero and non-zero values should be included in the same analysis, with a plausible model linking the two. This work underpins Pathology Section projects on *Prevention of Fomes root and butt rot on first rotation sites* and *Chemical control of Fomes root and butt rot.*

A Genstat program was written to obtain the outcrossing rate in a Sitka spruce seed orchard by maximum likelihood estimation, given the pollen and maternal allele contributions to the embryo at several loci in a random sample of seed. (See also the report from Tree Improvement Branch.)

Multiple regression was used to relate the average daily tatter rate of cotton flags to the aspect, elevation and topographic profile of 1100 sites.

Work has begun on dynamic modelling of tree stability; this will continue in the medium term and will contribute to the output of the Stability Project Team.

Further courses have taken place during the year on experimental design, elementary mathematical techniques, and the use of statistical packages. This is an on-going activity, designed to reinforce the trend towards researchers doing their own basic statistical analysis.

IAN WHITE AND IAN MARTIN

STATISTICS AND COMPUTING (SOUTH)

The work of the Branch is divided into four main areas: statistical consultancy, process modelling, computing and programming.

With the exception of modelling, the branch activities relate mainly to service work, but opportunities are also taken to earn income through approved contracts. Some branches which employ tour-of-duty forest officers still look for a full data analysis service. Others, staffed mainly by scientists, carry out their own computing and require help only with design and interpretation problems. In the statistics area, the final analysis of the open top chamber experiments was completed this year and over 130 other experiments were analysed for Silviculture and Environmental Research Branches.

Alice Holt and Northern Research Station (NRS) computer systems were linked via the Forestry Commission (FC) wide area network during the year and access to the Joint Academic Network (JANET) is available via the NRS connection to Edinburgh University. A modem link to the local network has been added, new menus implemented and network cards fitted to PCs. New computing strategy and security documents were produced.

An archiving system has been created for use on the UNIX system, and project costing software written to record staff time and calculate costs. Following an audit of the FC, a number of changes to production forecasting programs were required. The program has been modified in time for the 1995 FC forecast.

A contract to create a new nursery sampling system and data capturing facility was completed and has been used in this year's Forest Enterprise nursery stock take. Modelling work on carbon allocation within the tree and stem respiration has continued in collaboration with Edinburgh University and partners from elsewhere in Europe.

DAVID MOBBS

DATA COLLECTION

A revolution in the approach to data collection has been made with the advent of hand held MS-DOS[1] micro-computers. Object-oriented programming techniques have been used to create a versatile data collection program used for a variety of data collection tasks. The object is a form, and the user is able to move freely around the form, filling in data and editing it as required, as if it were a paper form.

As each field is accessed, its name appears at the top of the screen. Any warning messages relating to the field are shown at the bottom of the screen. The program displays a row identifier on the left of the screen so that users always know where they are on the form.

The data are validated as they are entered. Entry of individual fields can be restricted to certain characters and ranges, while consistency checks can be made against other data entered. The program has a facility for checking the current data against previously recorded values. The user is queried if an entry is significantly different from the previous data or if an exceptional assessment has been made.

The program uses picklists for filling fields such as the surveyor's name, thus ensuring consistent entry of information. Picklists are also used as menus.

An on-line context-sensitive help facility is built into the program. At any stage during data collection, the user can call up this help with a single keystroke. Information will be displayed about the current field. The help contains an explanation of the information required and a definition of the codes allowed as input for the field. Further help is available on the use of the program: moving about the screen; field editing capabilities, and so on.

The program has been written using Turbo Pascal[2] (version 6.0) and the Object Professional[3]

[1] MS–DOS is a registered trademark of Microsoft Corporation.

[2] Turbo Pascal is a registered trademark or Borland Interantional Inc.

[3] Object Professional is a trademark of TurboPower Software.

library routines. It was developed on a desktop PC and is generally used on hand held MS-DOS units such as the Micro Palm[4] PC5000 and PC3000 units and the Husky[5] FS/2.

The program is used in several projects including the annual Forest Condition Monitoring Survey (Pathology (North)) and the computerisation of the production of timber load despatch notes (Forest Enterprise, Wales).

JOHN HALL AND LESLEY HALSALL

SENSITIVITY ANALYSIS OF AN INDIVIDUAL TREE MODEL

As part of a project with other research groups across Europe, the Forestry Commission model has been used to simulate a stand of Scots pine in Finland, using Finnish site conditions and weather data. We varied a number of inputs to the model including crown angle (degrees) the light extinction coefficient (m^2 ground area m^{-2} leaf area) the light-saturated photosynthetic rate (g CO_2 m^{-2} leaf area h^{-1}) and the efficiency of light-use (g CO_2 J^{-1}).

There were 16 trees in the simulated stand and they were identical at planting except for the parameter being varied. When this was crown angle, for example, the 16 trees were allocated angles randomly from a normal distribution with a coefficient of variation (CV) of 10% (standard deviation = 10% of the mean). The trees grew from 0 to 70 years and the stem mass at age 70 had a CV of 5.2% (Table 11). In other words, a 10% variation in crown angle of individual trees produced a 5.2% variation in stem mass at 70 years.

When the mean crown angle of the whole stand was varied with a CV of 10%, the mean stem mass of the stands varied by only 1%. In other words, a wide crown angle makes a tree a good competitor, but a clonal stand of wide-angled trees would do no better than a narrow angled stand at the same spacing, because they intercept similar amounts of light per hectare after canopy closure.

Table 11 shows that the light extinction coefficient and efficiency of light use had a large effect on final stem mass, while light-saturated rate of photosynthesis had little effect. Under Finnish conditions, needles were light saturated for very little of the year but the light saturated photosynthesis rate may be more important further south.

Table 11. Coefficients of variation (CV) in stem mass at 70 years when input parameters were varied in the Forestry Commission growth model. Only one parameter was varied at a time and variation in the input parameter had a CV of 10% between trees or 10% between stands.

Parameter	*Between tree variation (CV[1])*	*Between stand variation (CV)*
Crown angle	5.2	1.0
Light extinction coefficient	18.4	13.6
Light saturated gross photosynthesis rate	3.9	2.6
Light-use efficiency	41.3	26.5

Note:
[1] CV = (s.d. × 100)/mean

The effect of each parameter was greater on individual trees than on the whole stand (Table 11) because competition between neighbouring trees amplified the parameter's effect. Such amplification complicates the way we should scale up from measurements on single trees to the whole stand, so the study has implications for interpreting experiments as well as for tree improvement research.

ANTHONY LUDLOW AND TIMOTHY RANDLE

THE SEED GERMINATION ANALYSIS PROGRAM

The seed germination program automates the basic analysis required for standard seed germination data sets.

Analysis of variance (ANOVA) is performed to examine any difference between treatments for germination rate, maximum germination reached and for seed viability. There is an option to graph the germination profiles over time when the number of treatments is within reasonable limits. In addition to the ANOVA output, summary files are produced to provide basic summary information and to format data for graphing with a spreadsheet. Various other features are built in, including error checking procedures and identification.

To use the program, a Fortran program is run which prompts the user for the name of the data file, and then creates basic file management information, before automatically calling the main Genstat program.

JONATHAN TAYLOR

[4] Micro Palm is a registered trademark of Micro Palm Computers Inc.

[5] Husky is a trademark of Husky Computers Limited.

PUBLICATIONS BY RESEARCH DIVISION STAFF

APPENDIX 1

ANDERSON, A.R., [ADAMSON, J.K.,] PYATT, D.G. and HORNUNG, M. (1993). pH, aluminium and calcium concentrations of streams draining acidic soils on calcareous till at Kershope, Cumbria. *Journal of Hydrology*, **149(1–4)**, 27–37.

[AUSTARA, O.] and CARTER, C.I. (1993). On the distribution and biology of *Aphrastasia pectinatae* (Cholodkovsky 1888) in Norway. *In:* P. KINDLMANN and A.F.G. DIXON, eds. *Critical issues in aphid biology: proceedings of the 4th International symposium on aphids*. pp. 21–24.

BALDWIN, E. (1993). Leader breakage in upland spruce plantations. *Scottish Forestry*, **47(2)**, 25–29.

[BAMBRIDGE, L.,] HARMER, R. [and MACLEOD, R.] (1993). *Root growth in Sitka spruce grown in filtered and unfiltered air.* Research Information Note 234. Forestry Commission, Edinburgh.

[BATES, M.R., BUCK, K.W. and] BRASIER, C.M. (1993). Molecular relationships between *Ophiostoma ulmi* and the NAN and EAN races of *O. novo-ulmi* determined by restriction fragment length polymorphisms of nuclear DNA. *Mycological Research*, **97(4)**, 449–455.

[BATES, M.R., BUCK, K.W. and] BRASIER, C.M. (1993). Molecular relationships of the mitochondrial DNA of *Ophiostoma ulmi* and the NAN and EAN races of *O. novo-ulmi* determined by restriction fragment length polymorphisms. *Mycological Research*, **97(9)**, 1093–1100.

[BODMER, R.E., FANG, T.G., MOYA, I.L. and] GILL, R.M.A. (1994). Managing wildlife to conserve Amazonian forests: population biology and economic considerations of game hunting. *Biological Conservation*, **67**, 29–35.

[BORLAND, A.M., GRIFFITHS, H.,] BROADMEADOW, M.S.J., [FORDHAM, M.C. and MAXWELL, C.] (1993). Short-term changes in carbon-isotope discrimination in the C3-CAM intermediate *Clusia minor* L. growing in Trinidad. *Oecologia*, **95(3)**, 444–453.

BRASIER, C.M. (1993). *Ceratocystis* or *Ophiostoma?* The status of Ceratocystis and Ophiostoma species on Quercus. *In:* N. LUISI, P.PERARIO, and A. VANNINIA, eds. *Recent advances in studies on oak decline.* pp. 241–245.

BRASIER, C.M. (1993). *Phytophthora cinnamomi* as a contributory factor in European oak declines. *In:* N. LUISI, P. LERARIO and A. VANNINI, eds. *Recent advances in studies on oak decline.* pp. 49–57.

BRASIER, C.M. (1993). The genetic system as a fungal taxonomic tool: gene flow, molecular variation and sibling species in the *Ophiostoma piceae-Ophiostoma ulmi* complex and its taxonomic and ecological significance. *In:* M.J. WINGFIELD, K.A. SEIFERT and J.F. WEBBER, eds. *Ceratocystis and Ophiostoma: taxonomy, ecology and pathogenicity.* (American Phytopathological Society). pp. 77–92.

BRASIER, C.M. and KIRK, S.A. (1993). Sibling species within *Ophiostoma piceae. Mycological Research*, **97(7)**, 811–816.

BRASIER, C.M. [and STEPHENS, T.M.] (1993). Temperature-growth responses distinguish the OPC and OPH sibling species within *Ophiostoma piceae. Mycological Research*, **97(12)**, 1416–1418.

BRASIER, C.M., [BATES, M.R., CHARTER, N.W. and BUCK, K.W.] (1993). DNA polymorphism, perithecial size, and molecular aspects of d-factors in *Ophiostoma ulmi* and *O. novo-ulmi. In*: M.B. STICKLEN and J.-SHERALD, eds. *Dutch elm disease research: cellular and molecular approaches.* pp. 308–321.

BRASIER, C.M., [HAMM, P.B. and HANSEN, E.M.] (1993). Cultural characters, protein patterns and unusual mating behaviour of *Phytophthora gonapodyides* isolates from Britain and North America. *Mycological Research*, **97(11)**, 1287–1298.

BRASIER, C.M., [ROBREDO, F. and FERRAZ, J.F.P.] (1993). Evidence for *Phytophthora cinnamomi* involvement in Iberian oak decline. *Plant Pathology*, **42**, 140–145.

[BRAZIER, J.D. and] MOBBS, I.D. (1993). The influence of planting distance on structural wood yields of unthinned Sitka spruce. *Forestry*, **66(4)**, 333–352.

BROADMEADOW, M.S.J. [and GRIFFITHS, H.] (1993). Carbon isotope discrimination and the coupling of CO_2 fluxes within canopies. *In*: J.R. EHLERINGER, G.D. FARQUHAR and A.E. HALL, eds. *Stable isotopes and plant carbon/water relations.*

BROADMEADOW, M.S.J. [and GRIFFITHS, H.] (1993). Genotypic variation in *Plantago major* in response to elevated CO_2. *Journal of Experimental Botany*, **44 (Supplement)**, 15.

[BROEKHUIZEN, N.,] EVANS, H.F. [and HASSELL, M.P.] (1993). Site characteristics and the population dynamics of the pine looper moth. *Journal of Animal Ecology*, **62(3)**, 511–518.

[CANNELL, M.G.R., DEWAR, R.C. and] PYATT, D.G. (1993). Conifer plantations on drained peatlands in Britain: a net gain or loss of carbon? *Forestry*, **66(4)**, 353–369.

CARTER, C.I. (1993). A rare pine aphid established in Cornwall. *Zoological Cornwall and the Isles of Scilly*, **2**, 4.

CARTER, C.I. (1993). Aspen and its insect fauna (brief item). *Native Woodlands Discussion Group Newsletter*, **18**, 47.

CARTER, C.I. [and DANIELSSON, R.] (1993). New and additional records of gall-forming aphids of the family *Pemphigidae* in Britain. *The Entomologist*, **112(2)**, 99–104.

COUTTS, M.P. and NICOLL, B.C. (1993). Orientation of the lateral roots of trees. 2: Hydrotropic and gravitropic responses of lateral roots of Sitka spruce grown in air at different humidities. *New Phytologist*, **124**, 277–281.

[DAVIS, H. and] MOFFAT, A.J. (1992). Trees and woodland on restored soils. *In: Sixth ADAS national land restoration seminar.* Wolverhampton, West Midlands, 12 October 1992. pp.15–22.

[DIXON, A.F.G., WELLINGS, P.W.,] CARTER, C.I. and NICHOLS, J.F.A. (1993). The role of food quality and competition in shaping the seasonal cycle in the reproductive activity of the sycamore aphid. *Oecologia*, **95(1)**, 89–92.

DOBSON, M.C. and MOFFAT, A.J. (1993). Should trees be planted on capped landfills? *Waste Planning*, **7**, 30–32.

DOBSON, M.C. and MOFFAT, A.J. (1993). Trees and desiccation of clays (letter). *Waste Planning*, **8**, 32.

DOBSON, M.C. and MOFFAT, A.J. (1994). Landfill and trees: are the two compatible? *Environmental Manager's Journal*, **2(2)**, 31–34.

DURRANT, D.W.H., BARTON C.V.M., LEE, H.S.J. and JARVIS, P.G. (1994). Long-term CO_2 enrichment experiment examining the interaction with nutrition in Sitka spruce (*Picea sitchensis* Bong. Carr.). *In: Biological indicators of climate change.* Royal Society of Edinburgh, Edinburgh.

DURRANT, D.W.H., LEE. H.S.J., BARTON, C.V.M. and JARVIS, P.G. (1993). Long term CO_2 enrichment experiment examining the intraction with nutrition in Sitka spruce (*Picea sitchensis* Bong. Carr.). *In: Abstracts book for ecophysiology and genetics of trees and forests in a changing environment.* IUFRO conference, Viterbo, Italy, May 1993. p. 38.

DURRANT, D.W.H., LEE, H.S.J., BARTON, C.V.M. and JARVIS, P.G. (1993). *A long-term carbon dioxide enrichment experiment examining the interaction with nutrition in Sitka spruce.* Research Information Note 238. Forestry Commission, Edinburgh.

EDWARDS, C., MORGAN, J.L. and WILLOUGHBY, I. (1994). *Approved herbicides for use in forestry.* Research Information Note 246. Forestry Commission, Edinburgh.

EDWARDS, C., TRACY, D. and MORGAN, J.L. (1993). *Rhododendron control by imazapyr.* Research Information Note 233. Forestry Commission, Edinburgh.

EVANS, J. (1993). *Long-term experimentation in forestry and site change.* Invited paper at Rothamsted 150th Anniversary Conference, July 1993.

EVANS, J. [and HIBBERD, B.G.] (1993). Shell–WWF tree plantation review. Study 9: Operations.

EVANS, J. [and WOOD, P.J.] (1993). *The place of plantations in sustainable tropical forestry.* Invited paper at the 14th Commonwealth Forestry Conference, Kuala Lumpur, Malaysia, September 1993.

EVANS, J. (compiler) (1992). *Ten years of forestry research: an account of the work of the Forestry Research Co-ordination Committee, 1982 to 1992.* Forestry Commission, Edinburgh.

EVANS, J., [MORRIS, A.R. and MASSON, P.] (1993). *Sustainability of pulpwood plantations in the Usutu forest, Swaziland.* Invited case study, 14th Commonwealth Forestry Conference, Kuala Lumpur, Malaysia, September 1993.

[FENNING, T.M., GARTLAND, K.M.A. and] BRASIER, C.M. (1993). Micropropagation and regeneration of English elm *Ulmus procera* Salisbury. *Journal of Experimental Botany*, **44(264)**, 1211–1217.

FERRIS-KAAN, R., LONSDALE, D. and WINTER, T.G. (1993). *The conservation management of deadwood in forests.* Research Information Note 241. Forestry Commission, Edinburgh.

FORREST, G.I. (1994). Biochemical markers in tree improvement programmes. *Forestry Abstracts*, **55(2)**, 123–153.

GARDINER, B.A. (1994). Wind and wind forces in a plantation spruce forest. *Boundary-layer Meteorology*, **67**, 161–186.

GARDINER, B.A. (1994). Windthrow special: mechanics and management. *Timber Grower*, **130**, 22.

GIBBS, J.N. (1993). Impacts of the terrestrial environment: forest and amenity trees. *In:* M.G.R. CANNELL and C.E.R. PITCAIRN, eds. *Impacts of the mild winters and hot summers in the United Kingdom in 1988–1990.* pp. 96–98.

GIBBS, J.N. (1993). Saving salt and the earth: research has proven that over-use of de-icing salt destroys trees, but have highway authorities taken this on board? *Surveyor*, **7, October 1993**, 14–15.

GIBBS, J.N. (1993). The biology of Ophiostomatoid fungi causing sapstain in trees and freshly cut logs. *In:* M.J. WINGFIELD, K.A. SEIFERT and J.F. WEBBER, eds. *Ceratocystis and Ophiostoma: taxonomy, ecology, and pathogenicity.* pp. 153–160.

GIBBS, J.N. (1994). *De-icing salt damage to trees: the current position.* Arboriculture Research Note 119–94-PATH. Arboricultural Advisory and Information Service, Farnham, Surrey.

GIBBS, J.N. [and CANNELL, M.G.R.] (1993). Impacts on the terrestrial environment: impacts on forestry. *In:* M.G.R. CANNELL and C.E.R. PITCAIRN, eds. *Impacts of the mild winters and hot summers in the United Kingdom in 1988–1990.* pp. 33–35.

GILL, R.M.A. (1990). The Global Environment Monitoring System: monitoring the status of European and North American cervids. UNEP, Nairobi, Kenya. United Nations Environment Programme and University of Cambridge, Department of Zoology, Large Animal Research Group. (GEMS Information Series 8).

[GUILLAUMIN, J-J., MOHAMMED, C., ANSELMI, N., COURTECUISSE, R.,] GREGORY, S.C., [HOLDENRIEDER, O., INTINI, M., LUNG, B., MARXMULLER, H., MORRISON, D., RISHBETH, J., TERMORSHUIZEN, A.J., TIRRO, A. and VAN DAM, B.] (1993). Geographical distribution and ecology of the *Armillaria* species in western Europe. *European Journal of Forest Pathology*, **23(6–7)**, 321–341.

[GURNELL, J. and] PEPPER, H.W. (1993). A critical look at conserving the British red squirrel *Sciurus vulgaris*. *Mammal Review*, **23(3–4)**, 127–137.

HARMER, R. (1993). *Branching in young clonal oak.* Annales des Sciences Forestieres, Genetics of oaks: proceedings of the first meeting of the IUFRO working party S2.02–22, Arboretum National des Barres, France, 2–6 September 1991. **50**, Suppl.1, 399s–402s.

HARMER, R. and NIXON, C.J. (1993). The natural regeneration of native woodlands. *Native Woodlands Discussion Group Newsletter*, **18**, 32–34.

HODGE, S.J. (1993). *Setting up tree planting and woodland demonstrations.* Research Information Note 242. Forestry Commission, Edinburgh.

HODGE, S.J. (1993). The effect of stem nutrient injection and compressed air soil injection on the performance of established amenity trees. *Arboricultural Journal*, **17(3)**, 287–300.

HODGE, S.J. (1993). Trees to fuel the urban forest. *Horticulture Week*, **213(16)**, 23–24, 26–27.

HODGE, S.J. (1993). Treeshelters: the first years and where we are today. *Association of Professional Foresters Newsletter*, **June 1993**, 55–59.

HODGE, S.J. (1993). *Trials of organic backfill amendments on trunk road sites.*

Arboriculture Research Note 114–93-ARB. Arboricultural Advisory and Information Service, Farnham, Surrey.

HODGE, S.J. (1993). *Using steel rods to assess aeration in urban soils.* Arboriculture Research Note 115–93-ARB. Arboricultural Advisory and Information Service, Farnham, Surrey.

HODGE, S.J. and BOSWELL, R.C. (1993). A study of the relationship between site conditions and urban tree growth. *Journal of Arboriculture*, **19(6)**, 358–367.

HODGE, S.J. and KNOTT, K. (1993). A practical guide to the use of steel rods for the assessment of aeration in urban soils. *Journal of Arboriculture*, **19(5)**, 289–294.

HODGE, S.J., BOSWELL, R.C. and KNOTT, K. (1993). Development of the steel rod technique for the assessment of aeration in urban soils. *Journal of Arboriculture*, **19(5)**, 281–288.

HOLLINGSWORTH, M.K. and MASON, W.L. (1993). Vegetative propagation of native aspen: an update. *Native Woodlands Discussion Group Newsletter*, **18**, 34–36.

[INGLEBY, K.,] WALKER, C. [and MASON, P.A.] (1994). *Acaulospora excavata* sp. nov: an endomycorrhizal fungus from Cote d'Ivoire. *Mycotaxon*, **50**, 99–105.

JONES, S.K., [BERGSTEN, U. and] GOSLING, P.G. (1993). A comparison of 5°C and 15°C as dormancy breakage treatments for Sitka spruce seeds (*Picea sitchensis*). *In:* D.G.W. EDWARDS, ed. *Dormancy and barriers to germination:* Proceedings of the International Symposium IUFRO Project Group P2.04–00 (Seed Problems), Victoria, British Columbia, Canada, 23–26 April 1991. pp. 51–55.

KERR, G. (1993). Establishment and provenance of walnut in Britain. *Forestry*, **66(4)**, 381–393.

KERR, G. (1993). New visions for broadleaves. *Timber Grower*, **128**, 27.

KERR, G. (1993). Robust woodland establishment. *Quarterly Journal of Forestry*, **87(4)**, 302–304.

KERR, G. and EVANS, H.F. (1993). Beech in treeshelters. *Quarterly Journal of Forestry*, **87(2)**, 107–115.

LEE, S.J. (1994). *Sitka spruce genetic gain trials.* Research Information Note 245. Forestry Commission, Edinburgh.

LONSDALE, D. (1993). *A comparison of 'target' pruning, versus flush cuts and stub pruning.* Arboriculture Research Note 116–93-PATH. Arboricultural Advisory and Information Service, Farnham, Surrey.

LONSDALE, D. (1993). *Choosing the time of year to prune trees.* Arboriculture Research Note 117–93-PATH. Arboricultural Advisory and Arboriculture Information Service, Farnham, Surrey.

LUCAS, M., DURRANT, D.W.H., LEE. H.S.J. and JARVIS, P.G. (1993). Long-term CO_2 enrichment experiment examining the interaction with nutrition in Sitka spruce (*Picea sitchensis* Bong. Carr.). *Journal of Experimental Botany*, **44**, (Supplement), 17.

MASON, W.L. (1993). The challenge to silviculturists: rethinking options in northern Britain. *Timber Grower*, **128**, 24–25.

MASON, W.L. (1993). The ecology, genetics and silviculture of aspen in Scotland. *Native Woodlands Discussion Group Newsletter*, **18**, 45–46.

MATTHEWS, R.W. (1992). Role of carbon budgeting in assessing the environmental costs and benefits of forestry schemes. *In:* G.E. RICHARDS, ed. *Wood: energy and the environment.* Proceedings of a workshop held in Harrogate, England, 9–10 September 1992. pp. 21–27.

MATTHEWS, R.W. [and ROBINSON, R.L.] (1993). Biomass from energy: progress in computer modelling of energy and carbon budgets for wood fuel production from short rotation coppice. *In: Short rotation coppice: growing for profit.* National Agricultural Conference, 24 March 1993. Royal Agricultural Society of England and The Wood Energy Development Group.

MAYLE, B.A. (1992). Fallow under scrutiny: the third largest species of deer in Britain is now the subject of a major research project which, it is hoped, will lead to guidelines for its management. *Timber Grower*, **124**, 20.

MAYLE, B.A. (1993). Bat activity in a mixed lowland woodland in relationship to insect prey availability. *In:* G. ROBERTS, ed. *The Isle of Wight bat detector workshop report.* Bat Conservation Trust. pp. 29–30.

McKAY, H.M. (1993). *Deterioration of fine tree roots during cold storage in two contrasting winters.* Technical Paper 2. Forestry Commission, Edinburgh.

McKAY, H.M. (1994). *The quality of Sitka spruce at the time of planting.* Research

Information Note 243. Forestry Commission, Edinburgh.

McKAY, H.M., GARDINER, B.A., MASON, W.L., NELSON, D.G. and HOLLINGSWORTH, M.K. (1993). The gravitational forces generated by dropping plants and the response of Sitka spruce seedlings to dropping. *Canadian Journal of Forest Research*, **23**, 2443–2451.

MOFFAT, A.J. (1993). Silvan sludge: more sewage sludge will be used on the land as sea disposal is phased out; its application as a forest fertiliser. *Landscape Design*, **219**, 24–27.

MOFFAT, A.J. (1994). *Sewage sludge as a fertilizer in amenity and reclamation plantings.* Arboriculture Research Note 76–94-SSS. Arboricultural Advisory and Information Service, Farnham, Surrey.

MOFFAT, A.J. [and SHAW, P.J.A.] (1993). Establishment of trees on mixtures of pulverized fuel ash and gypsum. 1: Tree performance. *Land Degradation and Rehabilitation*, **4(2)**, 87–97.

MOFFAT, A.J., [ARMSTRONG, A.T. and COLLYER, E.L.] (1994). Site preparation for tree establishment on lowland clay soils. *Quarterly Journal of Forestry*, **88(1)**, 35–41.

MORGAN, J.L. and MASON, W.L. (1993). Vegetative propagation of conifers in Great Britain. *In:* C.M. KOOISTRA, ed. *Proceedings of the 12th Annual Forestry Nursery Association of British Columbia meeting.* Penticton, British Columbia, Canada, 28 September–1 October 1992. pp.-23–28.

MORGAN, J.L. (1994). *Fertilization regimes to produce different size classes of cell-grown birch.* Research Information Note 247. Forestry Commission, Edinburgh.

MORGAN, J.L. (1994). Forest nurseries herbicide update. *Forestry and British Timber*, **23(2)**, 35.

NISBET, T.R. (1993). *The effects of a pelletised limestone treatment on drainage water acidity within a forest catchment in mid-Wales.* Paper presented at the International symposium on forest hydrology, Canberra, Australia, 22–26 November 1993. *Journal of Hydrology*, **150(2–4)**, 521–539.

NISBET, T.R., [FOWLER, D. and SMITH, R.I.] (1993). The effect of conifer afforestation on stream water acidity within the Loch Dee catchment in SW Scotland. *In:* Foundation for Water Research, ed. *Proceedings of the Loch Dee symposium: acidification, forestry and fisheries management in upland Galloway.* Gatehouse of Fleet, Dumfries and Galloway, Scotland, 8–9 December 1992. pp. 123–136.

NIXON, C.J. (1994). Effectiveness of treeshelters in upland Britain. *Quarterly Journal of Forestry*, **88(1)**, 55–62.

NIXON, C.J. [and CAMERON, E.] (1994). A pilot study on the age structure and viability of the Mar Lodge pinewoods. *Scottish Forestry*, **48(1)**, 22–27.

PATTERSON, G.S. (1993). *The value of birch in upland forests for wildlife conservation.* Forestry Commission Bulletin 109. HMSO, London.

PATTERSON, G.S. [and MORRISON, B.R.S.] (1993). *Invertebrate animals as indicators of acidity in upland streams.* Forestry Commission Field Book 13. HMSO, London.

PEPPER, H.W. (1993). *Red squirrel supplementary food hopper.* Research Information Note 235. Forestry Commission, Edinburgh.

PEPPER, H.W. [and STOCKER, D.] (1993). *Grey squirrel control using modified hoppers.* Research Information Note 232. Forestry Commission, Edinburgh.

PETTY, S.J. and PEACE, A.J. (1993). Temporal and spatial fluctuations in field vole abundance in a predator/prey study. *In: Report on forest research 1992.* HMSO, London. pp. 40–42.

PRATT, J.E. (1993). Some experiments with borates and with urea to control stump infection by *H.annosum* in Britain. *In:* M. JOHANSSON and J. STENLID, eds. *Proceedings of the eighth international conference on root and butt rots.* Uppsala, Sweden and Finland, 1993. IUFRO S2.06–01. pp. 662–667.

PYATT, D.G. (1993). Multi-purpose forestry on peatland. *Biodiversity and Conservation*, **2(5)**, 548–555.

QUINE, C.P. (1994). Windthrow special: classified information. *Timber Grower*, **130**, 23 and 25.

QUINE, C.P. and WHITE, I.M.S. (1993). *Revised windiness scores for the windthrow hazard classification: the revised scoring method.* Research Information Note 230. Forestry Commission, Edinburgh.

QUINE, C.P. and WRIGHT, J.A. (1993). *The effects of revised windiness scores on the calculation and distribution of windthrow hazard classes.* Research Information Note 231. Forestry Commission, Edinburgh.

[RAHMAN, M.A., MILLAR, C.S. and] GIBBS, J.N. (1994). Shoot dieback of lodgepole pine in Scotland caused by *Ramichloridium pini. European Journal of Forest Pathology*, **24(1)**, 40–47.

RATCLIFFE, P.R. (1993). *Biodiversity in Britain's forests.* Forestry Commission, Edinburgh.

RATCLIFFE, P.R. and MAYLE, B.A. (1994). An objective approach to roe deer management. *Deer*, **9(3)**, 151–152.

RAY, D. (1993). *Forests and water guidelines* update. *Forestry and British Timber*, **22(11)**, 21–22, 24.

RAY, D. (1994). The *Forests and water guidelines* and riparian management. *In:* I. GLIMMERVEEN and A. RICHIE, eds. *Proceedings of river woodlands conference at Melrose.* Institute of Chartered Foresters and British Ecological Society. pp. 13–15.

REDFERN, D.B. (1993). Climatic injury as a problem of introduced species in northern Britain. *In:* R. JALKANEN, T. AALTO and M-L. LAHTI, eds. *Forest pathological research in northern forests with special reference to abiotic stress factors.* Finnish Forest Research Institute Paper 451. pp. 44–49.

REDFERN, D.B. (1993). The effect of wood moisture on infection of Sitka spruce stumps by basidiospores of *Heterobasidion annosum. European Journal of Forest Pathology*, **23(4)**, 218–235.

REDFERN, D.B. (1993). Monitoring in the United Kingdom. Proceedings from the meeting of the SNS ad hoc group on monitoring forest damage. Ås, Norway, 26–28 April 1993. *Aktuelt fra Skogforsk*, **2–93**, 18–19.

REDFERN, D.B., BOSWELL, R.C. and PROUDFOOT, J.C. (1993). *Forest condition 1992.* Research Information Note 236. Forestry Commission, Edinburgh.

RILEY, M. and NIXON, C.J. (1993). 50 year results from an oak spacing trial in south Scotland. *Scottish Forestry*, **47(3)**, 79–82.

[RODWELL, J.S. and] PATTERSON, G.S. (1994). *Creating new native woodlands.* Forestry Commission Bulletin 112. HMSO, London.

[SEIFERT, K.A.,] WEBBER, J.F. [and WINGFIELD, M.J.] (1993). Methods for studying species of *Ophiostoma* and *Ceratocystis. In:* M.J.WINGFIELD, K.A. SEIFERT and J.F. WEBBER, eds. *Ceratocystis and Ophiostoma: taxonomy, ecology, and pathogenicity.* American Phytopathological Society, Minnesota. pp. 255–259.

[SHAW, P.J.A. and] MOFFAT, A.J. (1993). Establishment of trees on mixtures of pulverized fuel ash and gypsum. 2: Nutrition and trace elements. *Land Degradation and Rehabilitation*, **4(3)**, 123–129.

[SOUTH, D.B., MITCHELL, R.J., ZUTTER, B.R., BALNEAVES, J.M., BARBER, B.L.,] NELSON,D.G. [and ZWOLINSKI, J.B.] (1993). Integration of nursery practices and vegetation management: economic and biological potential for improving regeneration. *Canadian Journal of Forest Research*, **23(10)**, 2083–2092.

STROUTS, R.G. [and PATCH, D.] (1994). *Fireblight of ornamental trees and shrubs.* Arboriculture Research Note 118–94-PATH.Arboricultural Advisory and Information Service, Farnham, Surrey.

TABBUSH, P.M. (1993). *Coppiced trees as energy crops: final report.* ETSU B 1291. Department of Trade and Industry, Energy Technology Support Unit.

TABBUSH, P.M. (1993). Poplar husbandry. *In: Poplar: a profitable farm and woodland crop.* National Agricultural Conference, 25 March 1993. Royal Agricultural Society of England, The Wood Energy Development Group and The Poplar Working Group.

TABBUSH, P.M. (1993). Poplar husbandry. *Quarterly Journal of Forestry*, **87(3)**, 203–205.

[TAYLOR, M.A., DAVIES, H.V., SMITH, S.B., ABRUZZESE, A. and] GOSLING, P.G. (1993). Cold-induced changes in gene expression during dormancy breakage in seeds of Douglas fir (*Pseudotsuga menziesii*). *Journal of Plant Physiology*, **142(1)**, 120–123.

WALKER, C., [GIANINAZZI-PEARSON, V. and MARION-ESPINASSE, H.] (1993). *Scutellospora castanea*, a newly described arbuscular mycorrhizal fungus. *Cryptogamie Mycologie*, **14(4)**, 279–286.

[WANG, G.M., STRIBLEY, D.P., TINKER, P.B. and] WALKER, C. (1993). Effects of pH on arbuscular mycorrhiza. 1: Field observations on the long-term liming experiments at Rothamsted and Woburn. *New Phytologist*, **124**, 465–472.

WARD, E. and DEANS, J.D. (1993). A simple method for the routine extraction and quantification of non-structural sugars in tree tissues. *Forestry*, **66(2)**, 171–180.

WEBBER, J.F. (1993). D factors and their potential for controlling Dutch elm disease. *In*: M.B.STICKLEN and J.L. SHERALD, eds. *Dutch elm disease research: cellular and molecular approaches*. pp. 322–332.

WHITE, J.E.J. (1993). *Black poplar: the most endangered native timber tree in Britain*. Research Information Note 239. Forestry Commission, Edinburgh.

[WILCOX, W.F., SCOTT, P.H., HAMM, P.B., KENNEDY, D.M., DUNCAN, J.M.,] BRASIER, C.M. [and HANSEN, E.M.] (1993). Identity of a *Phytophthora* species attacking raspberry in Europe and North America. *Mycological Research*, **97(7)**, 818–831.

WILLIAMSON, D.R. (1993). Forestry Commission research on farm woodland establishment. *In*: D.A.GREIG, ed. *Farm and small scale forestry*. Proceedings of an ICF discussion meeting, University of Reading, 3–5 April 1992. Institute of Chartered Foresters. pp. 96–102.

WILLIAMSON, D.R., MASON, W.L., MORGAN, J.L. [and CLAY, D.V.] (1993). *Forest nursery herbicides*. Technical Paper 3. Forestry Commission, Edinburgh.

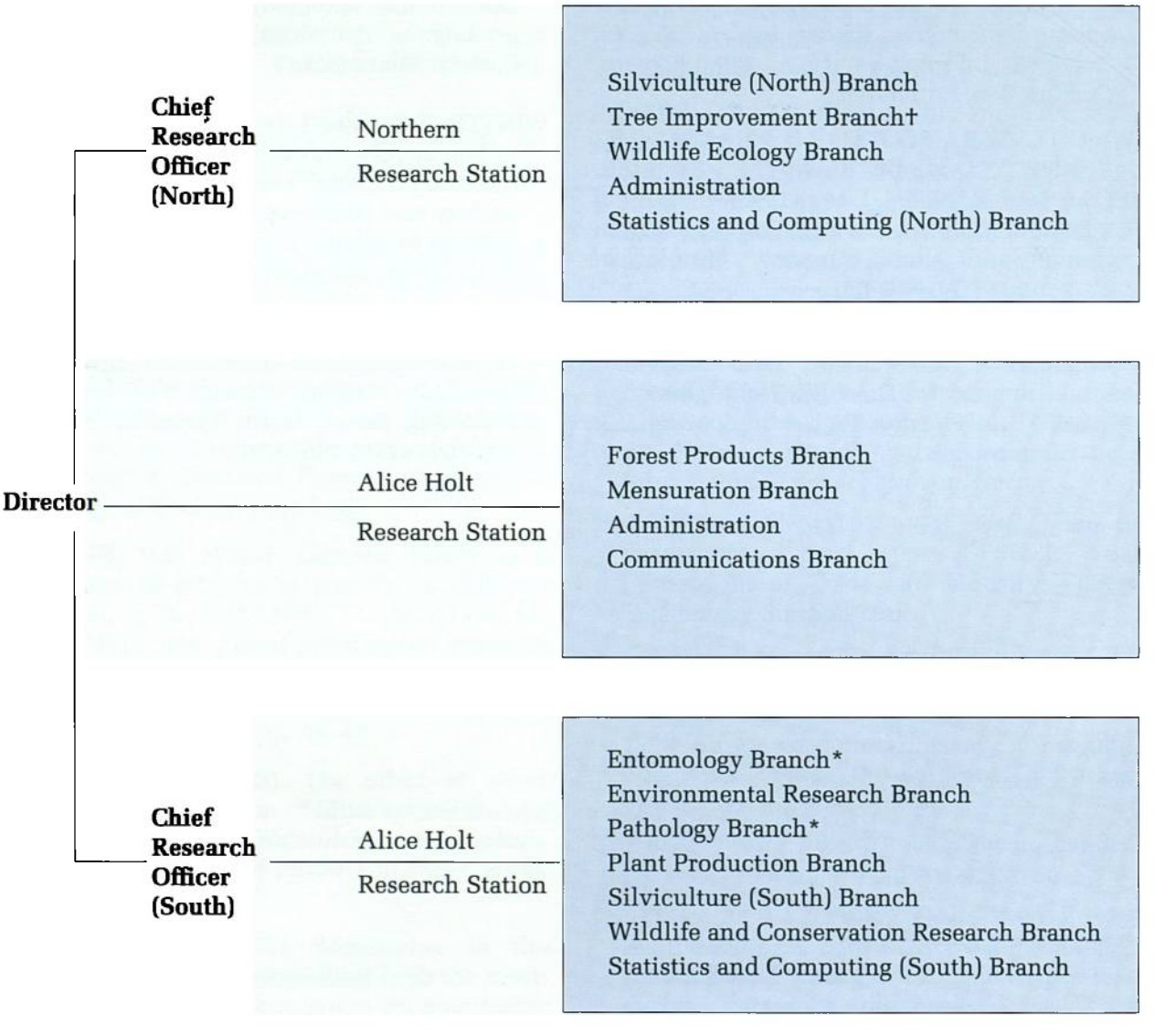
[WINGFIELD, M.J., SEIFERT, K.A. and] WEBBER, J.F. (eds) (1993). *Ceratocystis and Ophiostoma: taxonomy, ecology and pathogenicity*. American Phytopathological Society, Minnesota.

WINTER, T.G. (1993). Deadwood: is it a threat to commercial forestry? In: K.J. KIRBY and C.M.DRAKE, eds. *Dead wood matters: the ecology and conservation of saproxylic invertebrates in Britain*. English Nature Science 7. English Nature, Peterborough.

WRIGHT, J.A. and QUINE, C.P. (1993). The use of a Geographical Information System to investigate storm damage to trees at Wykeham Forest, North Yorkshire. *Scottish Forestry*, **47(4)**, 166–174.

RESEARCH DIVISION ORGANISATION

APPENDIX 2



† – with section at Alice Holt
* – with section at Northern Research Station

RESEARCH DIVISION BRANCHES AND THEIR PROJECT GROUPS[1]

APPENDIX 3

	Project leader(s) at 31 March 1994
Entomology	
Advisory and taxonomic	T.G. Winter
Beech bark disease	D. Wainhouse
Biodiversity	C.I. Carter
Dendroctonus micans	N.J. Fielding, D. Wainhouse
Elatobium abietinum	C.I. Carter
Hylastes and *Hylobius*	S.G. Heritage, R. Moore
Impact	N.A. Straw
Panolis flammea	S.G. Heritage
Stress	D. Wainhouse
Environmental Research	
Air pollution	M.S.J. Broadmeadow, D.W.H. Durrant, P.H. Freer-Smith A.J. Moffat
Chemical analysis	E. Ward
Effects of trees on sites	A.J. Moffat, T.R. Nisbet
Forestry and environmental change	M.S.J. Broadmeadow, P.H. Freer-Smith, D.A. Waddell
Hydrology: water quality	T.R. Nisbet
Instrumentation	T.R. Nisbet
Lowland production forestry	A.J. Moffat
Reclamation	A.J. Moffat
Forest Products	
Preservation	J.F. Webber
Quality and value enhancement	J.F. Webber
Wood and timber properties	J.F. Webber
Mensuration	
Advisory services	J.M. Methley
Measurement studies	J.M. Methley
Sample plots	J.M. Methley, J.C. Proudfoot
Site yield	R.W. Matthews, P.C. Jokiel
Yield modelling	R.W. Matthews
Mycorrhiza Research Unit	
Development of rooting patterns	C. Walker
Mycorrhizas	C. Walker
Pathology	
Damage monitoring and risk assessment	J.N. Gibbs, S.C. Gregory D.B. Redfern, R.G. Strouts
Disease diagnosis	D.B. Redfern, D.R. Rose, R.G. Strouts
Dutch elm disease	C.M. Brasier
Fomes root rot	B.J.W. Greig, J.E. Pratt, D.B. Redfern
Oak dieback	B.J.W. Greig
Poplar diseases	D. Lonsdale
Stem decays	D. Lonsdale
Plant Production	
Nursery research	R.L. Jinks
Seed research	P.G. Gosling, S.K. Jones
Seed testing	P.G. Gosling, Y.K. Samuel
Silviculture (North)	
Crofter forestry	A.L. Sharpe
Farm and community forestry	J. Simpson
Nurseries and establishment	J.L. Morgan
Nutrition and site yield	J.C. Dutch
Planting stock quality	H.M. McKay
Reclamation (north)	M. Riley
Root growth and form	B. Nicoll
Species and long-term experiments	W.L. Mason
Stability	B.A. Gardiner, C.P. Quine
Stand structure and natural regeneration	C.J. Nixon

[1] 'Advisory' is distinguished as a separate project group in certain branches, but is an activity in all of them.

	Project leader(s) at 31 March 1994
Stability	B.A. Gardiner, C.P. Quine
Stand structure and natural regeneration	C.J. Nixon
Silviculture (South)	
Ecology of native broadleaves	R. Harmer
Establishment and stand silviculture	G. Kerr
Farm woodlands, short rotation coppice & weed control	I. Willoughby
Poplars	P.M. Tabbush
Species and arboreta	J.E.J. White
Urban and community forestry	S.J. Hodge
Statistics and Computing (South)	
Forest growth process modelling	A.R. Ludlow
Tree Improvement	
Biochemical variation	G.I. Forrest, J. Cottrell
Biometrical studies	C.J.A. Samuel
Flowering	J.J. Philipson
Forest reproductive materials regulations	A.M. Fletcher, C.J.A. Samuel
Improvement and propagation of farm forestry broadleaves	C.M. Cahalan
Micropropagation	A. John
Origin	C.J.A. Samuel
Production: clone banks and orchards	W. Brown
Rejuvenation	A. John
Testing progeny and clones	S.J. Lee
Wildlife and Conservation Research	
Roe and fallow deer; bats	B.A. Mayle
The impact of mammals on forest vegetation	R.M.A. Gill
Squirrels, rabbits and tree protection	H.W. Pepper
Stand manipulation and vegetation management	R. Ferris-Kaan
Wildlife Ecology	
Birds	S.J. Petty
Carnivores	A.H. Chadwick
Clay soils	D. Ray
Deep peats	A.R. Anderson
Ecological site classification	D.G. Pyatt
Loamy gleys	A.R. Anderson
Red and sika deer	A.H. Chadwick
Streams and riparian vegetation	J.W. Humphrey
Vegetation management	J.W. Humphrey

NET EXPENDITURE OF RESEARCH DIVISION 1993/94

APPENDIX 4

£000

Branch (a)	*Expenditure by Branch direct (b)*	*Net value of in-house services less those provided (c)*	*Commissioned research (d)*	*Expenditure attributable to Branch*
Entomology	677	133	26	836
Environmental Research	509	160	75	744
Forest Products	87	17	246	350
Mensuration	360	47	-	407
Pathology	568	133	58	759
Physiology	269	57	9	335
Plant Production	116	56	-	172
Silviculture (North)	1978	-41	4	1941
Silviculture (South)	1222	93	28	1343
Tree Improvement	1106	214	10	1330
Wildlife and Conservation Research	475	91	88	654
Wildlife Ecology	181	90	–	271
Communications	556	–192	–	364
Stats & Computing (North)	292	–194	–	98
Stats & Computing (South)	607	–479	–	128
Engineering Services	185	–185	–	–
Total	**9188**	**–**	**544**	**9732**

Notes:

(a) Ordered as in the text of this Report.

(b) All directly incurred expenditure on wages and salaries, pension provisions, travelling and subsistence, materials, equipment, etc., plus office overheads of the Division of £2.023m plus Forestry Commission headquarters overheads for common services of £0.494m, net of income of £1.139m for contract services provided to outside parties.

(c) Figures show net effect of charges for services received (principally research information, engineering workshops and statistics and computing) less charges for services provided by the specific branch to other branches.

(d) Work commissioned at other government institutes, universities, etc.

CONTRACT WORK DONE BY RESEARCH DIVISION

APPENDIX 5

British Coal	Opencast coal spoil reclamation Amenity tree health monitoring in England Demonstration and research in the New National Forest
Department of the Environment – Arb VI	Development of plant quality index for broadleaved trees Minimising pavement damage from street trees Production of manual on decay and safety in trees
Department of the Environment	Potential for woodland establishment on landfill sites
Department of Trade and Industry (Energy Technology Support Unit)	Coppiced trees as energy crops Initial spacing in short rotation coppice
Department of Transport	Alternatives to peat Backfill studies
EU	Forest condition surveys Interdisciplinary research for poplar improvement Tree seed dormancy
EU/AFOCEL	Northern conifers in fast growing conditions - a step towards an adequate wood supply for industry
EU/Imperial College	Chemical control of bluestain
EU/Institute of Virology and Environmental Microbiology	Transgenic poplar
EU/Irish Forestry Service	Wind stability
EU/Macaulay Land Use Research Institute	Agroforestry
EU/Madaus AG	European *Aesculus* cultivation system
EU/University of Edinburgh	The likely impact of rising CO_2 and temperature on European forests
FAO	Establishment of Mycorrhiza research programmes
Kemforschungszentrum (Germany)	Spruce root stock
Lothian Regional Council	Transplant performance
MacFarlane Smith	Animal repellent studies
Ministry of Agriculture, Fisheries & Food	Provenance testing Vegetative propagation Yield assessments

Niko Chemical Co Ltd	Animal repellent studies
ODA	Nutritional aspects of Chinese fir
	Tropical legume seed pretreatment
ODA/ECTF	China larch tree breeding project
Pilkington Trust	Control of *Ophiostoma novo-ulmi* by the'd-factor'
Scottish Enterprise	Condition of large planting stock
Scottish Forestry Trust, via TGUK	Physiology of native Scots pine
	Private woodlands squirrel questionnaire 1991
Sierra UK	Fertilization of birch
Southern Water Services	Short rotation coppice/sewage sludge
Strathclyde Greenbelt Co	Mycorrhizas in spoil heaps
	Species choice on reclamation sites
	Use of sewage sludge

RESEARCH CONTRACTS AWARDED BY RESEARCH DIVISION

APPENDIX 6

Avon Vegetation Research	Herbicide evaluation
Building Research Establishment	Dimensional stability of Sitka spruce
	Effects of water storage on strength and porosity of timber
	Modelling strength properties of Sitka spruce
	Modelling wood characteristics
	Testing British grown hardwoods for British standards
	Testing British grown softwoods for European standards
Dundee Institute of Technology	Genetic engineering of English elm
Environmental Management Consultants Ltd	Introduction and establishment of understorey vegetation in woodlands
Forest Insect Surveys and ITE	Invertebrate fauna of birch in spruce forests
George Peterken	Dead wood
	New native woodlands
Imperial College, London	Biological control of decay in utility poles
	Greenwood preservative treatments
	Potential of entomopathogenic nematodes for control of restocking pests
Institute of Hydrology	Effects of afforestation on water resources
Institute of Terrestrial Ecology	Capercaillie breeding ecology
National Rivers Authority (Welsh Region)	Effects of forestry on surface water acidification
Royal Society for the Protection of Birds	Golden eagle ranging behaviour
Tweed Foundation	Fauna of a small stream
University College of North Wales, Bangor	Crown development and timber quality
	Effect of provenance and silviculture on timber quality of oak
University College of Wales, Aberystwyth	Biology of *Ramichloridium* dieback of lodgepole pine
University of Aberdeen	Biocontrol of *Heterobasidion annosum* in Sitka spruce stumps
University of East Anglia	Windspeed prediction in complex terrain
University of Lancaster	The physiological impact of long-term exposure of trees to elevated CO_2

University of Nottingham	Development of transformation systems for Sitka spruce
University of Portsmouth	Management of bluestain in sawn timber
University of Wales, Cardiff	Conifer seed as a food for vertebrates

STAFF EMPLOYED IN RESEARCH DIVISION AT 31 MARCH 1994

APPENDIX 7

RESEARCH DIVISION

Director	D. A. Burdekin, B.A., Dip. Ag. Sci., M.I.C. For. (*Alice Holt*)
Chief Research Officer (North)	D. Rook, B.Sc., F.I.C. For. (*Northern Research Station*)

Head of the Northern Research Station. General responsibility for research north of the Mersey/Humber line and in Wales, with specific responsibilities for silviculture and for environmental and wildlife research in the uplands, and throughout Britain for research in tree improvement.

Chief Research Officer (South)	J. Evans, B.Sc., Ph.D., D.Sc., F.I.C. For. (*Alice Holt*)

General responsibility for research south of the Mersey/Humber line, with specific responsibility for silviculture and for environmental and wildlife research in the lowlands, and throughout Britain for research in pathology, entomology, plant production, instrumentation and technical aspects of legislation relating to plant health.

STAFF BASED AT ALICE HOLT LODGE

Administration Branch

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

Finance Section
R. Murray, Head of Section
Miss J. M. Atkins
P. A. Filewood
D. M. Payne
Ms S. J. Worman

Health and Safety Section
M. R. Jukes, C.Biol., M.I.Biol., Head of Section

Office Services Section
Mrs C. A. Evans, Head of Section
Miss F. J. Parsells
E. W. Perrins
Mrs T. M. Smalley
Mrs A. Smith
Mrs D. Steel

Personnel Section
M. G. Wheeler, Head of Section
Miss L. J. Caless
Mrs P. C. Fawcett
Mrs P. A. Iremonger
Miss J. R. Lacey
Mrs S. E. Robson

Typing Section
Mrs J. Shipp, Head of Section
Mrs J. M. Bell
Mrs B. E. Dickinson
Mrs C. A. Holmes
Mrs H. R. Payne
Mrs M. C. Peacock
Mrs S. G. Stiles
Mrs P. J. Wright

Communications Branch

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

Library and Information Section
Miss C. A. Oldham, B.A., M.A., Dip. Lib., A.L.A., Head of Section and Librarian
Mrs E. M. Harland, M.A., Dip. Lib., Assistant Librarian
Mrs D. Whitehead

Photography Section
G. L. Gate, Head of Section
G. R. Brearley (*Northern Research Station*)
Miss M. Trusler
J. Williams

Publications Section
Ms K. A. Davies, Head of Section
Miss M. J. Froud
Miss M. Taylor

Entomology Branch *(with section at Northern Research Station)*

H. F. Evans, B.Sc., D.Phil., F.R.E.S., Head of Branch
R. Ashburner, B.Sc.
C. I. Carter, M.Sc., C. Biol., M.I.Biol., F.R.E.S.
N. J. Fielding (*Ludlow*)
Mrs G. Green, B.Sc.
Mrs W. Groves
Mrs J. F. A. Johnson, B.Sc., M. Phil., C. Biol., M.I.Biol., F.R.E.S.
N. A. Straw, B.Sc., Ph.D., F.R.E.S.
Mrs C. A. Tilbury, B.Sc.
D. Wainhouse, M.Sc., Ph.D., F.R.E.S.
T. G. Winter, F.R.E.S.

Environmental Research Branch

P. H. Freer-Smith, B.Sc., Ph.D., Head of Branch
A. T. Armstrong, M.I.C. For.
Mrs S. E. Benham
M. S. J. Broadmeadow, B.Sc., Ph.D.
P. G. Crow
M. C. Dobson, B.Sc., Ph.D.
D. W. H. Durrant, B.A.
T. R. Hutchings
A. J. Moffat, B.Sc., Ph.D.
T. R. Nisbet, B.Sc., Ph.D.
Mrs J. E. Stonard
Mrs D. A. Waddell
E. Ward, B.Sc., M.Sc., C.Chem., M.R.S.C.
Miss C. Woods

Instrumentation (South) Section

T. R. Nisbet, B.Sc., Ph.D., Head of Section

Forest Products Branch

J. F. Webber, B.Sc., Ph.D., Head of Branch
Mrs C. M. Lishman

Mensuration Branch

Mrs J. M. Methley, B.Sc., Head of Branch
S. R. Abbott
N. Fearis, B.Sc.
P. C. Jokiel, B.Sc.
R. W. Matthews, B.Sc., M.Sc.
J. C. Proudfoot
Mrs S.A. Stephens

Pathology Branch *(with section at Northern Research Station)*

J. N. Gibbs, M.A., Ph.D., Sc. D., Head of Branch
Miss F. Baldwin
C. M. Brasier, B.Sc., Ph.D., D.Sc.
B. J. W. Greig, M.I.C. For.
Mrs S. A. Kirk
M. A. Lipscombe
D. Lonsdale, B.Sc., Ph.D.
D. R. Rose, B.A.
Mrs J. Rose
R. G. Strouts
M. L. Sutherland, B.Sc., M.Sc., Ph.D.
Miss M. Trusler

Plant Production Branch

P. G. Gosling, B.Sc., Ph.D., Head of Branch
A. S. Gardiner
R. L. Jinks, B.Sc., Ph.D.,
S. K. Jones, C. Biol., M.I. Biol., M.I.Hort.
Mrs Y. K. Samuel, B.A.

Silviculture (South) Branch

P. M. Tabbush, B.Sc., M.I.C. For., Head of Branch
J. L. Budd
I. Collier (*Midlands*)
D. Elgy
A. R. Hall
R. Harmer, B.Sc., Ph.D.
D. A. Hendrie (*Thetford*)
S. J. Hodge, B.Sc., M.Sc., M.I.C. For.
G. Kerr, B.Sc., M.I.C. For.
S. Minton (*Exeter*)
R. A. Nickerson
D. G. Rogers (*Exeter*)
N. Rylance
P. de Silva
D. West (*Thetford*)
J. E. J. White (*Westonbirt*)
I. Willoughby, B.Sc.
Mrs A. Yeomans

Statistics and Computing (South) Branch

I. D. Mobbs, C.Stat., Head of Branch
R. C. Boswell, B.Sc., M.I.S.
Mrs C.A.V. Foden
G. J. Hall, B.Sc., B.A.
Miss L. M. Halsall, B.Sc.
S. D. Hibbs, B.Sc.
Miss T. J. Houston, B.Sc., M.I.S.
A. R. Ludlow, B.Sc., Ph.D.
Mrs P.F. Newell
A. J. Peace, B.Sc.
Mrs L.P. Pearce
T. Porter, B.Sc.
T. J. Randle, B.Sc.
Miss B. J. Smyth, B.Sc.
J. Taylor, B.Sc.

Tree Improvement Section (of branch at Northern Research Station)

C. M. Cahalan, B.Sc., M.Sc., Ph.D.,
Mrs C. A. Baker
M. R. Plowman, B.Sc., M.Sc.

Wildlife and Conservation Research Branch

H.W. Pepper, Acting Head of Branch
R. Ferris-Kaan, B.Sc., Ph.D.

R. M. A. Gill, B.Sc.
Mrs B. A. Mayle, M.Sc.
Miss C. Woods

STAFF BASED AT NORTHERN RESEARCH STATION

Administration

M. Abrahams, Head of Section
Mrs J. Atkinson
N. Campbell
G. Cockerell
Mrs M. Farm
Miss E. Hall
Mrs H. Hirst
Mrs M. Holmes
Mrs K. Hutchinson
Mrs L. Legge
Mrs C. McIlwhan
Mrs M. Plews
Mrs M. Rendall
Mrs R. Shields
Mrs S. Walker

Entomology Section (of branch at Alice Holt)

S. G. Heritage, C.Biol., M.I. Biol, Head of Section
A. C. Hendry, B.Sc.,
D. Johnson, B.Sc. (Mabie, Dumfriesshire)
R. Moore, B.Sc., Ph.D.

Mycorrhiza Research Unit

C. Walker, B.A., Ph.D., Head of Unit
Miss A.C. Broome, B.Sc.

Pathology Section (of branch at Alice Holt)

D. B. Redfern, B.Sc., Ph.D., M.I.C. For., Head of Section
S. C. Gregory, M.A., Ph.D.
Miss G. A. MacAskill
J. E. Pratt

Silviculture (North) Branch

W. L. Mason, B.A., B.Sc., M.I.C. For., Head of Branch
D. Anderson
J. Boluski (*Lairg, Highland*)
P. Cairns (*Cairnbaan by Lochgilphead*)
N. P. Danby (*Talybont-on-Usk*)
J. Davidson, B.A., M.I.C. For. (*Newton, Grampian*)
J. Dick (*Wykeham, North Yorkshire*)
J. C. Dutch, B.Sc., Ph.D.
C. Edwards
B. A. Gardiner, B.Sc., Ph.D., F.R. Met.S.
P. W. Gough (*Kielder, Northumberland*)
A. J. Harrison, B.Sc.
M. K. Hollingsworth
R. E. J. Howes (*Wykeham, North Yorkshire*)
C. D. Jones, B.Sc. (*Talybont-on-Usk*)
A. L. Mackie, M.I.C. For.
A. W. MacLeod (*Newton, Grampian*)
C. McEvoy, B.A.
H.M. McKay, B.Sc., Ph.D.
J. D. McNeill (in charge of outstations)
J. L. Morgan, B.Sc., Ph.D.
B.C. Nicoll, B.Sc.
C. J. Nixon, B.Sc., M.I.C. For.
C. P. Quine, M.A., M.Sc., M.I.C. For.
M. J. Ridley (*Kielder, Northumberland*)
M. Riley
A. L. Sharpe (*Newton, Grampian*)
J. M. S. Simpson, B.Sc.
D. R. Tracy (*Cairnbaan by Lochgilphead*)
D. M. Watterson (*Mabie, Dumfriesshire*)

Statistics and Computing (North) Branch

I. W. Martin, B.Sc., M.Sc., Head of Branch
R. W. Blackburn, B.Sc.
A. D. Milner, B.Sc., Ph.D.
I. M. S. White, B.Sc., M.Sc.

Tree Improvement Branch *(with section at Alice Holt)*

A. M. Fletcher, B.Sc., Ph.D., Head of Branch
Miss C. M. M. Baldwin
W. Brown
J. Cottrell, B.Sc., Ph.D.
C. E. S. Fleming (*Newton, Grampian*)
G. I. Forrest, B.Sc., M.Sc., Ph.D.
A. John, B.Sc., Ph.D.
S. J. Lee, B.Sc., M.I.C. For.
J. S. McIntyre
Mrs M. O'Donnell
S. Osborne, B.Sc.
J. J. Philipson, B.A., Ph.D.
C. J. A. Samuel, B.Sc., Ph.D.
R. J. Sykes (*Shobdon, Hereford*)
G. C. Webb (*Shobdon, Hereford*)

Wildlife Ecology Branch

D.G. Pyatt, B.A., B.Sc., Ph.D., M.I. Soil Sci., Acting Head of Branch
A.R. Anderson
A.H. Chadwick (*Ardentinny, Argyll*)
J.W. Humphrey, B.Sc., Ph.D.
S.J. Petty, Ph.D. (*Ardentinny, Argyll*)
D. Ray, B.Sc.

INDUSTRIAL STAFF

The total number of industrial employees in Research Division at 31 March 1994 was 93.5.

STAFF MOVEMENTS

New appointments

Dr M. S. J. Broadmeadow, HSO, Environmental Research Branch, Alice Holt (3-year Period Appointment)

Miss C. A. Broome, ASO, Mycorrhiza Research Unit, Northern Research Station

Dr E. P. Cundall, SSO, Tree Improvement Branch, Alice Holt

Dr J. W. Humphrey, SSO, Wildlife Ecology Branch, Northern Research Station

T. R. Hutchings, ASO, Environmental Research Branch, Alice Holt

Dr R. Moore, HSO, Entomology Branch, Northern Research Station

Transfers in:

K. N. Charles, Grade 7, from Headquarters to Administration, Alice Holt

A. H. Dowell, FOIII, from Forestry Authority Wales to Silviculture (South) Branch, Alice Holt

S. Minton, FOIII, from Wiltshire and Avon Forest District to Silviculture (South) Branch, Exeter

N. C. Rylance, FOIII, from Forest Enterprise North Yorkshire Moors Forest District to Silviculture (South) Branch, Arley

Promotions:

W. Brown, Tree Improvement Branch, Northern Research Station, to FOI

Dr J. E. Cottrell, Tree Improvement Branch, Northern Research Station, to HSO

Dr B. A. Gardiner, Silviculture (North) Branch, Northern Research Station, to Grade 7

S. K. Jones, Plant Production Branch, Alice Holt, to SSO

R. Murray, Finance, Alice Holt, to SEO

D. R. Rose, Pathology Branch, Alice Holt, to FOI

Mrs J. Rose, Pathology Branch, Alice Holt, to SO

Transfers out:

M. Allen, FOIII, from Silviculture (South) Branch, Arley to West Midlands Conservancy (Delamere)

A. Hall, FOIII, from Silviculture (South) Branch, Alice Holt to Ministry of Defence

J. Lumley, Grade 7, from Alice Holt to Crown Prosecution Service

N. Smith, FOIII, from Silviculture (South) Branch, Exeter to Wye and Avon Conservancy

Detached duty:

P. R. Ratcliffe, Grade 7, from Wildlife Ecology Branch, Northern Research Station to Headquarters

J. M. S. Simpson, FOII, from Silviculture (North) Branch, Northern Research Station to Headquarters

Special unpaid leave:

D. Patch, Grade 7, (3 years)

Resignations:

Dr C. Cahalan, SSO, Tree Improvement Branch, Alice Holt

Retirements:

T. C. Booth, Grade 6, Chief Research Officer (North), Northern Research Station

Dr M. P. Coutts, Grade 6, Physiology, Northern Research Station

ADDRESSES OF RESEARCH LOCATIONS

APPENDIX 8

MAIN CENTRES

The Forestry Authority

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

The Forestry Authority
Northern Research Station
Roslin
Midlothian
EH25 9SY
Tel: 031 445 2176
Fax: 031 445 5124

Some staff engaged in research are stationed at:
Forestry Commission
Headquarters
231 Corstorphine Road
Edinburgh EH12 7AT
Tel: 031 334 0303
Fax: 031 334 3047

Research outstations

Ardentinny *Wildlife Ecology*
Forestry Authority
Wildlife Ecology Branch
Ardentinny
Dunoon
Argyll
PA23 8TS
Tel: 036 981 253

Bush *Silviculture (N)*
Forestry Authority
Northern Research Station
Roslin
Midlothian
EH25 9SY
Tel: 031 445 2176

Cairnbaan *Silviculture (N)*
Forestry Authority
Research Office
Cairnbaan
Lochgilphead
Argyll
PA31 8SQ
Tel: 0546 602304

Exeter *Silviculture (S)*
Forestry Authority
Research Office
Bullers Hill
Kennford
Exeter
Devon EX6 7XR
Tel: 0392 832687

Headley *Silviculture (S)*
Forestry Authority
Headley Research Nursery
Headley Park
Bordon
Hampshire
All mail via Alice Holt Lodge
Tel: 0420 473466

Kielder *Silviculture (N) and Entomology*
Forestry Authority
Research Office
Kielder
by Hexham
Northumberland
NE48 1HF
Tel: 0434 250235

Lairg *Silviculture (N)*
Forestry Authority
Research Office
Ord Croft
Lairg
Sutherland
IV27 4AZ
Tel: 0549 402150

Ludlow *Entomology*
Forestry Authority
Entomology Office
Whitcliffe
Ludlow
Shropshire
SY8 2HD
Tel: 0584 878322

Mabie *Silviculture (N) and Entomology*
Forestry Authority
Research Office
Mabie
Troqueer
Dumfries
DG2 8HB
Tel: 0387 52267

Midlands *Silviculture (S)*
Forestry Authority
Research Office
Woodside
Arley
Coventry
Warwickshire
CV7 8GH
Tel: 0676 41668

Newton *Silviculture (N) and Tree Improvement*
Forestry Authority
Research Office
Newton Nursery
Elgin
Morayshire
IV30 3XR
Tel: 0343 543165

Shobdon *Tree Improvement*
Forestry Authority
Research Division
Uphampton
Shobdon, Leominster
Hereford HR6 9PB
Tel: 056 881 8881

Talybont-on-Usk *Silviculture (N)*
Forestry Authority
Research Office
Cefn Gethiniog
Talybont-on-Usk
Brecon
Powys LD3 7YN
Tel: 0874 87444

Thetford *Silviculture (S)*
Forestry Authority
Research Office
Santon Downham
Brandon
Suffolk IP27 0TJ
Tel: 0842 810271

Westonbirt *Silviculture (S)*
Forestry Commission
Westonbirt Arboretum
Tetbury
Gloucestershire GL8 8QS
Tel: 0666 88220

Wykeham *Silviculture (N)*
Forestry Authority
Research Office
Wykeham, Scarborough
N. Yorks YO13 9HQ
Tel: 0723 862031

INDEX

Printed in the United Kingdom for HMSO Dd. 0297918 12/94 C13 3400/1 12521

HMSO publications are available from:

HMSO Publications Centre
(Mail, fax and telephone orders only)
PO Box 276, London, SW8 5DT
Telephone orders 0171-873 9090
General enquiries 0171-873 0011
(queuing system in operation for both numbers)
Fax orders 0171-873 8200

HMSO Bookshops
49 High Holborn, London, WC1V 6HB
(counter service only)
0171-873 0011 Fax 0171-831 1326
68–69 Bull Street, Birmingham, B4 6AD
0121-236 9696 Fax 0121-236 9699
33 Wine Street, Bristol, BS1 2BQ
0117 9264306 Fax 0117 9294515
9-21 Princess Street, Manchester, M60 8AS
0161-834 7201 Fax 0161-833 0634
16 Arthur Street, Belfast, BT1 4GD
01232 238451 Fax 01232 235401
71 Lothian Road, Edinburgh, EH3 9AZ
0131-228 4181 Fax 0131-229 2734

HMSO's Accredited Agents
(see Yellow Pages)

and through good booksellers

£20 net

ISBN 0-11-710327-6

9 780117 103276