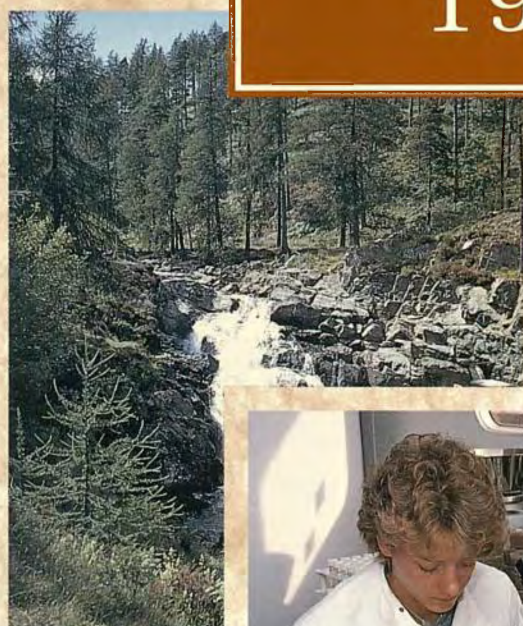
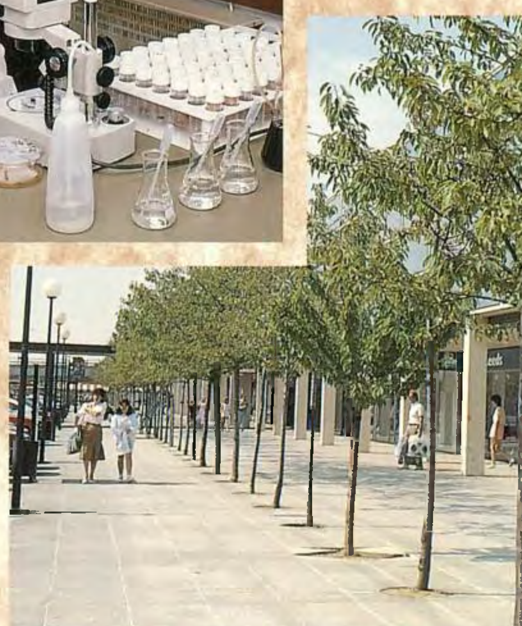
Forestry Commission

REPORT ON FOREST RESEARCH

1992





REPORT ON FOREST RESEARCH

for the year ended March 1992

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INTRODUCTION

by David Burdekin
Director Research

During 1991 and into the early part of 1992 the Forestry Commission prepared for a major internal reorganisation. The Forestry Authority was separated from Forest Enterprise so that their activities were clearly distinct. The Forestry Authority would be responsible for the promotion and administration of forestry grants, for implementing forestry policy, for education and training, and for research. Forest Enterprise would manage the forest estate of some 900000 hectares and have clear financial targets.

As a result of this reorganisation there was considerable movement of staff within the Forestry Commission as a whole.

This inevitably led to a rather unsettled period and even though the Research Division was not directly affected there were a number of knock-on effects. Movement of staff between the different parts of the Forestry Commission, agreed in principle by the Director General, has, not surprisingly, been difficult at this time. There have been delays but no insurmountable problems. Research Division positively encourages interchange between forest officers in managerial posts and as researchers.

There has been a tightening of the purse strings throughout the Forestry Commission aimed primarily at increasing efficiency. The Research Division has taken its share of this and, as a result, has been seeking greater efficiency. At the same time, the Research Division is determined to maintain its strong position in forestry research in the UK and has enhanced its efforts to seek outside funding. A Research Income Group was established, under the chairmanship of the Chief Research Officer (South), to investigate and promote ways of increasing income. As a result a number of new avenues for income have been identified including more customers for research, overseas consultancies, and a variety of advisory and extension enquiries in the UK.

Advisory Committee on Forest Research

The Advisory Committee has continued its policy of establishing Visiting Groups to examine specific sectors of research as part of a rolling programme. In 1991, the work of Site Studies (South) Branch was reviewed. The Visiting Group consisted of Professor T. A. Mansfield, Chairman (University of Lancaster), with Professor M. Hornung (NERC Institute of Terrestrial Ecology, Merlewood), Dr E. M. Bridges (University of Wales, Swansea) and Dr G. Price (recently AFRC) as members.

Major projects reviewed included research on air and water pollution as well as studies on afforestation of land reclaimed from industrial use. The Visiting Group was clearly impressed by the quality of research being undertaken by the Branch and suggested lines of possible future research. In particular, it proposed that work on the effects of air pollutants on trees should be replaced, in a programmed manner, by studies of the effects of enhanced CO_2 on tree growth.

As a new venture during 1991 the Research Advisory Committee took part in a field visit to mid and south Wales. This visit enabled the committee to see some of the field research programme of the Branch including research on tree planting on reclaimed open-cast coal sites. The opportunity was also taken to see aspects of the research of Silviculture (South) and Pathology Branches which were being undertaken in the vicinity.

Forestry Research Co-ordination Committee

The FRCC plays an important role in co-ordinating the research activities of a number of different government departments and agencies. The special programme concerned with farm forestry funded by three FRCC members – Department of the Environment, Forestry

Commission and Natural Environment Research Council – is in its final year. A conference reporting results of this important initiative is planned for early autumn 1992.

The major review of forestry research needs in the light of climate change was completed in December 1991. The uniquely long life of forest crops brings special challenges when research programmes are being devised but, equally, provides a mechanism for carbon sequestration. The importance of process-based modelling to provide a sounder scientific basis and the need to develop further monitoring techniques to determine trends and the extent of the change were emphasised as priorities.

The annual collation of total expenditure on forestry research in Britain has shown that spending amounted to £20.5 million. The trend towards increased research involving broadleaved species and environmental matters continues. Climate change and wildlife conservation show significant increases in research funding.

RESEARCH HIGHLIGHTS

The format of this annual research report is kept under close review. In the past 2 years a new style report was published with a different size, a double column layout and an increase in illustrations. The response from our readers was positive and this style has been retained.

Following a review of the content of the report, for the first time the Branch reports now include a brief review by the Heads of Branch and detailed reports from selected project leaders.

The following are a selection of achievements in the Research Division during the year.

Forest products

Following the severe gale damage to trees in 1987 a log store under continuous water sprinklers was established in Thetford Forest. The opportunity was taken to sample logs of different species over a 3-year period. The treatment was remarkably successful and the logs from the store sawed readily and cleanly and had minimal amounts of discoloration. Microbial studies indicated that there were abundant bacteria in wet-stored beech and Scots pine and that this was positively correlated with increased porosity of the timber.

Yields from lowland trees

A joint Forestry Commission and Ministry of Agriculture, Fisheries and Food project has been designed to enable farmers and others to predict yields on a range of sites in lowland Britain. Initially models are being developed for oak, beech, Corsican pine and Douglas fir. Soil type, soil moisture deficit and accumulated temperature have been identified as primary site factors affecting yield.

Farm woodland weeds

Many agricultural fields contain a large weed seed population which is kept under control by cultivation and the regular application of herbicides. When trees are planted on these sites prolific growth of arable weeds often occurs. This can be extremely damaging to the survival and early growth of trees. At the same time it may increase biodiversity and give ensuing environmental benefits. Strip weeding has been undertaken to promote tree growth and various inter-row treatments, including wild flower sowing, have been investigated. A happy compromise has been demonstrated on an experimental scale.

Upland silviculture – new directions

A considerable effort has been made by Silviculture (North) Branch during the year to implement changes recommended by the Visiting Group in 1990. In addition to a number of organisational changes, two new areas of research have been identified: natural regeneration, and site/yield relationships in the uplands.

The former has arisen as natural regeneration is occurring commonly after felling, and subsequent management for multi-purpose forestry has not been the subject of major research. Site/yield studies in Scotland are a further development of research undertaken by the Forestry Commission in collaboration with other research institutes. They are particularly important in relation to the development of indicative strategies for forestry.

Trees on landfill sites

This topic has assumed considerable significance as many of the sites for woodland established within Community Forests are on sites where land filling has occurred. These may be sites restored after mineral extraction by infilling with wastes or other treatments. There are special problems posed by landfilling operations including methane and carbon dioxide production and potentially dangerous leachates.

A contract report for the Department of the Environment has been prepared indicating the requirements for successful tree establishment on landfill sites. Particular attention needs to be paid to the depth of soil materials over the seal above the waste material.

Target moisture content

A new method of prechilling seed has been developed by the Plant Production Branch. With the advent of machine sowing, chitted seed is easily damaged and can foul the machinery. The technique of a 'target moisture content' provides the seeds with enough moisture to respond to the chill treatment but not enough to chit during the chilling process. The method was also successful in promoting the germination of several conifer species when sown at 10°C, the average spring soil temperature.

Impact of insects on tree growth

The impact of non-lethal insect attacks on tree growth has long been the subject of debate. An experimental approach using controlled insect population densities has shown that high infestation rates of *Rhyacionia buoliana* reduce height growth of pine by about 25%. A similar approach is now being adopted in a study of the impact of the pervasive *Elatobium abietinum* on the growth of Sitka spruce.

Oak dieback

Symptoms of oak dieback have been observed in the past but a particularly noticeable incidence occurred in 1988/89 and subsequent years. Most cases are in southern England, especially the east Midlands but also in areas ranging from Devon to Kent. Studies of growth patterns in increment cores suggest that growth decline started coincident with the summer droughts of 1983/84 or the severe winters of 1984/5/6. Previous experience indicates that affected trees will recover but the current situation is being monitored.

THANKS

Finally, none of the achievements mentioned in this brief summary or in the pages which follow could have been made without the expertise, enthusiasm and commitment of the entire staff. This is wholeheartedly acknowledged.

PART I

THE WORK OF THE FORESTRY COMMISSION

RESEARCH DIVISION

PLANT PRODUCTION

Plant Production Branch research covers seed research on all tree species (conifers and broadleaves), and the propagation of those species associated with lowland forestry (mainly broadleaves but also Corsican pine). Responsibility for research on the propagation of upland forestry species resides with Silviculture (North) Branch.

The aim of seed research is to understand seed physiology and hence increase the accuracy of laboratory seed tests and improve nursery emergence. Over the last 12 months the final work in developing a 'target moisture content' dormancy breakage method has been completed. This technique offers significant improvements over traditional prechill procedures (see below). Also, the comparative benefits of 'priming' versus 'prechilling' have been studied; and co-operative work between Plant Production and Tree Improvement Branches has investigated the testing, handling and pretreatment of ash fruits.

Nursery research investigates the effects of cultural and environmental factors on the morphology and physiology of both sexually and vegetatively propagated stock raised in open nurseries and containers. Current research is examining the effects on root and shoot morphology of undercutting bare-root stock, and container seedling density. Encouraging results of research into the vegetative propagation of ash, sycamore and sweet chestnut are reported here in more detail.

Plant Production Branch is also the British Official Seed Testing Station (OSTS) for tree and shrub species. Trees covered by the Forest Reproductive Material (FRM) Regulations and marketed in the UK must be tested here during their year of sale. The OSTS also offers advisory tests to growers and seed merchants for broadleaved species.

PETER GOSLING

SEED

A new way of prechilling conifer seed to overcome dormancy

Most temperate conifer seeds are shallowly dormant and germination benefits from a prechill before sowing. Seeds must be moist before they can respond to chilling, so conifer seeds which are usually stored at moisture contents of 6–8% (fresh weight basis) must first be hydrated. The most widely used prechill method is to soak seeds for 48 hours at 4°C in excess water, drain off the water, then place the moist seed in loosely tied polythene bags to chill at 4°C for 3–6 weeks. Extending the chill period to 12 weeks or longer is even better at promoting faster and higher germination at lower temperatures; however, if surface water remains around individual seeds, chitting during the pretreatment can occur.

Chitted seeds are unsuitable for machine sowing, since the germinating seed is both easily damaged and can foul up the machinery. To prevent chitting, but still gain the benefits of an extended chill period, we have developed a new prechill method, the target moisture content (TMC) prechill. Seeds are given a limited amount of water to reach a pre-set target moisture content. Correct TMCs give seeds enough moisture to respond to the chill but not enough to chit during chilling.

The TMC method has successfully prevented chitting for up to 76 weeks of chilling for seed lots of Douglas fir, lodgepole pine and Sitka spruce. The method was also successful in promoting germination of all these seed lots when sown at 10°C, which approximates to the average spring soil temperatures.

Figure 1 shows the course of germination at 10°C for Sitka spruce seeds chilled for different periods of time. The progressively higher and faster germination of seeds receiving longer prechill durations was also a characteristic of Douglas fir and lodgepole pine. A 12-week TMC prechill raised the germination of Douglas fir, lodgepole and Sitka spruce from 1 to 84%, 0 to 91% and 2 to 96% respectively.

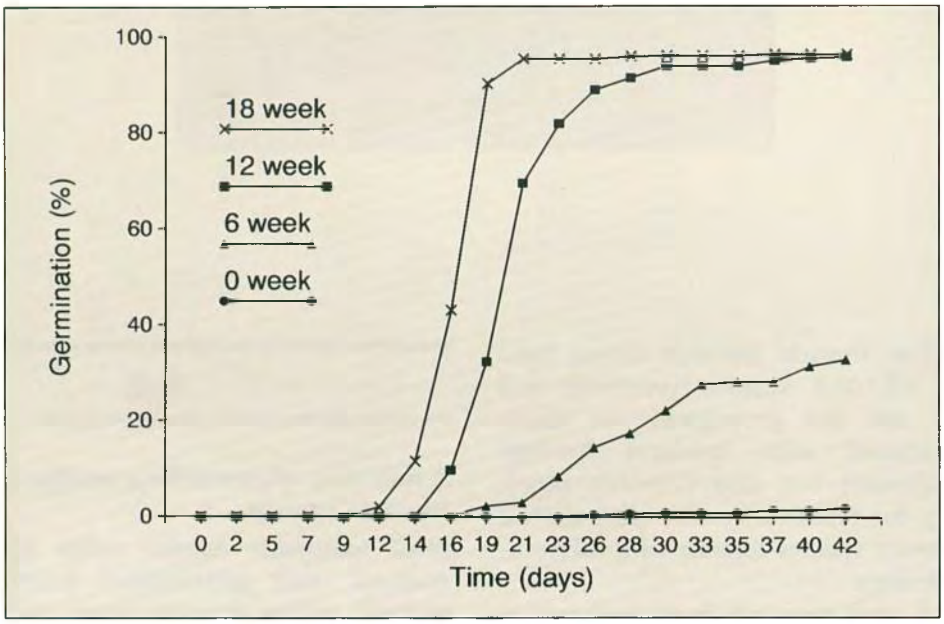


Figure 1. Germination at 10°C of Sitka spruce after 0, 6, 12 and 18 weeks target moisture content prechill.

Lodgepole pine and Sitka spruce seed lots were also redried to storage moisture contents after 76 weeks of TMC prechill without apparent harm to germination or reimposing dormancy. Not only is the TMC method an extremely useful technique for avoiding chitting but nursery managers could redry surplus TMC treated seed for later use, or TMC prechill then redry seed in advance of the sowing season.

STEVE JONES AND PETER GOSLING

NURSERIES

Propagation of ash, sycamore and sweet chestnut from softwood cuttings

Research on the genetic improvement of broadleaved species (*Report* 1991, pp. 26–27) requires reliable methods for propagating selected trees. Past work has shown that species such as ash, sycamore and oak can be propagated by rooting softwood stem cuttings. Research has continued on refining this experience to develop dependable systems for the mass propagation of selected clones.

The rooting of softwood cuttings of ash, sycamore and sweet chestnut was compared in three different rooting environments (Hartmann, Kester and Davies, 1990): intermittent mist (open mist); intermittent mist enclosed in a polythene tent (closed mist); and a non-mist system which consisted of a sheet of polythene laid directly over the cuttings (contact polythene). The effects of three rooting media with different physical structures (peat:grit in proportions of 3:1, 1:1 and 1:3) on the rooting of each species in the three environments was also investigated.

The percentage rooting of all three species was not affected by the physical structure of the rooting medium. However, there were significant differences ($P<0.001$) in the rooting of each species in the different propagation environments. Sycamore produced the highest percentage rooting of the three species in each of the propagation systems. The highest percentage rooting for this species occurred in open mist (81.4%). The rooting of ash was significantly reduced by nearly 30% from an average of 58.3% for the two enclosed systems to 29.2% in the open mist system. Sweet chestnut produced the lowest overall percentage rooting of the three species, the highest percentage rooting (47.2%) occurred in the closed mist system.

Overall these results suggest that closed mist is the best system for rooting cuttings of all three species, especially ash and sweet chestnut. Contact polythene also produced reasonable rooting of ash and sycamore and may be an acceptable cheap system for the mass propagation of clones of these species.

RICHARD JINKS

REFERENCE

HARTMANN, H. T., KESTER, D. E. and DAVIES, F. T. (1990). *Plant propagation – principles and practices.* Fifth edition. Prentice-Hall International, Inc.

Table 1. Percentage rooting of ash, sycamore and sweet chestnut in three propagation systems: open mist, closed mist and contact polythene

System	*Species*		
	Ash	*Sycamore*	*Sweet chestnut*
Open mist	29.2 (31.0)	81.4 (65.8)	30.3 (32.5)
Closed mist	64.4 (54.6)	73.9 (60.3)	47.2 (43.3)
Contact polythene	52.2 (46.2)	58.9 (50.4)	28.6 (31.4)

Note: Figures in parentheses are the angular transformed means, the corresponding S.E.D. = 5.81, N = 72.

Official Seed Testing Station

The OSTS employs procedures laid down by the International Seed Testing Association (ISTA). This organisation exists to standardise and improve seed testing methods throughout the world and the Forestry Commission has a long history of supporting ISTA aims. In 1991 Dr P. Gosling (the current Head of the OSTS and chairman of ISTA's tree and shrub committee), finalised the publication of an ISTA 'Handbook' exclusively on tree seed testing. The Commission is especially pleased to be associated with this, given that the project was initiated by the previous Head of the OSTS (Dr A. Gordon) and will be used throughout the world.

Following the reduction in seed analysts in 1991 and the withdrawal of advisory tests on conifers, the number of samples tested decreased from 582 (1990/91) to 435 (1991/92). 350 Forestry Commission seed lots were tested; 50 lots from seed merchants and nursery managers; and 35 from the Oxford Forestry Institute.

Peter Gosling and Yvonne Samuel

SILVICULTURE SOUTH

Arboreta

Following investigations at Markshall Arboretum and Hatfield Chase in Essex, a method of pollarding old and often neglected oaks was formulated and published by the Corporation of London in the Proceedings of their Pollard and Veteran Tree Management meeting. The method has been put into practice at various locations including Westonbirt.

A paper on the ornamental use of willows was published in the Royal Society of Edinburgh Proceedings, and a manuscript for an upmarket, well-illustrated book *Forest and woodland trees of Britain* has been presented for publication.

A review of the 1200 tree species (attaining over 6 metres in height), of which more than 100 individual specimens are known, was undertaken to identify those with plantation potential in Britain. Due regard was given to the increasing availability of agricultural land for forestry, climatic change, and a projected decline in tropical hardwood imports. Some 240 taxa in 54 genera have been selected for further review.

Beech in treeshelters

Although beech has performed well in treeshelters during experiments, continuing reports of poor performance have prompted further investigation. Joint work with Entomology Branch, and funded by Correx Plastics Ltd., investigated the effects of the beech woolly aphid, *Phyllaphis fagi*, on the performance of young beech trees in treeshelters. The insects were shown to be associated with poor growth, and a survey showed high populations of insects on sites with poor growth of beech in treeshelters.

Poplars

Poplar research continues actively owing to the promise offered by the new Belgian clones (*Report* 1990, p.3) and the suitability of poplar for arable farmland. An interdisciplinary Poplar Study Team co-ordinates work on yield modelling, timber testing, disease research and clonal testing. Sixty clones have been received from Belgium since 1985; 20 of these were collected in February 1991. The 11 collected in 1985 are well known as the UNAL clones described in Research Information Note 181. Of the 29 clones collected in 1990, 24 are of the most promising 'balsam hybrid' (*P. trichocarpa* × *deltoides*).

Thirty-six clones from eight hybrid groups were planted in March at Wetherby, Yorks, using l-year-old unrooted sets. This is the first of a series of trials throughout Britain to test the 49 new clones.

Arboriculture

The published proceedings of a major conference *Seed-in-Time* (1991) contain a paper by Simon Hodge on the applicability of low-cost forestry techniques in urban areas, reporting that "after 3 growing seasons transplants in treeshelters and whips were taller than light standards". There are considerable savings to be made from applying these results.

Herbicides

Off-label approvals have been obtained for five products during the year, based on our on-farm trials. Several other applications for approval are pending. New product screening has identified a number of herbicides for use on transplants and 2-year undercut beds in the nursery.

PAUL TABBUSH

REFERENCES

HODGE, S. J. (1991). BS 3936 Part 1 take 2. *A Seed in Time: the second UK/International conference on urban forestry, 18–22 June 1991*, 45–53. Seed in Time Ltd., Edinburgh.

WHITE, J. E. J. (1991). Suggestions for re-pollarding oaks at Markshall, Essex. *Proceedings of the Corporation of London (Burnham Beeches)*, p.46.

WHITE, J. E. J. (1991). Ornamental uses of willow in Britain. *Proceedings of the Royal Society of Edinburgh* **98B**, *183–192*.

Vegetation management on bare land, farm woodland planting sites

The management of ground vegetation on fertile ex-agricultural sites in lowland Britain is the major challenge to efficient and successful tree establishment on these sites. The high fertility coupled with a large weed seed population on most sites can lead to prolific growth of arable weeds when agricultural management is withdrawn. This weed growth can severely reduce the survival and early growth of trees and where rank weed growth is taller than trees, physical damage can be a major problem when weeds collapse in the autumn.

When establishing trees in lowland Britain, a one metre diameter spot weed control or a one metre wide strip kept weed free at the base of trees greatly improves the survival and early growth of trees. But, whatever the objectives of afforestation of ex-arable land, the ground vegetation between the weed-free areas must be managed.

Maintaining bare earth is undesirable because it leads to high pesticide input, has little aesthetic value and can on some sites lead to soil erosion and greater nitrate leaching during the winter. The cheapest practical option is to manage the indigenous vegetation by mowing; this prevents weeds becoming a nuisance while maintaining a low level of ground cover. Although mowing is cheap, it must be repeated regularly to prevent weeds from seeding and sustaining the annual cycle. Instead of managing the vegetation which a site produces voluntarily, there is potential to sow desirable ground vegetation which not only suppresses weeds, but satisfies other objectives as well. Examples of this are: kale, to increase the value of a farm shoot, or a herb rich sward to produce a range of environmental benefits. Table 2 gives the results of an experiment to investigate the effects of the different ground vegetation management mentioned above on tree survival and early growth. The experiment, which was established in March 1990, included two tree species, Corsican pine and Norway maple.

None of the treatments caused significant differences in the survival, tree height or height increment of Corsican pine during the first two growing seasons. Survival was 100% for all treatments at the end of 1990 with a mean survival of 96% at the end of 1991. None of the treatments caused any significant differences in the survival, tree height, tree height increment, stem diameter or diameter increment of Norway maple at the end of the first growing season and in October 1990 the mean survival was 95%. At the end of the second growing season in October 1991, there were no significant differences in survival though mean survival had dropped by 1%. However, by this date there were significant differences in both height and stem diameter (Table 2). Trees in the untreated plots or in the grass/wild flower plots were significantly smaller than trees in the mown or kale plots, which were significantly smaller than trees in the bare earth treatment.

The most cost-effective way of achieving weed control is to use herbicides. Work is therefore continuing to identify herbicides which can be used selectively around trees to maintain satisfactory weed control during the establishment period.

David Williamson

Table 2. Effect of ground vegetation treatments on the growth of Norway maple

Treatments	*Tree height Oct 91 (cm)*	*Tree height increment April 90 – Oct 91 (cm)*	*Stem diameter Oct 91 (mm)*	*Stem diameter increment April 90 – Oct 91 (mm)*
1. Untreated	125.5[a]	63.5[a]	13.47[a]	7.14[a]
2. Bare soil	190.7[c]	128.6[c]	18.62[c]	12.28[c]
3. Strip weed + mow	169.1[b]	107.0[b]	16.23[b]	9.90[b]
4. Strip weed + kale	155.7[b]	93.6[b]	14.94[ab]	8.61[ab]
5. Strip weed + grass/wild flowers	137.6[a]	75.5[a]	14.30[a]	7.97[a]

Note: Values not sharing the same superscript letter are significantly different at $P<0.05$ level.

Demonstration woodlands for community forests

The emphasis of forestry in Britain is changing, the focus moving from upland, principally coniferous, afforestation to the establishment of broadleaves in lowland areas. The basis for the increase in broadleaved tree planting is twofold: the use of surplus agricultural land and environmental improvement in populated areas.

This change of emphasis is drawing a new constituency of landscape architects, farmers and amenity horticulturists into woodland establishment. There is a pressing need to relate the importance and detail of good establishment techniques to these new groups, and the value of demonstrating recommended techniques on sites is becoming widely recognised.

In 1988 a series of demonstration plots was set up at agricultural colleges to show farmers and amenity horticulturists the importance and effect of weed control, correct choice of stock size, method of protection and site preparation. This series of 17 demonstration plots is under review and the focus is switching to designated community forest areas on the edge of large towns.

Linked with this change of focus has been the need to demonstrate wider aspects of new woodland establishment such as design to meet multiple objectives, species choice, robust establishment methods, maximising conservation and landscape value, and dealing with 'people pressure'. Demonstration woodlands of between 1.5 and 19 ha are being planned and planted in partnership with the various community/urban forest initiatives.

Existing demonstration woodlands are fully interpreted with signs funded by the Countryside Commission, and are already being used intensively by project teams. As well as demonstrating particular points, the woodlands will act as a quality benchmark in the locality to show what can be reasonably achieved using low input forestry techniques.

Simon Hodge

Urban trees and trees in community forests: Department of the Environment contract

Plant quality at establishment

Can the ability of broadleaved transplants to survive and grow be predicted before planting? At present predictions are made on subjective assessments of root collar diameter, height, root structure and root:shoot balance, i.e. the morphology of the tree. These are measures used in British Standard 3936 (Part 4: 1984) *Nursery stock*. However, a tree with desirable morphological characteristics can still die or grow slowly after planting because of poor internal water relations, damage to cell walls in the root or low enzyme activity, i.e. poor physiological condition. In order to devise more reliable measures of plant quality this project has been designed to investigate both the morphological and physiological characteristics of broadleaved transplants. Many people in the arboricultural and forestry industries are now familiar with root growth potential (RGP) and root electrolyte leakage (REL) for conifers in British conditions. This work has many parallels but with the interesting complication for broadleaves of dormancy at the time of assessment.

A preliminary experiment was conducted on eight broadleaved tree species. These were artificially water stressed by drying for up to 4 hours in a growth chamber at 20°C and 70%

Table 3. Community forest demonstration woodlands

	Planting year	Location (land type)	Area
Already planted	90/91	Black Country Urban Forest (derelict)	1.5 ha
	91/92	Thames Chase (arable)	2.0 ha
		Thames Chase (reclamation)	1.5 ha
		Mercia (coal spoil)	2.5 ha
Planned	92/93	Nottingham Greenwood (coal spoil)	19.0 ha
		Bedfordshire Marston Vale (mixed land use)	2.0 ha
	93/94	The National Forest	?

RH; subsamples of the treated trees were tested (Figure 2) and others were planted.

The loss of moisture and increased membrane leakage in fine roots of broadleaved transplants did not correlate well with survival in the first growing season. However, there was a good correlation between growth (height increment) and various parameters measured (Table 4 and Figure 3) which were affected by the desiccation treatment.

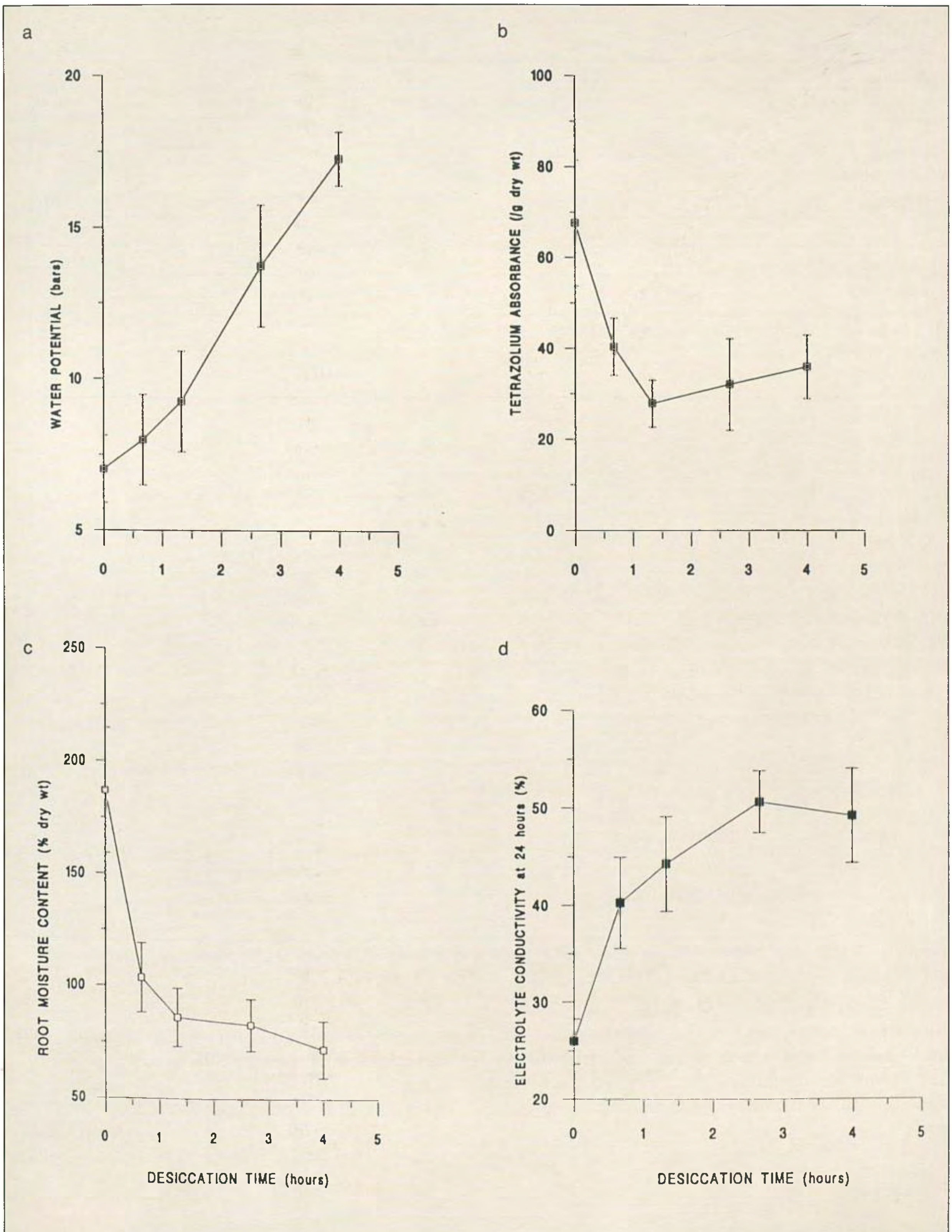


Figure 2. Response of test to increasing desiccation of birch; a) stem water potential, b) root tetrazolium staining, c) moisture content of fine roots, and d) percentage electrolyte conductivity of fine roots measured at 24 hours. Bars indicate 95% confidence interval.

Table 4. Correlations between test result and field performance

	Root moisture content	*Stem water potential*	*Root membrane leakage*	*Root tetrazolium staining*
Survival				
Norway maple	0.64	–0.54	–0.63	0.64
Birch	0.54	–0.36	–0.66	0.66
Corsican pine	0.82(†)	–0.79	–0.83(†)	0.81(†)
Height increment				
Norway maple	0.83(†)	–0.76	–0.87(†)	0.86(†)
Birch	0.85(†)	–0.93(†)	–0.94*	0.75
Corsican pine	0.67	–0.75	–0.56	0.67
Ash	0.73	–0.89*	–0.78	0.68

(†) = Correlations significant at the 10% level $P<0.1$ and * = 5% level $P<0.05$.
Degrees of freedom = 3.

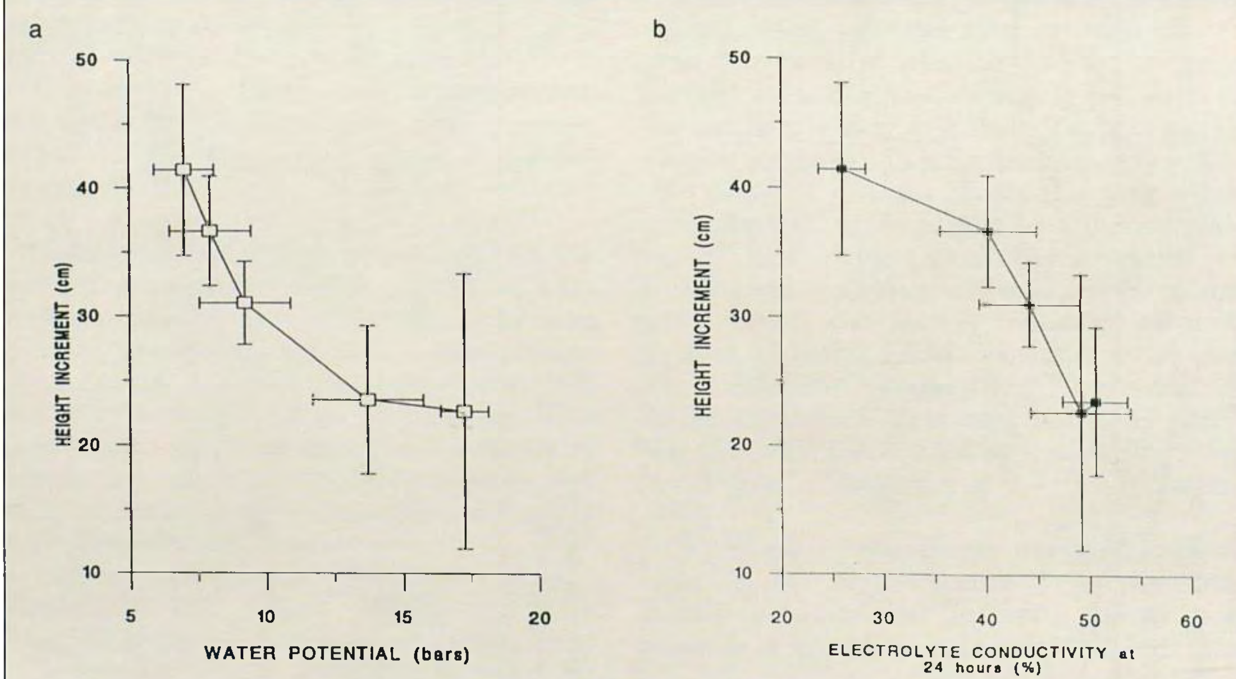


Figure 3. Relationship between height increment in birch and test result; a) stem water potential, b) percentage electrolyte/conductivity at 24 hours. Bars indicate 95% confidence interval.

Subsequent work has been confined to oak, ash and beech and the range of treatments expanded to include cold storage, nursery spacing, desiccation (range increased up to that required to kill) and nursery wrenching. Trees were planted in spring 1992.

Charlie Harper, Gary Kerr, Ken Knott and Simon Hodge

SILVICULTURE NORTH

A considerable amount of staff time was taken up with reconsidering priority areas for silvicultural research and reviewing the organisation of the Branch in the light of the recommendations of the 1990 Visiting Group (*Report* 1991, p. 7). Recent changes in forestry policy with the greater emphasis laid upon sustainable forest management, upon community forestry and upon the need for forests to provide multiple benefits were all taken into account. As a result, five broad project groups have been identified within which future silvicultural research will be concentrated. These are: nurseries and establishment (previously two separate topics); fundamental and applied aspects of tree stability; site yield research including nutrition; farm and community woodlands; and natural regeneration (including native woodlands and species).

A recommendation of the Visiting Group was that the responsibility for the management of the Branch's nine outstations should be devolved so that the Head of Branch should have more time to devote both to direction of the research effort and to his own research. This recommendation has been accepted and J.D. McNeill took up the position as officer in charge of the outstations in early 1992. The number of existing field experiments and the workloads at individual outstations were also reviewed in the light of the change in project areas. An appreciable number of field experiments were felt to be no longer relevant to the new research portfolio and have been closed. Similarly, an internal review group under the direction of D.G. Nelson showed that there were appreciable differences in current and predicted workloads at the various outstations. As a result, we have taken the decision to close the Perth outstation in 1992 and to reduce the complement at both Lairg and Mabie. Following a separate review, the old Silviculture (South) outstation at the Dean has been closed and the experiments in that area are being run from Talybont. As well as reducing the overall expenditure of the Branch, these measures have allowed us to redeploy staff to provide greater support to specific project areas.

Table 5. Height, root collar diameter (RCD), shoot: root dry weight ratio, lateral root cross sectional area and deformation score of three plant types of Douglas fir and Sitka spruce 4 years after planting

Species and treatment code[1]	*Height (cm)*	*RCD (mm)*	*Shoot:root ratio*	*Total CSA*[2] *(mm^2)*	*Deformation score*[3]
Sitka spruce					
U	173	46	6.2	1125	1.92
E15	164	46	6.2	887	1.75
SLT	162	55	6.2	912	2.25
SED	10.5	4.1	1.4	205	0.25
Douglas fir					
U	147	40	4.9	261	2.10
E15	142	39	4.4	192	2.80
SLT	140	43	5.2	231	2.32
SED	12.5	4.9	0.6	64	0.34

Notes:

1. For treatment codes see text. Volume of containers: E15 = 305 cc; SLT = 350 cc.
2. Cross sectional area at a radius of 10 cm from the centre of the rootstock.
3. Deformation assessed on a score basis:
   1 = negligible deformation to
   5 = severe deformation with root spiralling.

Changes of this type cannot be achieved without considerable discussion and disruption to normal working. However, all members of the Branch have been very positive in their attitudes and have continued to produce work of high quality. I am very grateful for their support during this year of change.

BILL MASON

PLANT PRODUCTION

Root architecture of containerised seedlings

Forest performance and root system development of different Douglas fir plant types has been described for a 3-year-old experiment planted on a mounded brown earth soil in the North York Moors (*Report* 1991, p. 7). Containerised planting stock showed more root spiralling and less lateral root development than bare root stock despite container designs which included ribs or grooves to prevent root spiralling. Further investigations have been carried out in sister experiments with Douglas fir and Sitka spruce planted on a shallow ploughed surface water gley in Lennox Forest, Aberfoyle Forest District. Forest performance after two growing seasons has been reported previously (Mason and Hollingsworth, 1989) so this study was confined to measurements in one bare root and two containerised treatments; 1u1 undercuts (U), Ecopot 515 (E15) and Fleet Rootrainers (SLT). Results are shown in Table 5.

There were no significant differences between measurements of tree growth or root development of the different plant types of either species which contrasted with findings at the North York Moors site for Douglas fir. Root deformation of containerised plant types would therefore appear to be strongly influenced by site features such as soil type and cultivation.

JOHN MORGAN AND BILL MASON

REFERENCE

MASON, W.L. and HOLLINGSWORTH, M.K. (1989). *Use of containerised seedlings in upland forestry.* Forestry Commission Research Information Note 142

TREE STABILITY

Fundamental studies

Extensive analysis has been completed on data from the aeromechanics experiments in the Rivox (Nithsdale District) and Kershope (Borders District) forests (Gardiner, 1992a and Gardiner *et al.,* 1992) and the wind-tunnel experiments at Oxford University (Stacey *et al.,* 1992).

The field experiments have shown the dominating influence on turbulent transport of the intermittent gusts. These gusts can be seen clearly by plotting against time the short-term wind vectors from each anemometer placed on a mast twice as tall as the forest canopy (Figure 4). A strong downburst with clear vertical structure is seen penetrating the canopy at time zero but note how the flow becomes attenuated and becomes more and more vertical. Following the gust passage gentle vertical return flow can be seen moving out of the canopy. The canopy itself acts as a low pass filter allowing passage to only the strongest events so that the below canopy airflow is decoupled from the rest of the flow except on these occasions. Such observations have important consequences on understanding the nature of turbulent transport and for tree physiology. Trees do not live in a steady-state environment but must respond to intermittent large changes in carbon dioxide concentration, water vapour content and temperature.

The mechanical behaviour of the trees has been found to correspond closely to a damped harmonic oscillator (Gardiner, 1992b). The trees acting as oscillators efficiently absorb energy from the wind at their resonant frequencies. Plots of wind turbulence spectra within the canopy (Figure 5) show a significant reduction in energy within a region bounded by the estimated resonant frequencies of trees in the forest (vertical dashed lines). Since there is less energy available in the wind at high frequencies and since tree resonant frequency is proportional to dbh/tree height^2, short fat trees should be less vulnerable than tall skinny ones. The difficulty is to produce short fat trees without respacing or thinning which directly increases wind loading (Gardiner *et al.,* 1992).

The wind-tunnel experiments have confirmed many of the findings of the full-scale studies including the importance of resonance for increasing the extreme overturning moments experienced by trees, the importance of damping due to crown clashing and the rapid increase in wind loading following any opening up of the forest (e.g. thinning). Because the wind-tunnel simulations have been found to match the field measurements well this has provided confidence in wind-tunnel measurements which could not be replicated at full-scale. This has allowed the effects of clearings and forest edges to be explored. Figure 6 illustrates the development of

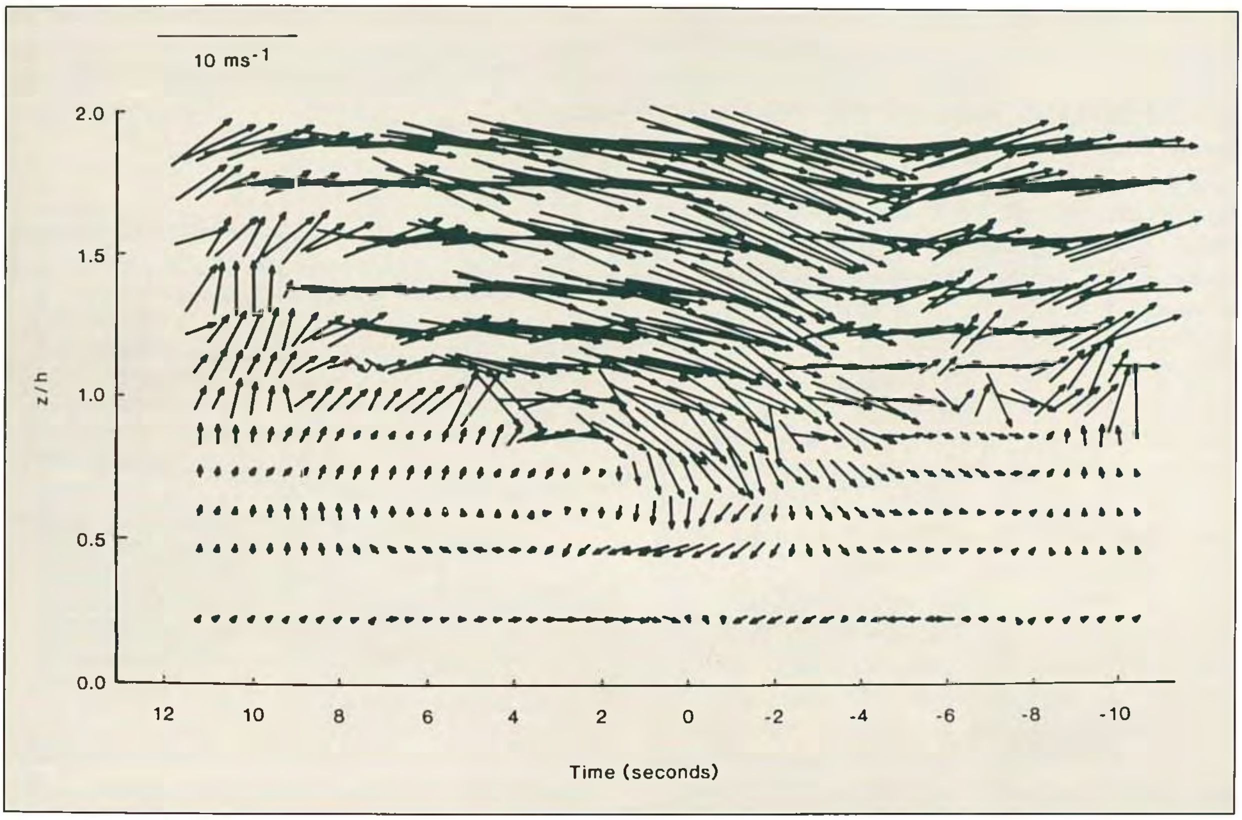


Figure 4. Vertical cross-section of the velocity field for a single sweep event with time going from right to left. Arrows represent the two-dimensional (u, w) wind velocities over a 0.4s period and canopy top is at z/h = 1.0.

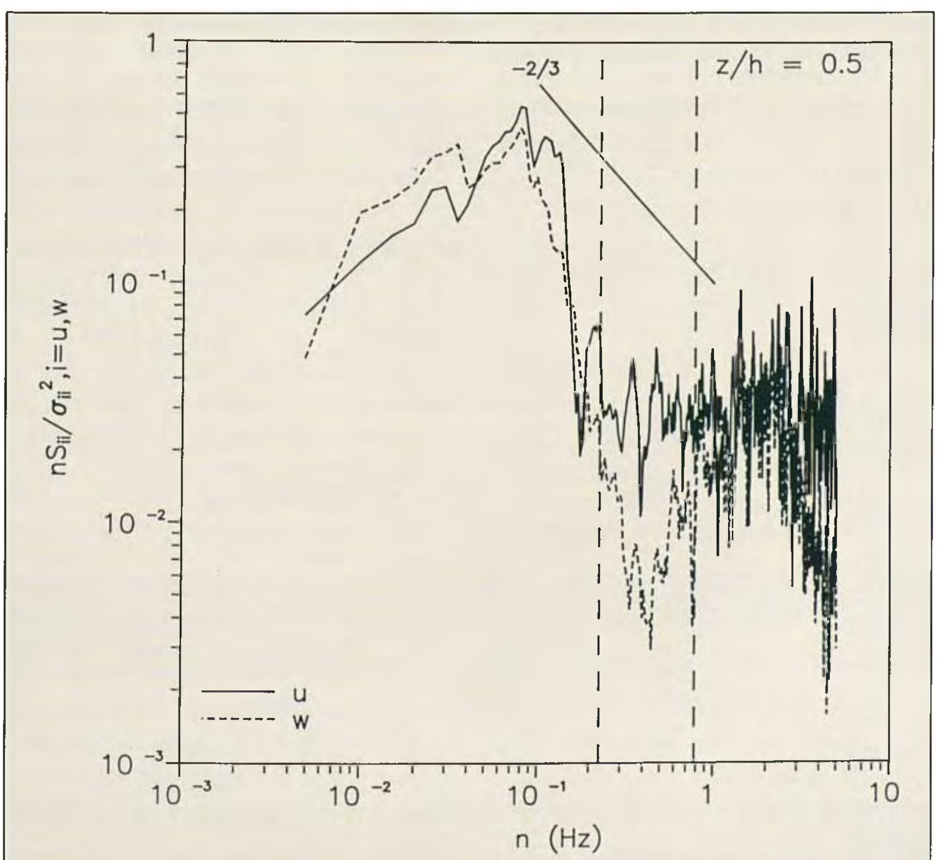


Figure 5. Streamwise (u) and vertical (w) velocity power spectra within the canopy over a 3.4 minute period. The vertical dashed lines represent the estimated upper and lower limits of the resonant frequencies of trees in the forest.

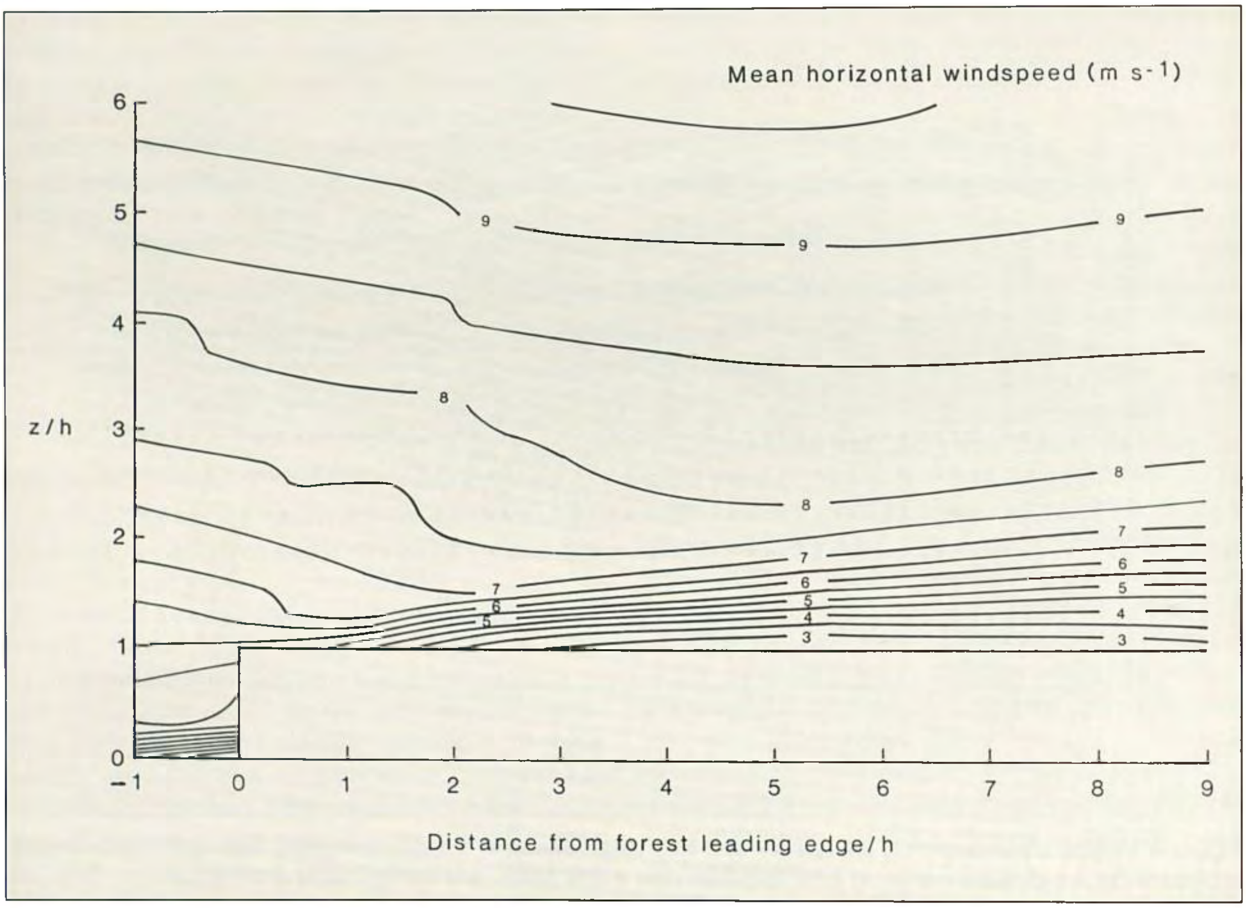
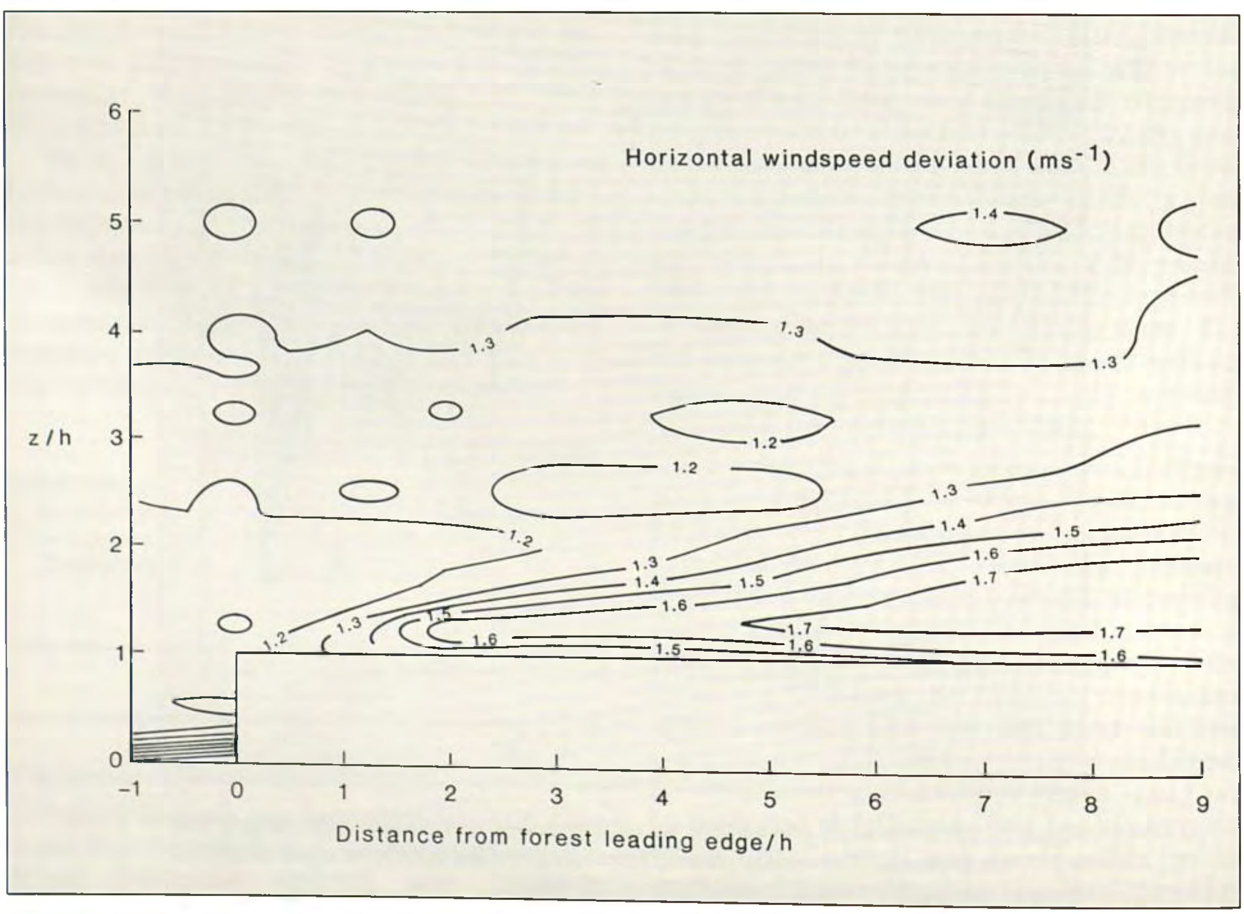


Figure 6. Contours of mean velocity (6a) and velocity standard deviation (6b) across a model forest edge. Higher standard deviations are an indication of greater turbulence.



the boundary layer behind the edge of the forest and shows the reduction in mean flow and corresponding increase in turbulence intensity at the top of the canopy.

BARRY GARDINER

REFERENCES

GARDINER, B.A. (1992a). Wind and wind forces in a plantation spruce forest. Submitted to *Boundary Layer Meteorology*.

GARDINER, B.A. (1992b). Mathematical modelling of the static and dynamic characteristics of plantation trees. In, *Mathematical modelling of forest ecosystems*, Franke J. and Roeder, A. (eds.). Sauerlander's Verlag, Frankfurt am Main; 40-61.

GARDINER, B.A., STACEY, G.R., BELCHER, R.E. and WOOD, C.J. (1992). Minimising windforces in a spruce forest: wind tunnel and field studies on thinning and respacing. Submitted to *Forestry*.

STACEY, G.R., BELCHER, R.E., WOOD, C.J. and GARDINER, B.A. (1992). Wind and wind forces in a model spruce forest. Submitted to *Boundary Layer Meteorology*.

Applied studies

Data collected in past years to validate and improve the Windthrow Hazard Classification (WHC) are now yielding worthwhile results.

A revised set of windiness scores have been calculated from the tatter flag records using multiple regression analysis. This provides objective scores for region, elevation, topex and uses the individual topex sector values to derive both an aspect and funnelling effect. The impact of these scores has been tested on the established windthrow monitoring areas (Quine and Reynard, 1990) in an exercise that has demonstrated the use of Geographic Information Systems (GIS). Topex was calculated from digital terrain models (DTM), and combined with elevation (also from the DTM), wind zone and soil (digitised soil map) using a PC-based GIS 'IDRISI'. DTM derived Topex measurements were found to be well correlated with field measurements; they could also be obtained at greater intensity, and for horizons masked by trees. Hazard class distribution under the new and existing schemes was compared, and the impact assessed (see Table 6).

The same GIS was used in an analysis of historical data for Kershope and Bowland forests as part of a review of terminal heights used in north England forests. Recently there have been indications that terminal heights (Miller, 1986) are pessimistic but the role of the annual variation in windiness has been hard to unravel. Information on the presence of windthrow was obtained for sample years spanning the period 1959–1990 at Kershope and 1981–1988 at Bowland. The actual amount of windthrow was compared with predictions generated from top height/hazard class relationships. At Bowland there was no suggestion that the WHC was pessimistic, whereas at Kershope there was strong evidence that damage was being over-predicted. As a consequence an increase of terminal heights in the Kershope/Kielder areas was recommended. Investigations continue to identify the differences between these study areas of apparently similar hazard class.

Both the Kershope and Bowland studies and the ongoing analysis of the windthrow monitoring areas demonstrate considerable variation in individual compartment behaviour against the hazard class standard. This indicates the need for further refinement of the WHC, including the development of a more probabilistic assessment of windthrow risk. Such a system will result from the integration of applied and fundamental studies and plans to develop this model are being made.

CHRIS QUINE, ANGUS MACKIE, JIM WRIGHT* AND JOHN MAYHEW**
* = consultant, ** = student

REFERENCES

QUINE, C.P. and REYNARD, B.R. (1990). *A new series of windthrow monitoring areas in upland Britain*. Forestry Commission Occasional Paper 25. Forestry Commission, Edinburgh.

MILLER, K.F. (1986). *Windthrow hazard classification*. Forestry Commission Leaflet 85. HMSO, London.

Table 6. Examples of the change in hazard class due to new windiness scoring system in four windthrow monitoring areas

	Percentage of windthrow monitoring area			
	Decrease by 1 class	*No change*	*Increase by 1 class*	*Increase by 2 classes*
Leanachan	0	3	94	3
Rosarie	9	73	18	
S. Kintyre	24	76		
Kielder	63	34		

Nutrition of trees on restock sites and in the forest nursery

Work has continued on an age-series of five Sitka spruce sites in Kielder Forest, Northumberland. This study aims to quantify the physical and nutritional roles of harvest residues in relation to tree growth on second rotation sites. During the last year attention has focused upon two of these sites. Detailed analyses of one site in the age-series have been carried out because a comparison is possible between whole-tree and conventionally harvested plots. These areas were harvested in 1980 and replanted in 1981. Results showed that whole-tree harvesting significantly ($P<0.05$) reduced second-rotation tree growth over a period of 10 years (Proe and Dutch, in press). In plots where residues were retained, trees planted through residues grew better ($P<0.05$) than trees planted in adjacent areas which were free from residues, but only for the first 3 years. These results were reflected in tree biomass and nutrient content. Trees on whole-tree harvested plots had 12 000 kg ha^{-1} less biomass and 50, 5 and 20 kg ha^{-1} less nitrogen, phosphorus and potassium respectively, compared with trees established on conventionally harvested plots.

Progress continues to be made on a project to improve nitrogen top dressing regimes in forest nurseries. Patterns of seasonal nitrogen uptake for a range of species have now been quantified in seedbeds at Newton nursery, Moray. These are now being compared with results from polyhouse studies. Nitrogen uptake will also be compared with predictions of soil nitrogen availability made at the start of the growing season based upon soil analyses. Early results show substantial differences between species in their recovery of both soil nitrogen and that added as fertiliser. New fertiliser regimes will be developed and tested based upon these initial experiments.

MIKE PROE*, JANET DUTCH AND JOHN MORGAN
* Macaulay Land Use Research Institute

REFERENCE

PROE, M.F. and DUTCH, J. (in press). Impact of whole-tree harvesting on second-rotation growth of Sitka spruce: the first 10 years. *Forest Ecology and Management.*

Silvicultural initiatives

Community woodlands

Silviculture (North) staff have been involved in the support of a number of Community Woodland initiatives throughout Scotland, north England and Wales. The work has included giving general silvicultural advice, establishing experiments to tackle specific site-related problems and preparing plans for demonstration plots to highlight the range of possible silvicultural options. Particular features include: developing two existing experiments in North Uist to demonstrate the potential of crofter forestry in the Highlands and Islands of Scotland; preparation of a plan for a large demonstration in the Blantyre Ferme community woodland near Glasgow; an experiment to compare a range of establishment and protection options on agricultural ground in the Cleveland Community Forest area. This work complements that being carried out by Silviculture (South) in lowland England (see page 6).

DEREK NELSON, TONY SHARPE, JOHN MCNEILL, PAUL GOUGH, BOBBY HOWES AND NEVILLE DANBY

Poplars

Potter *et al.* (1990) reported the early results of two experiments in southern England testing the growth rates of a range of new poplar hybrids imported from Belgium. In 1991, five further trials were established in Scotland (2), north England (2) and Wales to compare the

Table 7. First year height increment (cm) from three poplar clonal trials planted in 1991

Clone	Site and region: Newtown 8 (Wales)	York 5 (N. England)	Kirkhill 6 (N. Scotland)
Scott Pauley	119	118	66
Beaupré	118	140	66
Boelare	111	139	57
Fritzi Pauley	104	118	*
Trichobel	97	137	61
Gibecq	88	111	67
Columbia River	87	92	58
Ghoy	81	111	44
Primo	77	79	*
Gaver	75	104	*
Robusta	36	71	18

* not planted in this experiment

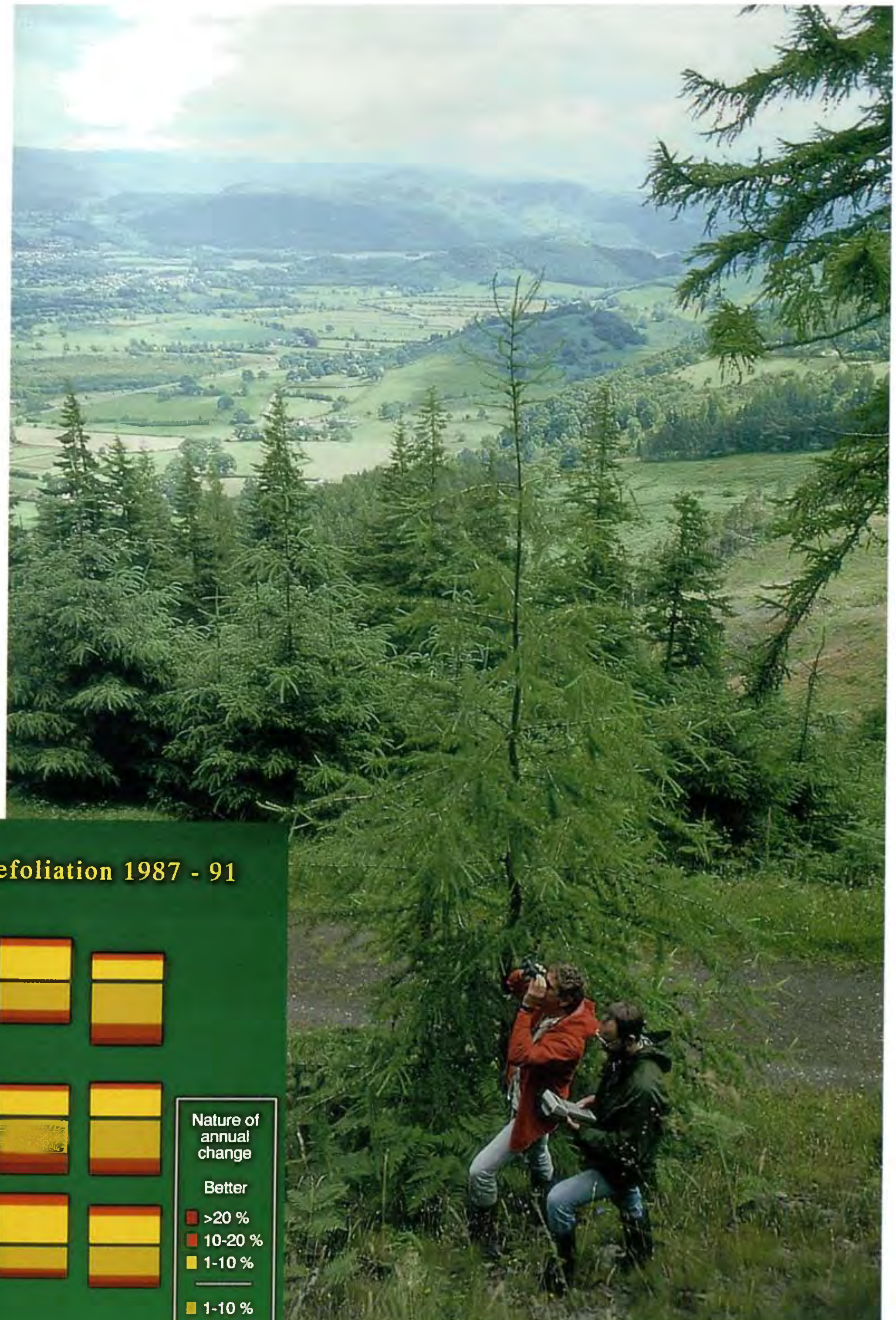


Plate 1 Foresters recording tree condition at one of the 369 plots of the 1991 forest monitoring programme. (40589)

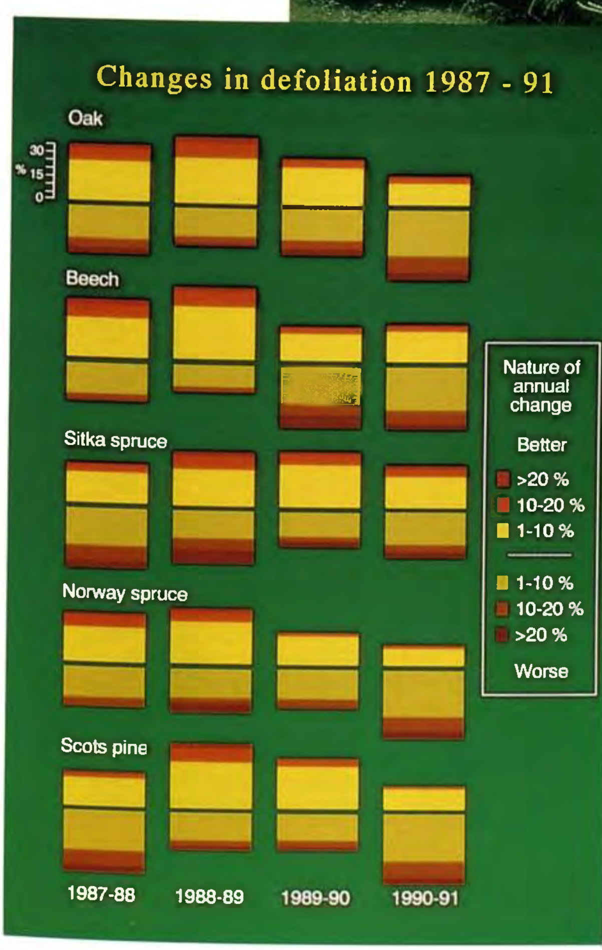


Plate 2 Annual fluctuations in crown density, 1987 to 1991. The scale bar at the top left of the figure indicates the percentage of the total sample of trees that improved or deteriorated by a specified amount. The colour key on the right indicates the degree of change. See text on p. 17 for further explanation.

Plate 3 Inchnacardoch expt 45/28, transect 3
Ground surface, peat depth and peat water content (kg water kg solids^{-1}), May 1991

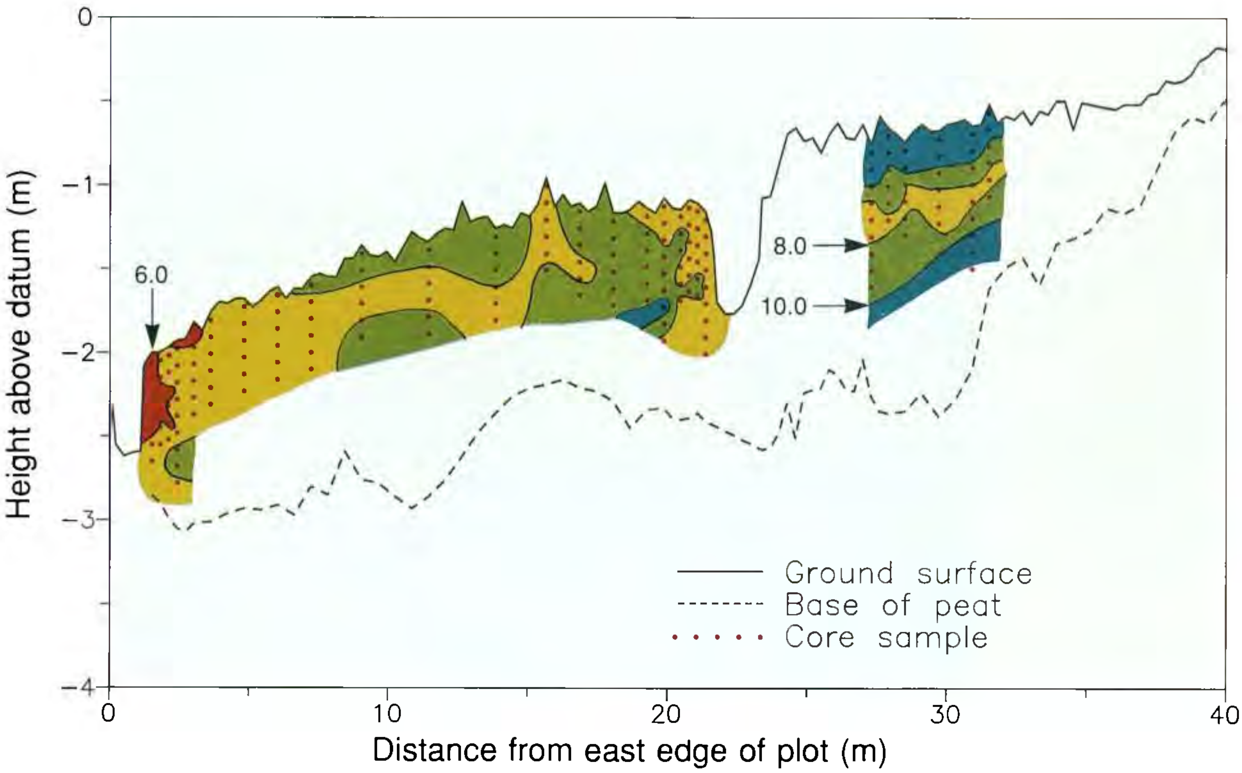


Plate 4 Inchnacardoch expt 45/28, transect 3
Ground surface, and peat depth, May 1991
Water-table depth, June-July 1991

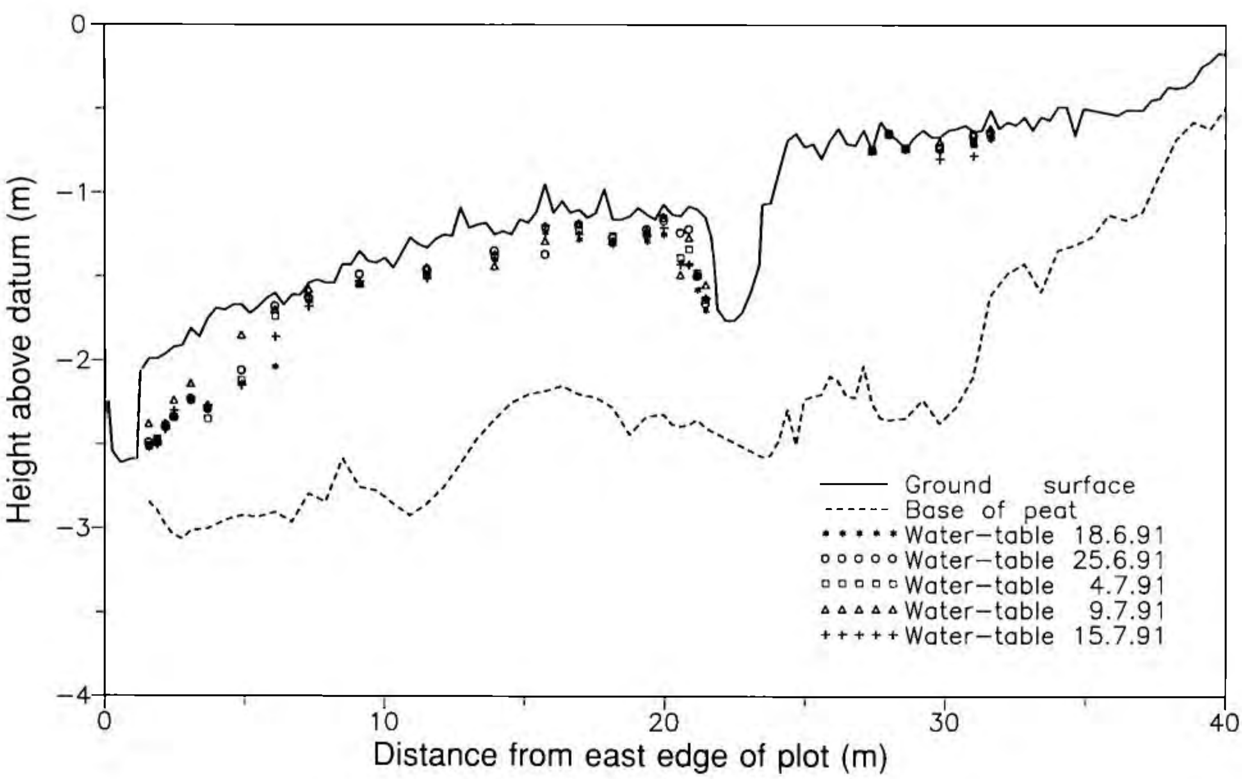


Plate 5 Water surface before draining – Kielder 125/89
22 August 1990

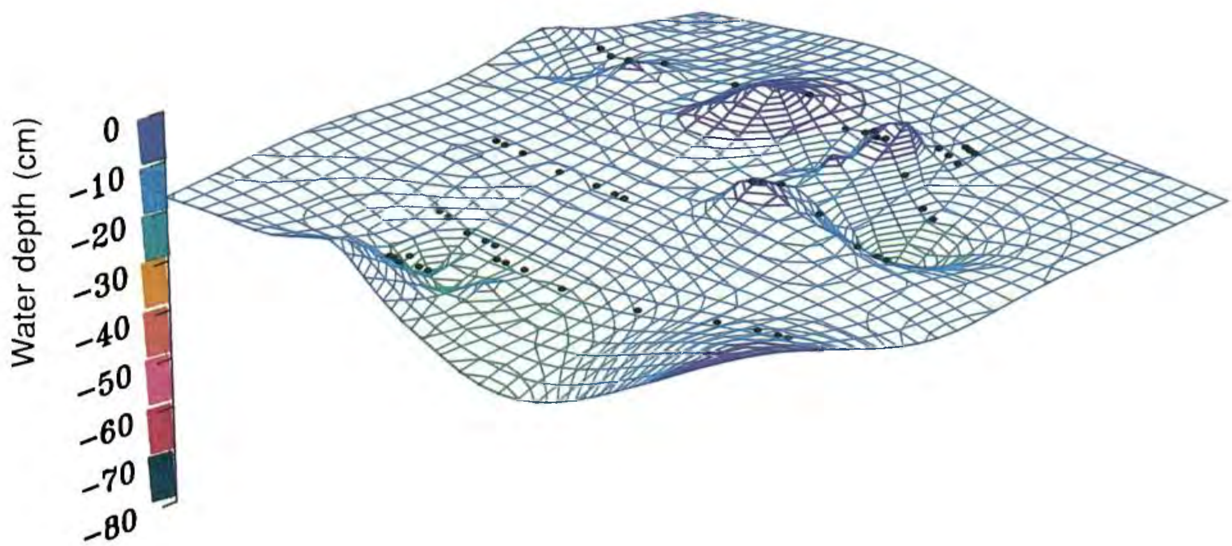


Plate 6 Water surface after draining – Kielder 125/89
21 August 1991
The black line is the Z drain

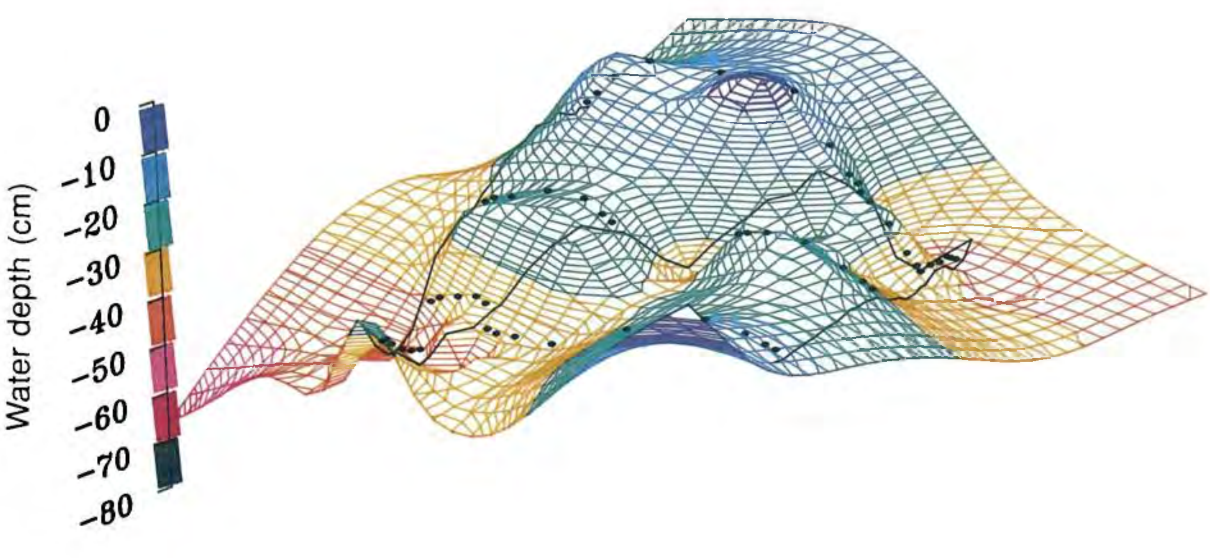


Plate 7 London plane in Trafalgar Square photographed in June 1992 showing severe damage from de-icing salt applied the previous winter. (401000)

Plate 9 Computerised tree ring measuring system. (40557)

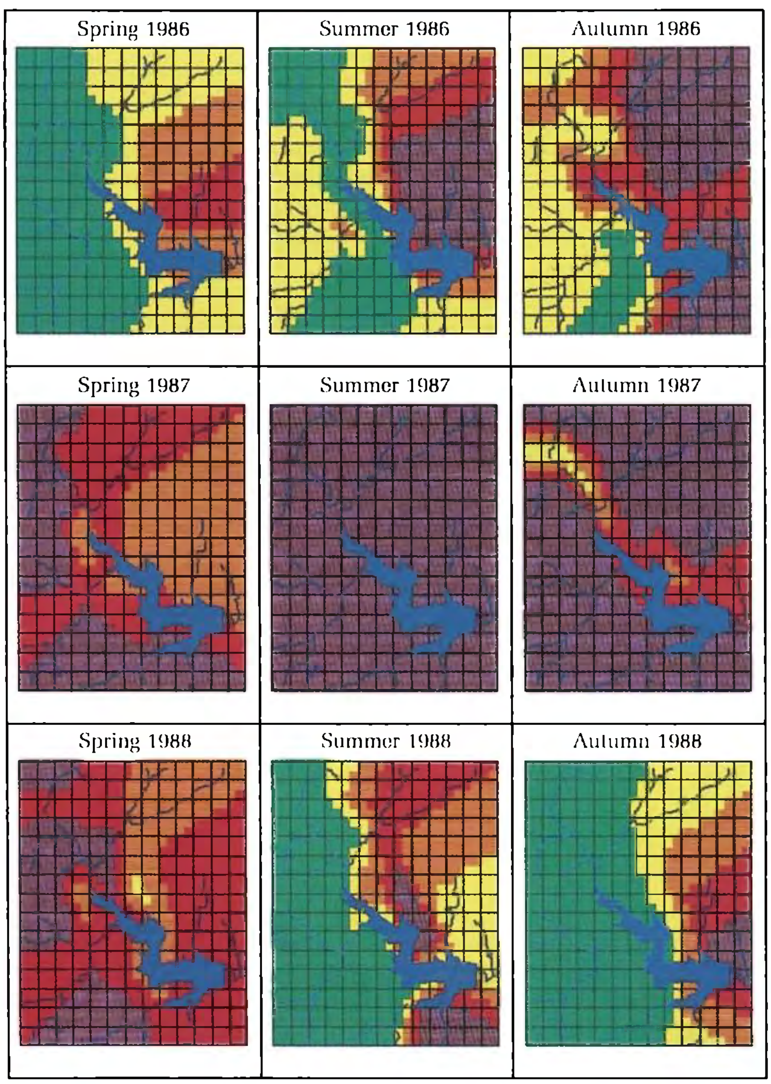


Plate 8 Spatial abundance of field voles in Kielder Forest during one 3-year vole cycle. Kielder Water is shown in the centre of each map. Each square is 1x1 km. The maps predict vole abundance in suitable habitat. No adjustments have been made for unsuitable vole habitat. Vole abundance is an index based on fresh grass clippings in vole runs, values are green <4.5, yellow 4.5-7.4, orange 7.5-10.4, red 10.5-13.4 and purple >13.4. The algorithm used to produce the maps was a modification of that described by Akima (1978)

growth rate of these clones (Primo, Ghoy, Gaver, Gibecq, Beaupré, Boelare, Trichobel and Columbia River) with three standard clones (Robusta, Scott Pauley and Fritzi Pauley). These new trials will extend the geographical range of sites in Britain. The two sites in Scotland are thought to be marginal for good poplar growth and so should prove to be particularly testing. Overall survival of the 1-year-old unrooted cuttings was reasonable to good and the growth rate has been particularly noteworthy (Table 7).

DEREK NELSON, BOBBY HOWES, CHRIS JONES, ALISTAIR MACLEOD AND MIKE RILEY

REFERENCE

POTTER, C.J., NIXON, C.J. and GIBBS, J.N. (1990). *The introduction of improved poplar clones from Belgium.* Forestry Commission Research Information Note 181.

Farm woodlands

As part of a joint investigation with the Scottish Agricultural College (SAC) into factors affecting the establishment and early growth on new farm woodlands (*Report* 1991, p. 24), two experiments were established in 1990 on each of three SAC owned farms at Edinburgh (hereafter 'Bush'), Ayr ('Kyle') and Aberdeen ('Kirkhill'). The sites cover the different climatic regions of Scotland where farm forestry could be expected to expand.

One experiment investigated the impact of weed control on growth, while the other assessed the impact of site preparation (i.e. the presence or absence of ploughing, four levels of weed control), site and climatic factors (soil temperature, rainfall, windspeed, sunshine hours, air temperature and extractable soil nitrogen at three depths) on tree growth. In this experiment monthly assessments of tree height, site and climatic factors were carried out throughout 1991 by the collaborators in an attempt to determine the most important factors affecting tree growth. SAC staff have carried out studies of the development of the ground flora.

Experiment 1 – The impact of weed control

Tree growth was markedly better on the more sheltered ex-arable site at Bush than on the more exposed ex-pasture site at Kyle. Maintaining a 1 m diameter weed-free spot resulted in an overall improvement in height growth but the differences tend to be small particularly with the conifers. At Bush where there were few weeds present at planting and weed competition was comparatively light in the early part of the first growing season, height growth of trees in the unweeded control plots was also satisfactory. Diameter growth followed a very similar pattern at both sites, though the improvements due to weeding were much more marked.

Experiment 2 – Impact of site and climatic factors on tree establishment

At Bush, the greatest impact on both height and diameter growth was due to the effect of weed control (all levels of weed control have been amalgamated as the results were very similar). Trees planted on a very shallow ploughed ridge at Bush showed reduced growth on this freely draining soil after a drought in 1990. At the two other sites on gleyed soils both ploughing and weed control improved height and diameter growth. The monthly height increment figures showed a different response of Sitka spruce and sycamore over the summer months with the latter showing a much greater benefit from weeding.

DEREK NELSON, MIKE HOLLINGSWORTH, MIKE RILEY AND ALISTAIR MACLEOD

SITE STUDIES SOUTH

In 1991 the Branch hosted visits by the Forest Soils Discussion Group, Research Advisory Committee and by a Visiting Group appointed by this committee. These groups have looked at the reclamation work undertaken on the South Wales coalfield, a liming trial and associated water quality work at Llyn Brianne *(Report* 1991, p.23), one of the sample plots of the forest monitoring programme and at the open-top chamber experiments; their comments have shaped progress with these projects over the year.

The condition of 8843 trees was assessed in this year's forest monitoring programme and an account of the last 5 years of work on this project is given on p.17. A project on tree planting on landfill sites which was funded by the Department of the Environment was completed.

A 3-year project, funded by British Coal, on the ability of trees to grow on opencast coal spoil *(Report* 1990, p.26) has shown that the ways of selecting spoil and placing it ready for tree planting should be reviewed. Spoils with a large content of alkaline shale, and of high pH and magnesium content should be rejected in favour of those containing more sandstone material. Placement by 'loose tipping' can now be recommended in order to minimise soil compaction, and infertility is best redressed using sewage sludge. Research continues on the use of sewage sludge on poplars and beech, on nitrogen-fixing by alders and further work on landfill sites is proposed.

The investigation of air pollutant impacts using open-top chambers is now in its fifth year and the main effects are becoming increasingly clear (see Research Information Note 221). At Headley the leader extensions of beech and Norway spruce have been significantly depressed in ambient, polluted air. The patterns of leader extension indicate that growth depressions have resulted from the cumulative effects of ambient pollutant concentrations rather than acute foliar damage at this site. At Chatsworth and Glendevon, no growth depressions have been detected in ambient air, but subtle effects, such as increases of needle weight, have occurred. These results indicate that the effects of air quality are site specific, being dependent on the pollutant mixture and concentrations. The adverse effects seen at Headley are primarily attributed to ozone episodes which occur during hot weather so that effects are also associated with periods of soil moisture deficit. The chambers have been increased to heights of 3.4 m at Headley and Glendevon to extend the present experiment and allow the initiation of work on elevated concentrations of carbon dioxide.

Concern continues to focus on the role of forestry in surface water acidification. Mature forest stands appear to be more effective at capturing atmospheric pollutants than shorter moorland vegetation. In 1991 a joint project was initiated with the National Rivers Authority (Welsh Region). The water chemistry of ten forested and two moorland catchments is being monitored to identify the long-term influence of pollutant 'scavenging' by forests. This study will complement other long-term catchment-specific studies which are underway. A small working group with representatives from the Scottish Office and National Rivers Authority has been responsible for revising the *Forests and water guidelines.* Updated guidelines with recommendations on how to minimise the problems caused by the interception of acidic pollutants by forests were released in December 1991. Concern has also arisen over the loss of ammonium in runoff water following aerial application of urea fertiliser. Even though use of this fertiliser in forestry is limited, it was decided to measure ammonium at six sites where urea has been applied. A number of other experiments have been established to test the effectiveness of the key measures in the *Forests and water guidelines,* and a new project has been initiated to assess the effects of harvesting on site.

A large number of foliar samples were submitted for chemical analysis: 7400 samples have been analysed for macronutrients, 340 for non-structural carbohydrates and 77 for chloride content. Water samples have been analysed for pH, conductivity and ammonium content.

Quality control has significantly improved over the last few years and attention is now focused on turnround time and flexibility of service. A number of important jobs were completed by the Instrumentation Section during the year, including Tullgren funnel banks for extracting soil animals, a photocell unit for counting bats, a 'red squirrel only' hopper, a glasshouse propagation bench for Bedgebury, a large number of soil water lysimeters and a new welding bench for the workshop.

PETER FREER-SMITH

FOREST MONITORING PROGRAMME 1987–1991

The forest monitoring programme evolved out of the annual forest health surveys which were started in 1984. The forest health surveys were initiated in response to the fear that acid rain might be affecting the health of forests in Britain. Over the first few years of the survey it became apparent that in order to make cause-effect inferences, a larger number of tree and site parameters would have to be assessed. In addition, it was discovered that there were inconsistencies between observation teams throughout the country. Comparisons with surveys being done in Europe revealed that there were also major differences between the British programme and those being conducted elsewhere. In recent years great care has therefore been taken over observer training and the intercalibration of the observation teams, and a calibration exercise has been undertaken with other European countries. As a result of these difficulties, the project was completely overhauled in 1987. Regrettably, the extent of the changes was such that the data collected prior to 1987 were not comparable with those collected afterwards. However, since 1987 the data collected in the forest monitoring programme are amongst the best that have been collected in Europe.

A wide variety of indices are assessed on individual trees. These include observations of the condition of the canopy (Plate 1) including the crown density, any discoloration of the foliage, the branching structure, evidence of mechanical damage within the crown, evidence of insect and fungal problems, and a number of other indices. In addition, records are kept of any other factors that might affect the condition of the trees, including evidence of damage to the stems, butts and roots. These data are collected by approximately ten observers from Forest Surveys Branch. Hand-held computers are used to record the data and this has greatly speeded up the transfer of data from the field to the annual report of the programme. This has now become so efficient that the annual results are known within a couple of days of the end of the period of data collection. Until 1991, annual results were published in the form of a Forestry Commission Bulletin. However, the 1991 results were published as a Research Information Note (No. 209).

The results for defoliation (crown density) from 1987 to 1991 are given in Plate 2. The scale bar at the top left of the figure indicates the percentage of the total sample of trees that have improved or deteriorated by a specified amount. The colour key on the right indicates the degree of change, thus for oak in 1988 (the top left-hand bar) the crown density in approximately 25% of the trees improved by between 1 and 10%, and about 10% of the trees improved by either 10–20% or more than 20%. Approximately 20% of the trees deteriorated by between 1% and 10% and about 5% and 3% deteriorated by 10–12% and more than 20% respectively.

As illustrated in Plate 2, the annual programme has revealed marked fluctuations in the condition of trees from year to year. The most obvious factors affecting trees appear to be related to the weather. For example, the storms in southern England in 1987 and 1990 had a major impact on trees in the areas that were affected. Mild winters result in an increased abundance of insects, particularly the green spruce aphid (*Elatobium abietinum*), and these have quite severe effects on species. The droughts of 1989 and 1990 have been of particular importance in recent years. These caused a marked deterioration in the condition of trees over much of the country and trees are still in the process of recovering from the stress. The monitoring programme will continue for some time as, with each new year of data, the value of the records increase substantially.

JOHN INNES

THE POTENTIAL FOR WOODLAND ESTABLISHMENT ON LANDFILL SITES

There is considerable interest in the establishment of trees on sites used for the disposal of waste materials. Landfilling is intimately associated with sites used for mineral extraction, and infilling with wastes is used more and more to raise the restored ground surface to a similar level to that before mineral extraction. Increasingly, restoration of mineral sites to woodland must embrace the possibility that landfilling materials occur beneath the soil cover. In addition, many sites for woodland establishment within designated areas of Community Forests have been previously used for the disposal of wastes of various kinds. It is important, therefore, that the special problems posed by landfilling are appreciated, and that appropriate remedies are identified before tree planting takes place. A desk study of the potential for woodland establishment on landfill sites was commissioned by the Department of the Environment to examine how landfilling influences tree growth, and how the presence of trees may affect pollution control measures on modern capped landfill sites.

Landfill gases, principally methane and carbon dioxide, and leachates containing a range of inorganic and organic substances, are the main causes for concern. Landfill gas is produced by the decomposition of organic constituents of waste materials. It can kill vegetation if it gets into the root zone because it displaces oxygen necessary for root respiration. Minor constituents of landfill gas can cause abnormal root growth. Leachate, too, can cause soil anaerobism and vegetation regression. For these reasons, modern landfill sites are capped with impermeable materials so that the soil above remains uncontaminated.

Landfill capping is an essential part of the restoration process before tree planting can be considered. On old sites which lack satisfactory caps, trees may fail if putrescible materials remain in the wastes beneath. Uncertainty over the ability of tree roots to penetrate landfill capping materials has been an important reason why only limited tree planting has taken place on modern sites. If tree roots can disrupt the landfill cap, rainfall ingress into the waste materials, and leachate production, could increase. However, the review has indicated that tree roots are unlikely to penetrate through a highly compacted clay cap or synthetic cap.

Other standards must be adopted in the restoration of landfill sites for woodland. It is important that there is an adequate thickness of rootable (i.e. uncompacted) soil materials above the cap. Loose tipping methods (*Report* 1991, p.18) are advisable for soil placement, and a minimum thickness of 1.5 m has been suggested to provide a satisfactory rooting environment (Figure 7). Tree species suitable for planting on landfill sites have been identified, including most that are suitable for conventional sites restored after mineral extraction. On particularly exposed sites where there may be a risk of landfill cap exposure if windthrow occurs, it may be necessary to choose species which are relatively small at maturity, or to practise coppice methods of woodland management. The contract report *(The potential for woodland establishment on landfill sites)* has been published by HMSO for the Department of the Environment (1993).

ANDY MOFFAT AND MARTIN DOBSON

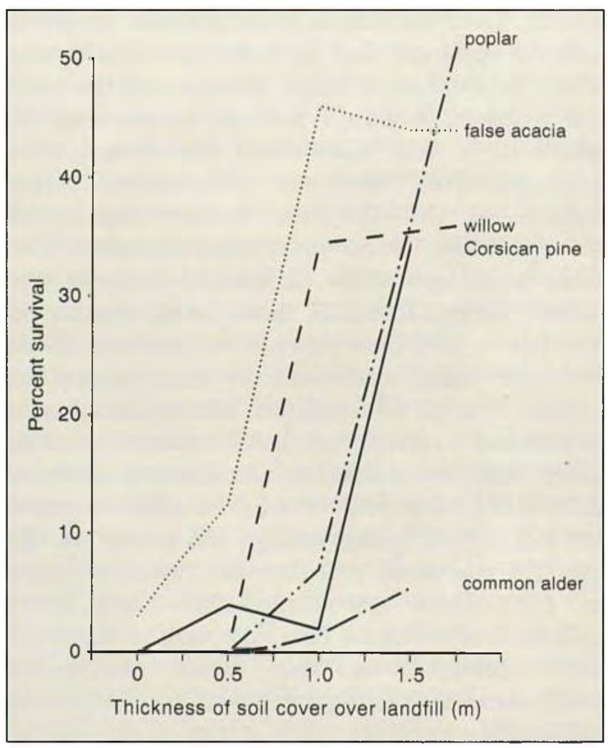


Figure 7. Tree survival as affected by thickness of soil cover over landfill.

SITE STUDIES NORTH

During as visit to British Columbia, Canada in the autumn of 1991 D. G. Pyatt and C. J. Nixon (Silviculture (North)) were impressed by the principles and practices of the Biogeoclimatic Ecosystem Classification (BEC) system which has formed the basis of resource management in the Provincial Forest Service for 15 years. The system has been developed for the natural forests of British Columbia, but the undoubted similarities of climate between parts of that province and Britain suggest that most features of the system could have similar application here. A project plan has been written to develop a BEC for Britain; such a system would incorporate our existing soil/site classification. It would have an application beyond silviculture, including conservation and the wider environmental aspects of land management.

Deep peats

In 1928 a series of six simple drainage experiments was laid down at the request of G. K. Fraser of the Macaulay Institute, Aberdeen. At each, a 20 m square of blanket peat was isolated with a deep ditch, with the intention of observing any shrinkage of the peat or change in the ground vegetation. Over the ensuing 20 years little of either was reported and the experiments were taken to demonstrate that blanket peat was virtually undrainable.

Long-term effects of drainage are of renewed interest because plantations may have adverse effects on adjoining peatlands of conservation value. The peat square at the Lon Mor, Inchnacardoch Forest (Highland) was looked at in detail in 1991. After 63 years the vegetation has changed dramatically, being dominated by *Molinia caerulea* whereas Zehetmayr (1954) reported that "...after 20 years the vegetation type with dominant *Scirpus* (*Trichophorum*) remains unchanged except within a foot or so of the drain...".

Ground level and peat depth were measured along three parallel transects across the plot and cores of peat were taken to 60–90 cm depth. Peat water content was measured for each 10 cm depth section. The transects were extended across the ditch into the adjacent bog on the uphill side of the plot and further peat cores taken. The holes from which the cores were taken were lined with perforated tubing and, after a suitable equilibration period, used to measure the depth of the water-table. Water contents and water-table depths for one of the transects are shown in Plates 3 and 4; results for the other transects were very similar.

Peat water content has been reduced and the depth of the water-table has been lowered, but major changes are confined to within 4 m of the ditch. The increase in the frequency of *Molinia* has been noticed on many parts of the Lon Mor research area and is not thought to be due to drainage alone. *Sphagnum* species are probably a more sensitive indicator of drainage conditions. These are still common on the plot except within 2 m of the ditch.

Graham Pyatt

REFERENCE

ZEHETMAYR, J.W.L. (1954). *Experiments in tree planting on peat.* Forestry Commission Bulletin 22. HMSO, London.

Clay soils

The assessment phase of the 'Z' drainage demonstration (see *Report* 1989, p.32; *Report* 1990, p.32 and *Report* 1991, p.25) will be completed in the summer of 1992, some 12 months after the excavation of the 'Z' ditch in May 1991. The preliminary analysis shows that before drainage there were regions of both 'wet' and 'dry' soil within the demonstration (Plate 5). The wet areas had shallow year-round water levels, whereas dry areas showed greater fluctuation in response to rain or no-rain. Following drainage there was a response close to the ditch, and particularly near the points of the 'Z' ditch (Plate 6).

Duncan Ray

Soil temperature

Difficulties and high costs in restocking with Douglas fir prompted this Silviculture (North) experiment in ground preparation and plant type. Soil and near-ground air temperatures were measured for a range of ground preparation treatments on a steeply sloping brown earth at Corris Forest in Powys (see *Report* 1990, p.15).

Three-year survival and height growth were good in all treatments (Table 8) with the best growth in the plots cultivated with the TTS Delta disc-trencher (DI and PL) and the poorest in the mounded (SM) ones, though differences were not significant.

Soil temperature 10 cm below the planting position in each ground preparation type is shown in Figure 8. Mounds (SM) had a more variable soil temperature regime than the other types. Daily soil temperature fluctuations at 20 cm depth were smaller than those at 10 cm. Night air temperatures were marginally higher in SM and NN treatments than in the others. Taking the number of degree-hours above 5°C as an index of root growth in the absence of other limiting factors (Tabbush, 1986) (Table 9), mounding (SM) had a more favourable soil temperature regime during the growing season than the other treatments. It is apparent that the potential benefits of the mounding were not realised in better height growth. This leads us to conclude that either soil temperature was not the main factor limiting growth at this site, or

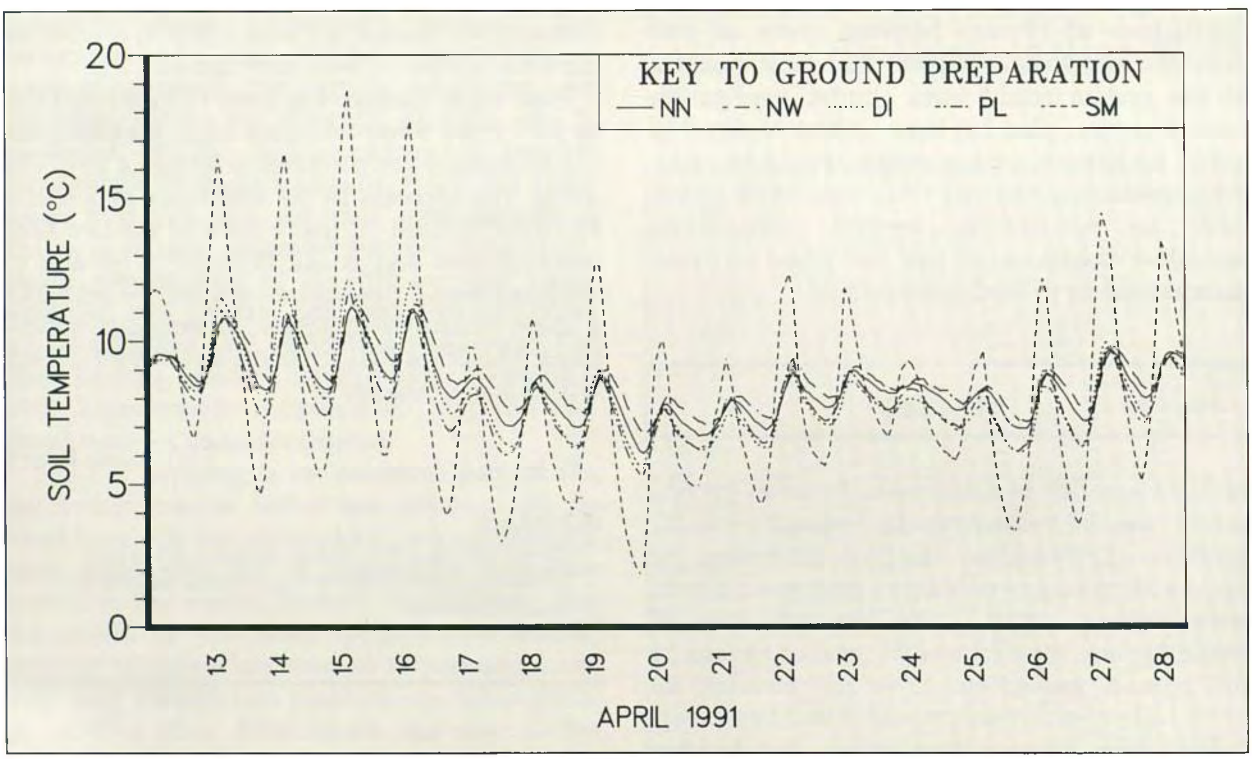


Figure 8. Soil temperature 10 cm below the surface of a Douglas fir restocking experiment. The types of ground preparation are listed in Table 8.

Table 8. Douglas fir 3-year survival and height for the five ground preparation treatments. Differences are not significant

Treatment	*Description*	*Survival (%)*	*Height (cm)*
NN	No cultivation, no weed control	93	92
NW	No cultivation, herbicide after planting	89	92
DI	Delta disc-trencher, intermediate setting	91	104
PL	Ploughing simulated by Delta disc-trencher	92	96
SM	Mounds, dug by hand or machine	92	89

that one of the assumptions we made (e.g. that 5°C is a threshold soil temperature for root growth) was wrong. Trees on the mounds suffered some drought problems in 1989 and 1990 suggesting that growth may have been limited by water availability.

RUSSELL ANDERSON

REFERENCE

TABBUSH, P.M. (1986). Rough handling, soil temperature and root development in outplanted Sitka spruce and Douglas fir. *Canadian Journal of Forest Research* **16**, 1385–1388.

Table 9. Degree-hours above 5°C over the growing season. Asterisks indicate estimated values, due to partial instrument failures

Month	*NN*	*NW*	*DI/PL*	*SM*
APR	51	36	37	30
MAY	145	134	132	146
JUN	240*	237	228	261
JUL	318*	315	305	356
AUG	235	243	237	254
SEP	212	216	212*	220
OCT	169	168	166	160
NOV	103	88	91	79
MEAN	184	180	176	188

TREE IMPROVEMENT

Resource allocation within the Branch now more accurately reflects the proportion of conifers to broadleaves in the forest estate, namely 70:30. The effort on broadleaves has been concentrated on oak, ash and sycamore. Dr Harmer briefly reviews progress with oak in the following section of the report. Research on vegetative propagation and selection of oak clones will be curtailed with Dr Harmer's transfer to Silviculture (South) Branch, but the performance of clones planted out will continue to be monitored, The comprehensive IUFRO seed origin trials with pedunculate and sessile oak are being planted out on nine experimental sites and establishment and early growth has been very satisfactory in the lots planted to date. With increased interest in birch species, natural stands in some parts of the country have been examined in terms of quality and a few individual good phenotypes selected. After this preliminary work is complete discussions on implementing a tree breeding and/or gene conservation programme will take place with other interested parties.

Good progress is continuing to be made in the genetic improvement of broadleaves for farm forestry. About 5% of the ash and sycamore stands visited in England and Wales were of seed stand quality. Seedlings from ten sycamore stands were planted out in field trials on agricultural land in spring and it is anticipated that ash material will be planted out in 1993. Vegetative propagation of these species has proved to be variable but some stock plants are in cultivation at Alice Holt.

The main effort of the tree improvement programme is on Sitka spruce and a review of the current status and desired future programme is presented as a separate contribution. Progress outlined for Sitka spruce depends on the level of continued resource allocation, but some reduction is inevitable to meet demands for work on other species. The Branch is collaborating with several other European institutes in a bid to obtain a substantial EC grant to investigate the scope for breeding and selection of Douglas fir. If successful this would assist in initiating a tree improvement programme for Douglas fir to meet the needs of British forestry. Meanwhile work on larch, particularly on flowering and progeny testing, is continuing.

The biochemical work of the Branch has increased with the start of a project on use of isoenzymes to assist in the identification of genotypes of Sitka spruce. Another study on resin characteristics and susceptibility of Sitka spruce to aphid attack, is reported on separately as a joint Physiology/Tree Improvement project. This year the Forestry Commission placed a research grant in the form of funding for a PhD student at Nottingham University to produce transgenic plants of Sitka spruce. This project builds on the research carried out at Northern Research Station on tissue culture of Sitka spruce. The objective is to have this technology available if at some future date we want to use this route for example to provide greater disease or insect resistance. During the year the role of rejuvenation in our Sitka spruce breeding programme was reviewed and a brief resumé of that area of research is also included.

DAVID ROOK

THE SELECTION OF SUPERIOR CLONES OF OAK

The aim of this work is to develop methods of identifying good individuals of pedunculate and sessile oak when they are juvenile and suitable for large scale propagation by cuttings and use in a programme of clonal forestry. Whilst the form of good mature trees is well known, the precise processes of growth that lead to the formation of a good oak tree are poorly understood. This study consists of two projects; the vegetative propagation of oak and the improvement of oak. We are propagating from selected trees and carrying out experiments in order to identify the patterns of growth and development which are characteristic of trees with different stem forms and crown architecture.

Vegetative propagation of oak

This project, which has been active for 5 years, has developed methods for the propagation of juvenile and mature trees, produced material for stock hedges and demonstration plots, and provided material for experiments on branching and growth.

Softwood cuttings, taken from seedlings grown in the nursery, root well if taken at the end of a flush of growth when the leaves are fully expanded and still light green in colour. Between 80 and 100% of cuttings from juvenile material will root in peat based substrates under mist. In contrast, cuttings from trees growing in the field often root very poorly and it is frequently found that no cuttings from mature trees produce roots. Whilst this may be related to the difficulty of collecting good quality cuttings of suitable length, the poor rooting is probably due to physiological changes associated with maturity. Propagation of mature trees is most successful when either epicormic or coppice shoots are used. Unless supplementary light and heat can be provided it is best to overwinter cuttings undisturbed in the rooting substrate before repotting in spring.

Rooted cuttings have been used to establish stock hedges in the nursery at Alice Holt and the research outstation at Shobdon. Demonstration plots of clonal oak have been planted at Alice Holt and Bacheiddeon in mid-Wales.

We are continuing to propagate not only from selected trees growing in the field but also from superior trees initially established by grafting.

Improvement of oak

In order to select juvenile trees it will be necessary to predict whether they will grow to produce superior mature trees. This project has investigated several basic aspects of growth that are important to the understanding of the development of stem and crown form. Experiments have been carried out under both controlled and natural conditions using material produced from acorns and by vegetative propagation. Particular attention has been paid to branching characteristics which are main detriments of growth and timber quality.

Field observations have shown that bud activity during spring generally begins at the tips of the branches and the upper parts of the tree, and progresses inwards and downwards. It is probable that most buds show some development but many absciss or return to dormancy without forming a shoot. The first flush of growth by crown shoots is usually completed by late May/mid-June whereas coppice and epicormic shoots developing from suppressed buds often continue growing until July. There appear to be genotypic differences in the susceptibility to lammas growth but the precise factors controlling episodic growth remain unknown.

Shoots produced during spring growth are shorter than lammas shoots and there are linear relationships between shoot length and numbers of buds and branches. The use of decapitation treatments as a method for selecting clones with different branching characteristics has shown that there are genotypic differences between clones in branch production but the results obtained depend on several factors including nutrition, flush of growth and positioning of treatment cut.

RALPH HARMER AND CORINNE BAKER

PROGRESS OF THE SITKA SPRUCE BREEDING PROGRAMME

A brief resumé of past activities

Figure 9 is a flow chart listing the activities and achievements of the Sitka spruce breeding strategy to date. It has involved the selection, and genetic testing of nearly 3000 'plus-trees'. As information from progeny trials becomes available, superior clones are selected for one of three different breeding populations. The very best clones of each breeding population are brought together to form the production population which supply the new generation of improved growing stock.

Gains from the first generation clonal seed orchards of Sitka spruce breeding are estimated as 15% in final rotation volume, which approximates to one full yield class, and 7% for stem straightness. Gains of 20% and 10% respectively are possible from the most recently composed (control pollinated) family mixtures.

Possible direction for the future

As the first round of selection and testing nears completion, it is time to consider the strategy for the second generation so that gains will be considerable, cumulative and efficiently achieved. We predict 25% gains by the year 2000 (assuming 1990 resources to the Sitka spruce programme continue) by testing and selecting the best full-sib families created between tested individuals.

Increased gain from existing generation: By reducing the number of clones in our production

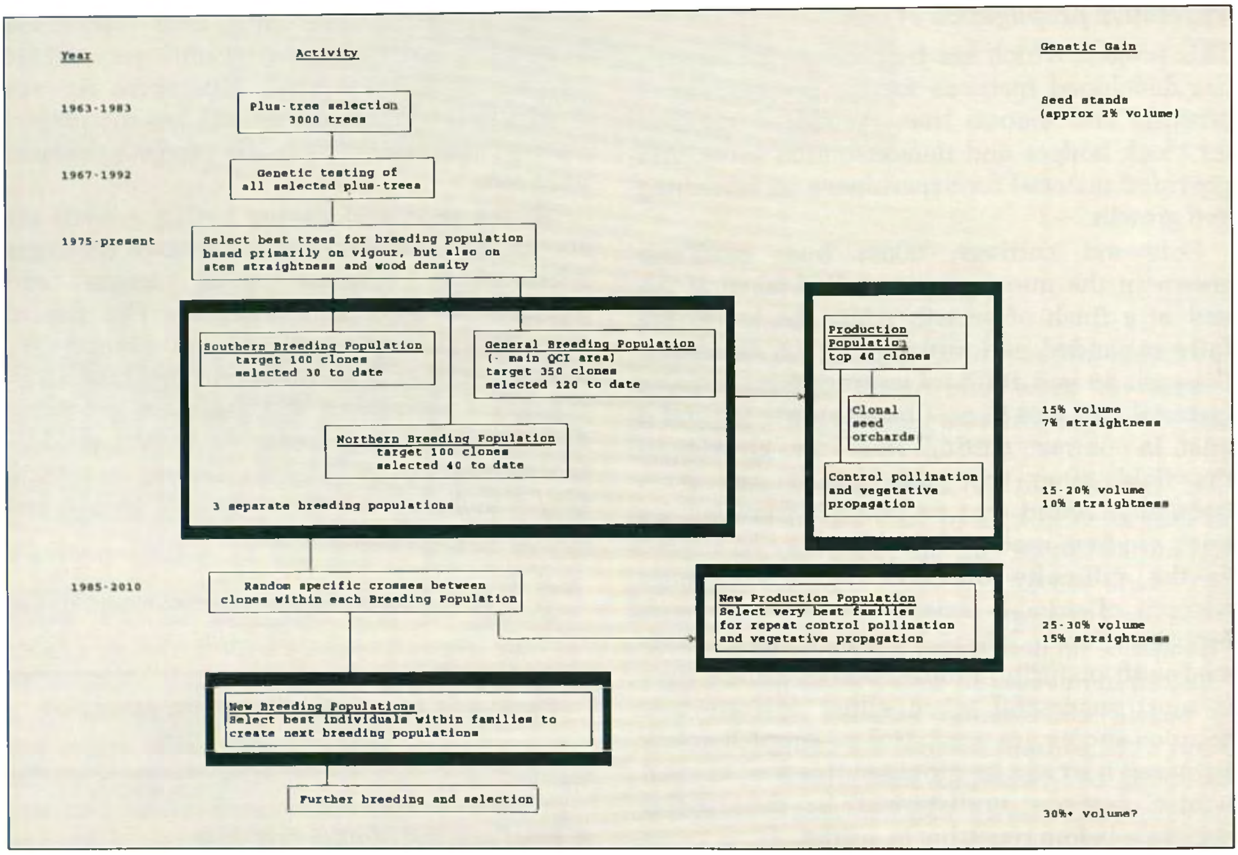


Figure 9. Sitka spruce breeding strategy.

populations from 40 to 25-30 we believe genetic diversity can be maintained at acceptable levels and gains increased by a further 3-4%.

Demonstration of genetic gain: Progeny tests evaluate the genetic values of selected trees. Separate tests are required to demonstrate the genetic gain available from current production populations and anticipated gain from future populations. 'Genetic gain trials' will be established in every district where Sitka spruce is a major species including across Windthrow Hazard Classes.

Full-sib family blocks: We intend to test large areas (>10 ha) of pure full-sib family blocks to compare silviculture and gains per hectare with mixtures of the same families. This could yield valuable information as a precursor to clonal forestry.

Finalise composition of breeding population: Existing progeny tests vary in age from 1 to 20+ years old. There is a need to make early selections in some tests so as to allow advancement into the next generation from a common point in time. This work should be completed by 1995.

Clonal trial: Random selection of individuals within full-sib families for clonal tests will yield valuable information on the extra gain available through full exploitation of all genetic variation.

Early testing: By initially screening families for 3-year height growth on fertile, uniform, agricultural sites the cost of the forest progeny testing programme could be reduced by 40%. Wood quality cannot be assessed until the trees are 15 years old and studies need to be undertaken to see if there is any way this can be reduced to 6 or 10 years.

Experimental design: Single tree plots will be considered as a means of reducing trial size and cost, whilst possibly increasing estimates of family means. In future the tendency will be to concentrate on a different species each year rather than a number of different species within a year. This will reduce the problems of comparison of families and traits across years.

Sub-populations: Create a core population of clones for growth and form for most of Britain and separate populations for:

a. the milder south and west;

b. the harsher far-north;

c. high density.

There will be assortative mating within groups and corrective mating across groups.

STEVE LEE

STUDIES ON THE REJUVENATION OF SITKA SPRUCE

Trees, as they get older and more complex, change from the juvenile phase where flowering is absent and they can be propagated vegetatively, through the adolescent phase to the mature phase, where flowering is present and the plants are almost impossible to propagate vegetatively. In the case of Sitka spruce reliable predictions of performance of individual genotypes of conifers are not made until the trees are up to 15 years old. The tree at this age has passed from the juvenile phase to the mid-adolescent phase where vegetative propagation is difficult. This precludes the vegetative multiplication of selected, tested genotypes unless the individual can be returned to the juvenile phase.

Many authors have reported adventitious bud development on mature explants but little or no subsequent development. Current ideas suggest that rejuvenation of conifers will be achieved only by gradual reversion of the epigenetic changes that occur during maturation. The rejuvenation stimulus will need continual re-application until reversion to the juvenile phase is completed since it is likely that the almost instantaneous rejuvenation that occurs during the sexual reproduction process is a unique event.

A requirement during any study of or attempt at rejuvenation of mature tissues is the ability to measure any change that might occur. A number of morphological, physiological and molecular biological markers have been investigated and it has been found that the best marker of physiological age in Sitka spruce is the level of bornyl acetate in the tissues. It is present in high levels in juvenile tissues and at very low levels or completely absent from mature tissues.

Attempts at the rejuvenation of commercial conifers are being made using *in vitro* techniques. Horticultural treatments on intact plants have been abandoned as they produced no measurable change in physiological age. Callus cultures have been established from adolescent Sitka spruce and hybrid larch needles and roots and rejuvenation attempted via serial subculture. Attempts are also being made to establish embryogenic cell lines from the callus. Intact, first order bud cultures have been established from adolescent and mature Sitka spruce trees and rejuvenation is being attempted by physiological manipulation, i.e. cyclic cold and warm treatment. Adventitious buds have been induced on female strobili of Sitka spruce but they have proved impossible to extend.

ALLAN JOHN

PHYSIOLOGY

The Branch carries out basic research on tree physiology in three areas of specialisation – mycorrhizas, planting stock quality, and roots. The Branch has also made a long-term study of growth decline in some of the Sitka spruce plantations of the South Wales Coalfield. This particular project is now almost complete, and is discussed below.

Much of the work of the Branch has been developed in co-operation with outside bodies, such as the universities and other research stations. International links have been strengthened with the European Community. Work on mycorrhizas and root architecture has benefited particularly from EC co-operation, and there are joint projects with research institutions in France, Denmark, Ireland and Spain. More informal, but nevertheless important, co-operation occurs with organisations in the United States, Germany, Sweden and Finland.

The research into mycorrhizas has concentrated on attempts to enhance growth of Sitka spruce by inoculating seedlings. Although some successes have been achieved, consistent results have proved impossible, and work on this species has almost ceased. Trials with Douglas fir have been more successful. Inoculations in the nursery and field testing have been encouraging.

The work on planting stock quality has been developed over the past 4 years, stimulated by the difficulties of determining, from visual inspection alone, the prospects of survival and optimum growth of planting stock. The research involves handling, transportation, and storage (particularly cold-storage).

Investigations into the development and structure of roots are made with special reference to their architecture as it relates to tree stability. This work is stimulated by the large losses to the forest industry caused by windthrow, particularly on thin upland soils with high water-tables. One of the EC co-operative projects, begun during the current year, is a study of biomass distribution in clonal Sitka spruce trees planted 11 years ago. Tree improvement programmes are usually based on selection for above-ground characteristics, especially growth rate. A genetic capacity for high shoot biomass may result partly from reduced carbon allocation to roots, with possible deleterious consequences for tree stability.

A related topic involving allocation of biomass is the extent to which trees adapt to prevailing winds, and to winds from other directions. Experiments with mechanical shakers, and with small wind tunnels are under way in collaboration with the University of York. Measurements include allocation between root and shoot; among lateral roots growing in different directions; and within individual roots, where eccentric radial growth which enhances stiffness is commonly found in the field. Commissioned work by the Scottish Centre for Agricultural Engineering on uprooting Sitka spruce under dynamic loading was completed during the year (pp. 55–56).

PHYSIOLOGICAL QUALITY OF NURSERY STOCK

The root frost hardiness of a range of conifers was measured between November 1991 and April 1992. Sitka spruce (QCI) and hybrid and Japanese larch became tolerant of severe temperatures as the winter progressed and by January these species were tolerant of 3 h exposures to –15°C. Douglas fir, Scots pine and Corsican pine were much less tolerant and showed little hardening. This confirms the results of the previous year. Thus our major conifers form two groups: a root frost hardy group comprising Sitka spruce of Alaskan, Queen Charlotte Islands and Oregon provenances, hybrid larch and Japanese larch, and a less tolerant group which includes Douglas fir, Scots pine and Corsican pine.

The ability of fine roots to withstand cold storage for 30 and 90 days was compared during two contrasting winters. The winter of 1989–90 was considerably warmer than the following winter: soil temperatures at a depth of 10 cm below the nursery crop at Wykeham nursery were approximately 2°C warmer in 1989–90 between early December and early March. In the more typical winter of 1990–91, Sitka spruce, Douglas fir and larch could tolerate storage for greater lengths of time and safe lifting windows were extended.

Bud dormancy of the main commercial conifers has been monitored for three winters. Plants were lifted at intervals through the winter, potted up in warm glasshouse conditions and the time required for the terminal bud to burst was recorded. As plants were exposed in the nursery to temperatures between 0 and 5°C for longer periods, the time for the terminal bud to flush decreased (Figure 10). For example, Sitka spruce, which had been put in the glasshouse in November and received no further chilling, took 150 days to burst bud whereas those left in the nursery until March took only 12 days. There were consistent differences in the species' response to chilling. Douglas fir was the slowest of the species tested to break bud. In early winter, the pines (Corsican and Scots) took least time to flush but from February onwards the larches were fastest to break bud.

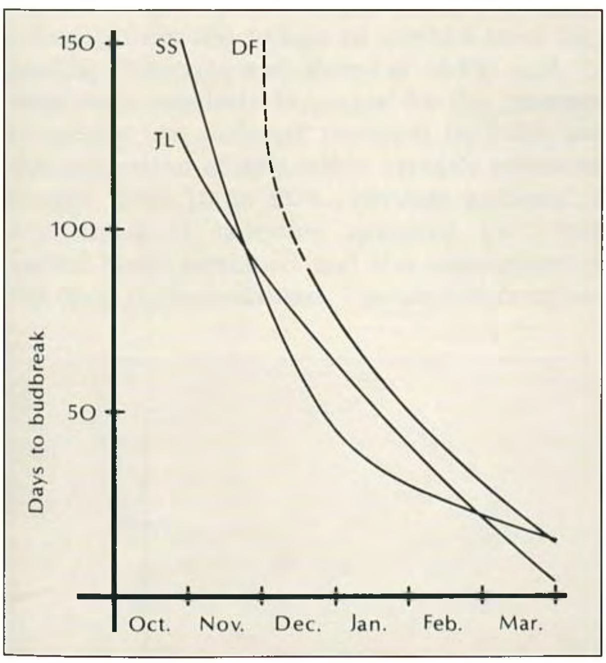


Figure 10. Bud dormancy of Sitka spruce (SS), Douglas fir (DF) and Japanese larch (JL) having different levels of natural chilling

HELEN MCKAY

DECLINE OF SITKA SPRUCE IN THE SOUTH WALES COALFIELD

The decline of Sitka spruce on the plateau area of the South Wales Coalfield (*Report* 1985, p. 32) is complex, involving many influences on the forest, from silvicultural practice to physiology of nutrient uptake and effects of such factors as pollution, insect and fungal attack, and climate. Study of this problem was therefore pursued through a multi-disciplinary approach, led by the Branch. Collaborators came both from within the Research Division (Physiology, Silviculture (North), Site Studies (North and South), Entomology (South), and Statistics and Computing (North) Branches) and from outside institutions (Polytechnic of Wales, Institute of Terrestrial Ecology (Bangor), Macaulay Land Use Research Institute, National Power and Technology and Environment Centre, University of East Anglia, and Cranfield Institute of Technology). The results have been compiled but not yet published, and contain contributions from all these collaborators.

The spruce in the affected areas grew adequately at first, but about the time of canopy closure, growth began to decrease. After about 4 years of decline, increment almost ceased, and the crowns became thin, accompanied by foliage discoloration and defoliation, with consequent dieback of branches. Bending of the leading shoot sometimes occurs, which has given rise to the commonly used description of the syndrome, 'bent top'.

Defoliation by the green spruce aphid, *Elatobium abietinum,* has sometimes been severe on the coalfield and stem analysis showed that an outbreak in 1980–81 was associated with reduced tree growth and wood density. Past defoliation has caused severe dieback of the crowns of some trees, and one of the principal hypotheses has been that the decline is triggered by the defoliation of trees suffering from other stresses. Additional defoliation agencies have been identified, namely the needle fungi *Lophodermium piceae* and *Rhizosphaera kalkhoffii.* Some discoloration and death of older needles in the autumn is probably caused by frosts in the late spring.

Measurements of atmospheric pollutants have shown that SO_2 and NO_2 levels are not sufficiently high to cause direct damage to the trees, though large concentrations of S were present in the needles. Nevertheless, while not causing damage in themselves, these pollutants may make the trees more susceptible to other stresses.

The problem occurs on three main soil types: peaty ironpan, peaty gley, and deep peat. On all three soils, the poorest crops were found on the wettest areas with high water-tables. Measurements of soil hydrology showed that the subsoil is permeable, and with the high rainfall in the area, this must lead to strong leaching of nutrients.

Concentrations of N, P and K in the peat are comparable to those where Sitka spruce grows well, but mineral and readily mineralised N concentrations are low. The acid condition of the peat, perhaps increased by atmospherically borne SO_2, partly explains the slow rate of mineralisation. Foliar N concentrations tended to be low, whereas P levels were variable and not well correlated with growth. Potassium concentration in the needles was the strongest discriminator for growth rate. Manganese levels were low in wood and foliage, but foliar Mg was normal. Application of NPK fertiliser to a 20-year-old crop improved its appearance, reduced dieback, and increased both diameter and height growth. Longer term responses to fertiliser are being monitored. Analysis of heavy metals in the soil indicated that they have no important role in the decline phenomenon.

Large between-tree variation in health gave the opportunity for examining clonal variation in tolerance to the coalfield conditions. Physiological experiments suggested that clones of unhealthy ortets have lower photosynthetic rates than those from healthy ones, though there was no difference in response to applied SO_2. Field experiments have been set up with seven pairs of contrasted clones (both grafts and cuttings). Cuttings of the same clones are being used at the Northern Research Station to study responses to defoliation (see Inter-Branch Report).

Mike Coutts

INTER-BRANCH REPORT PHYSIOLOGY AND TREE IMPROVEMENT

Resin and resin duct characteristics of Sitka spruce and defoliation by the green spruce aphid

During outbreaks of the green spruce aphid, *Elatobium abietinum*, on Sitka spruce striking differences in the amounts of defoliation are often seen between individual trees, even when they are in contact and the aphids can walk from one tree to the other. An experiment to investigate the causes of this apparent difference in resistance was started in 1987 in Afan Forest (South Wales). Samples were taken periodically from the foliage of marked trees in a healthy P68 crop, and stored at –20°C, and the trees were regularly inspected for the presence of aphids. An outbreak occurred in 1989, and the proportion of defoliation visually estimated ranged from 10 to 90%. Needles gathered at four times of sampling spanning the attack period were sectioned and the dimensions of the resin ducts measured. The terpene composition of the resin was also measured on needles from the same samples.

The analysis of resin duct dimensions (see p. 48) shows a significant negative correlation between defoliation and both the number of ducts ($P \leq 0.01$) and duct size ($P \leq 0.05$) (Figure 11). The correlations result from the association between high defoliation levels with few ducts and small duct sizes, while low defoliation levels occur over a wide range of frequencies and cross sectional areas of ducts. This implies a threshold of duct development above which heavy aphid attack does not take place.

In a pot experiment with the 14 clones of Sitka spruce from the area of forest decline in South Wales (p. 28), the effects of controlled defoliation by cutting or by the green spruce aphid on the resin canal systems and their terpene composition are being examined. Analysis of leaf and stem cortical resin composition, and measurements of leaf resin duct dimensions, were carried out before the treatments and will be repeated after defoliation. Older leaves were consistently characterised by

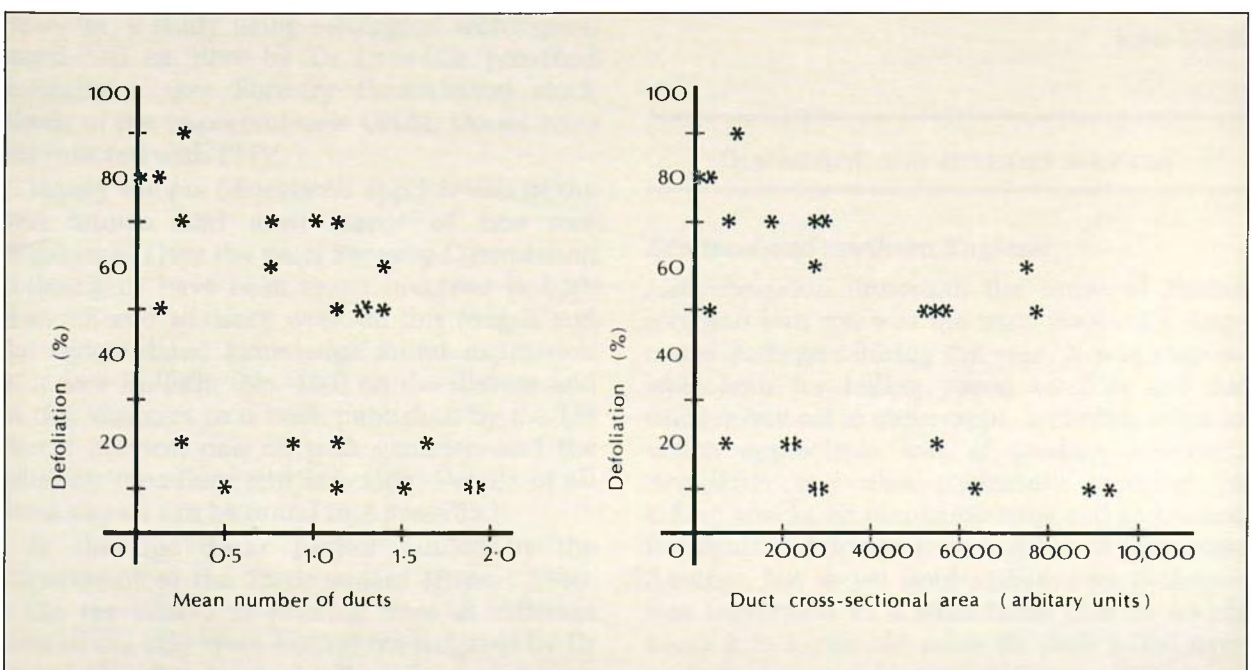


Figure 11. Number and size of resin ducts in the needles of Sitka spruce defoliated to different degrees by the green spruce aphid.

higher proportions of many of the simpler terpene components, especially the pinenes, camphene, beta-phellandrene, camphor and piperitone, and relative decreases in the abundant myrcene and diterpene components, compared with current year's leaves. Variation in terpene composition among ramets of a clone was in general small compared with clonal variation. A combination of various terpene characteristics of the two resin systems studied can be used to provide clonal markers which serve to identify most of the clones unequivocally.

There were substantial, significant differences ($P \leq 0.05$) in needle resin duct size between clones, but overall these did not relate to the performance of the original ortets in the field.

MIKE COUTTS AND IAN FORREST

PATHOLOGY

A significant part of the Branch resource is directed to research on the biology of Dutch elm disease. This has the aim of investigating the origin of the disease and biological means of control. At the same time it throws light on the behaviour of exotic pathogens released into a new environment. A feature of the 1991 summer was the first marked reappearance of disease in the large populations of young English elm that have grown up in southern England in the aftermath of the 1970s epidemic.

Mr Gyula Bohar from the Forest Research Institute in Hungary spent 3 months at Alice Holt during the year. In this time he worked on the variation present in a collection of *Ophiostoma* and *Ceratocystis* isolates. His project complemented the Branch research involvement in the problem of 'European oak decline' (*Report* 1991, pp. 38–39, and later in this *Report*).

Disease, whether of fungal or bacterial origin, is a major threat to the successful cultivation of poplar. There is also some concern over the possible impact on poplar growth of certain viruses, notably poplar mosaic virus (PMV). However, a study using serological techniques, conducted in 1991 by Dr Lonsdale provided reassurance that Forestry Commission stock plants of the important new UNAL clones were not infected with PMV.

Honey fungus (*Armillaria* spp.) is one of the best known and most feared of tree root pathogens. Over the years Forestry Commission pathologists have been much involved in both research and advisory work on this fungus and the accumulated knowledge found expression in a new Bulletin (No. 100) on the disease and in two chapters in a book published by the US Forest Service, one on pathogenicity, and the other on inoculum and infection. Details of all these papers can be found in Appendix I.

In the tree decay project funded by the Department of the Environment (*Report* 1990, p.55), the effects of pruning trees at different time of the year were further investigated by Dr Lonsdale. Beech and English oak were subjected to a weekly pruning schedule in spring and autumn, the periods during which large changes in wound responses had already been detected on a month-to-month basis. These changes were largely confirmed, although the exact timing of 'good' and 'bad' times to prune was not always identical with earlier findings. For example, the onset of a 'bad' time for beech in late October-early November was confirmed, but the previously recorded amelioration in late November did not occur.

The publication in June 1991 of a literature review on de-icing salt damage to trees and shrubs conducted for the Department of the Environment by Dr Dobson (see Appendix I) coincided with the appearance on many urban trees of striking symptoms due to salt applications made during the moderately severe 1990/91 winter. To assess the scale of the problem in London, a sample survey, largely funded by the London Boroughs, was established. This showed that 20% of main road and 9% of side road trees were affected, with London plane (Plate 7) showing the highest incidence of damage. The long-term impact will be assessed by re-survey in summer 1992.

JOHN GIBBS

DIAGNOSTIC AND ADVISORY SERVICES

Scotland and northern England

Heterobasidion annosum, the cause of Fomes root and butt rot, was the most frequently diagnosed pathogen during the year. It was responsible both for killing young conifers and for causing butt rot in older crops, including some in which appreciable loss of produce occurred. *Armillaria* was also commonly recorded in killing attacks on plantation trees and accounted for significant losses in a number of instances. Another, but as yet unidentified, root pathogen was implicated in a remarkable case in which many 2 to 3-year-old noble fir were killed over an area of several hectares of former pasture. In an earlier enquiry that involved virtually identical damage on a much smaller scale, a fungus resembling a *Pythium* or *Phytophthora* sp. was found consistently in affected tissues; this too is still under investigation. Though well known as root pathogens, *Phytophthora* spp. are not frequently encountered in forest trees in northern Britain. It is noteworthy therefore that one was associated with root and stem lesions of 1-year-old sweet chestnut seedlings growing in containers in a northern nursery.

Investigation of another problem with broadleaved nursery stock, first reported 3 years ago (*Report* 1989, p.42), was completed during the year. *Phoma macrostoma,* which was isolated from stem lesions on ash plants in two nurseries, was inoculated into wounds on young potted plants. Six weeks after inoculation, lesions up to 65 mm long were formed on 2-year-old shoots and a number of 1-year-old shoots were completely girdled. The fungus was re-isolated from 12 of the lesions. *P. macrostoma* is a common weak or wound parasite found on a wide range of hosts, including woody perennials. It has been associated with leaf spots and stem lesions of several species but this is the first demonstration of its pathogenicity on ash. The Alice Holt advisory service also received reports in 1988 of stem lesions on ash nursery stock. In these cases the damage was associated with *Phoma exigua,* suggesting that more than one *Phoma* species is able to infect young ash plants under nursery conditions. We are grateful to the International Mycological Institute for identifying both fungi.

In addition to this 'new' tree disease, many well known ones were identified for enquirers in the course of the year's work. These included shoot dieback of lodgepole pine caused by *Ramichloridium pini, Coleosporium tussilaginis* rust on Scots pine needles, *Nectria* cankers on a variety of hardwoods, killing of young Douglas fir by *Phacidiopycnis pseudotsugae* ('Phomopsis disease') and, in contrast to these fungal diseases, three bacterial diseases: ash canker, poplar canker and bacteriosis of *Prunus.*

The most frequently identified non-living cause of injury was frost. Frosts in early June caused severe damage to young Sitka spruce and other conifers in parts of northern England, southern, and western Scotland. A case of severe dieback in 6-year-old red alder was also thought to be attributable to spring frost. Later in the year, autumn frost injury was observed at several sites throughout Scotland and northern England on Sitka spruce, Corsican pine and, unusually for Britain, on Scots pine. Losses of newly planted trees due to inadequate handling and planting techniques were numerous, as were cases of injury by misuse of herbicides. The physiological disorder 'top-dying' continued to be prevalent, causing browning and mortality in Norway spruce stands throughout northern Britain.

STEVE GREGORY, GRACE MACASKILL, DEREK REDFERN AND JIM PRATT

Wales and southern England

Although the spring and early summer of 1991 were wetter than the two previous years, the period under review was still influenced by the droughts of 1989 and 1990. Many beech that had been drought-stressed failed to flush normally and subsequently died, while significant areas of dead bark appeared on the stems of others. In the latter case the bark-killing fungus *Nectria coccinea* was often isolated from the dying bark. The prediction by Gibbs (*Report* 1991, p.34) that beech dieback would not be as extensive as in 1976 was borne out, though damage was significant. As in Scotland and northern England, needle browning and mortality in Norway spruce stands continued, mainly in eastern England. There was some evidence to suggest that in addition to 'top-dying' there were also cases of direct drought damage.

Cases of sooty bark disease, caused by *Cryptostroma corticale,* continued to be reported from south-east England and also from as far north as Cheshire. At two sites, in south Essex and west Shropshire, drought-stressed pine suffered from shoot dieback caused by *Sphaeropsis sapinea.* This fungus is not normally considered to be a pathogen in this country but it can cause damage on severely stressed trees. During the early summer there were reports of damage to trees from road de-icing salt, particularly in London. Details of a damage survey carried out in London are given in the general review of this Branch's activities in this *Report.* A number of cases were reported of damage to street trees by the herbicide imazapyr. The symptoms at first sight resemble those of salt injury (failure to flush or death of leaves shortly after flushing), but in all cases the involvement of the herbicide was confirmed by chemical analysis. A dying *Kalopanax pictus* in Surrey was found to be infected with *Verticillium dahliae.* This is the first known record of this fungus on *Kalopanax* and, as far as we know, the first record of any disease on this species in Britain.

ROBERT STROUTS, DAVID ROSE AND SARAH BROWN

OAK DIEBACK

Over the past decade there have been many reports of death and dieback of oaks (pedunculate and sessile) in various European countries. In Britain only a few such cases had been reported prior to 1988, but in 1989 several enquiries about dieback in woodland and parkland oak were received.

The first symptom on a declining tree is an overall deterioration of the foliage which becomes pale green or yellow and may be rather sparse. Subsequently, dieback of fine twigs is followed by death of small branches. Within 2–3 years most of the main branches die back so that only the trunk and a few branches remain alive with epicormic shoots. Even at this late stage of decline the roots are normally still alive. Finally, various insects may attack the tree, especially Buprestid beetles *(Agrilus pannonicus)*, oak bark beetle *(Scolytus intricatus)* and longhorn beetles.

Most cases of oak decline are in southern England, especially in the East Midlands, but instances occur as far apart as Devon and Kent. The trees range from 40 to 200 years old and occur on a range of soil types. The symptomatology of the declining trees is broadly similar on all sites. Increment cores taken from declining trees indicate that radial growth started to decline around 1984/85, although symptoms were not generally apparent until 1988/89.

A variety of factors appear to be involved in the decline syndrome but the same factors may not be involved on each site. The onset of growth decline in the mid 1980s suggests that droughts in the summers of 1983/84 or the severe winters of 1984/85/86 may have acted as a trigger for the problem. The role of defoliating caterpillars such as those of the oak leaf roller moth *(Tortrix viridana)* and winter moth *(Opherophtera brumata)* is unclear, although the widespread death of oak in the 1920s is thought to have been associated with several years of heavy *T. viridana* infestations. Root-rot by honey fungus is not considered to be a major factor. No evidence of a vascular wilt disease has been found and tests for viruses and related pathogens have so far proved negative.

Previous outbreaks of oak dieback in Britain have involved isolated episodes with subsequent periods of recovery. The current situation will be monitored annually in a series of individual tree plots.

BRIAN GREIG

DUTCH ELM DISEASE

Dutch elm disease outbreak in New Zealand

An outbreak of Dutch elm disease in Auckland on the north island of New Zealand is the first recorded outbreak in the Southern Hemisphere. All elms in the region are introduced, and the disease was first recorded in December 1989 on English elm, *Ulmus procera* (Cooper, 1991). Only the smaller European elm bark beetle *Scolytus multistriatus,* a much less effective vector of Dutch elm disease than *S. scolytus* (Webber, 1990), is associated with the outbreak. However, by late 1990 beetles infested with the Dutch elm disease fungus were found as far as 30 km from the city.

Changes in the genetic make up of the pathogen population are being monitored at Alice Holt. Only the highly pathogenic species, *Ophiostoma novo-ulmi,* has been found. Also, of 62 isolates collected in 1990 and 1991, all have been shown to be of the NAN race of *O. novo-ulmi,* which is otherwise confined to North America and north-west Europe. All 62 isolates are of the same vegetative compatibility group, the 'NAN European vc supergroup', a dominant genotype of *O. novo-ulmi* at recent epidemic fronts across much of Europe (Brasier, 1988). They are all also of the B sexual mating type. The fungus in New Zealand therefore appears to be a single genetic clone. This offers an important opportunity not only to study the long-term genetic stability of the pathogen, but also to attempt biological control of the fungus by introducing d-factor mycoviruses (see below). The well characterised and highly deleterious d^2-factor was therefore transmitted in culture to a New Zealand isolate of the fungus during 1992, and sent to New Zealand for tests under quarantine regulations, with a view to its possible release.

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REFERENCES

BRASIER, C.M. (1988). Rapid changes in genetic structure of epidemic populations of *Ophiostoma ulmi*. *Nature* **332**, 538–541.

COOPER, A.N. (1991). Dutch elm disease in New Zealand. *Quarterly Journal of Forestry* **85**, 50–52.

WEBBER, J.F. (1990). Relative effectiveness of *Scolytus scolytus*, *S. multistriatus* and *S. kirschi* as vectors of Dutch elm disease. *European Journal of Forest Pathology* **20**, 184–192.

Molecular biology of d-factor mycoviruses

D-factors are cytoplasmically transmitted virus-like agents that can seriously debilitate the Dutch elm disease pathogen *Ophiostoma novo-ulmi* and have the potential to break the cycle of Dutch elm disease (see Webber, 1987). Their molecular biology is being investigated with a view to their manipulation for biological control of the disease.

Our earlier studies showed that such d-factor 'viruses' probably comprise dsRNA segments, and that most of this dsRNA is located within the fungus' mitochondrial organelles. Also, that d-factors may debilitate the fungus by disrupting the function of its cytochrome oxidase respiratory enzyme system, the genes for which are located on the mitochondrial DNA (Rogers, Buck and Brasier, 1987). We have now shown that small DNA segments called plasmids are also present in the mitochondria of certain d-infected isolates, and that the plasmids are generated only after transmission of the dsRNA during a d-factor's spread from one fungus individual to another. We have constructed genetic restriction maps of the fungus' mitochondrial DNA, and shown that the plasmid DNA is genetically homologous to portions of the mitochondrial DNA, and especially to 'map regions' containing the large ribosomal RNA gene or the cytochrome gene sub-units. The plasmids may therefore contain sequences of these genes. It is possible that the plasmids are directly involved in d-factor virus function, disrupting the metabolism of the Dutch elm disease fungus either by competing for replication factors or by producing aberrant transcription products. The plasmid DNA will now be sequenced to determine the genes present, and the mode of excision of the plasmid DNA from the mitochondrial DNA (see also Charter, 1992).

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REFERENCES

CHARTER, N.W. (1992). *Double stranded RNA and mitochondrial DNA plasmids in diseased isolates of the Dutch elm disease pathogen, Ophiostoma novo-ulmi.* Ph.D. thesis, Imperial College, London.

ROGERS, H.J., BUCK, K.W. and BRASIER, C.M. (1987). A mitochondrial target for double-stranded RNA in diseased isolates of the fungus that causes Dutch elm disease. *Nature* **329**, 558–560.

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.

ENTOMOLOGY

Research into two of the main pests, *Panolis flammea* and *Dendroctonus micans*, new to British forestry during the late 1970s and early 1980s, is now diminishing.

Two facets of *P. flammea* research have yielded very significant results. Major advances have been made in spray application technology, resulting in development of a new hanging boom system that can be attached to any helicopter. Power supply to the X-30 rotary atomisers and spray pump is provided by a generator directly on the boom system. An aerial application of Dimilin, in May 1991, to a potentially damaging population of *P. flammea* on 80 ha of lodgepole pine at Truderscaig Forest, Highland, was completely successful. Secondly, research into *P. flammea* population dynamics has shown that adult females respond to the chemical components of different provenances of lodgepole pine and lay their eggs on those most suitable for larval development. Research also indicates that maintenance of low, endemic, moth populations on the native Scots pine is influenced by the richer natural enemy complex present.

A new project on the effect of forest structure on the biodiversity of insects has been initiated. The aim is to quantify how existing and manipulated forest structure, such as tree species and age, size of forest block and ride-side management, affect the abundance and diversity of insects associated with those forests.

Tree stress as a factor potentially influencing susceptibility to insect attack is being vigorously addressed, especially in light of predictions arising from climate change. Early results indicate that both the genetic composition of Sitka spruce and the site on which it is grown can influence the likelihood of successful attack by bark beetles such as *D. micans*. Future work will concentrate on differentiating genetically controlled components of host tree suitability from those determined by site, climate and other biotic and abiotic constituents that can, together, be defined as stress.

HUGH EVANS

RESEARCH INTO THE BIOLOGY AND CONTROL OF *DENDROCTONUS MICANS*

The great European spruce bark beetle, *Dendroctonus micans*, is a major pest of spruce throughout its range in Eurasia. Following its discovery in Britain in 1982, a comprehensive research programme to develop a long-term control strategy has been mounted. The main facets are changes in forest management to restrict transport of infested material, surveys to determine spread away from the localised area of the main outbreak and biological control using the imported predatory beetle, *Rhizophagus grandis*.

Releases of *R. grandis* adults (132 000) have been made since 1984 at all known infested sites. The predator has established well under British conditions and is able to disperse to new *D. micans* infestations. Detailed research at a number of sites indicates that, within 4 years of low density releases, between 80% and 90% of *D. micans* galleries are colonised by the predator. Increasing the release rate from approximately one pair to 100 pairs of adults per infested tree can shorten this establishment period to 2 years.

Adult *R. grandis* released in the field respond to traps baited with a blend of monoterpenes present in *D. micans* larval frass (see *Report* 1990, p. 57). The monoterpene lure suitably formulated may be of practical value:

- i in confirming successful establishment of *R. grandis* following release for biological control;
- ii for enhancing attraction to *D. micans* attacked trees;
- iii in determining the extent of natural dispersal;
- iv possibly permitting indirect monitoring of *D. micans* around the periphery of infested regions.

A wick system using proprietary air freshener

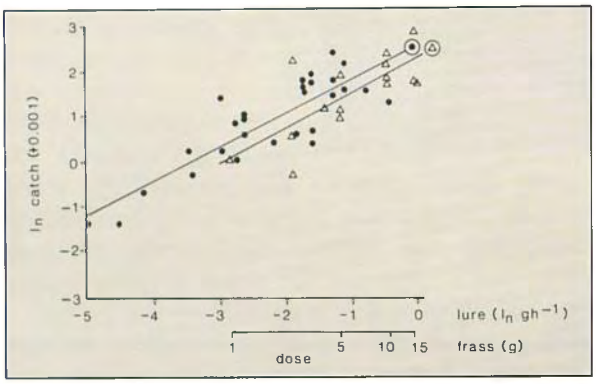

Figure 12. Dose response to frass (Δ) (y = 0.073 + 0.802x) and lure (•) (y = 2.624 + 0.770x) released from liquid dispensers. The catch to 5g of frass is equivalent to that of the lure released at 0.2g gh^{-1}; the relative position of the axes for doses of frass and lure has been adjusted accordingly.

technology was found to be a highly effective means of releasing the lure. Using 'Theyson' slot traps in an arrangement previously described (*Report* 1990, p. 57), a dose response to the lure released from 'air fresheners' and *D. micans* larval frass was determined (Figure 12). The relative response to lure and frass in the field was consistent over a wide range of doses.

DAVID WAINHOUSE, NICK FIELDING, HUGH EVANS, PAUL BEECH-GARWOOD, ALISON WATERS AND PETER HIGHAM

THE IMPACT OF INSECTS ON TREE GROWTH

Complete defoliation of trees by insects reduces tree growth rates and timber yield and, particularly in the case of conifers, may lead to tree death. Trees may be killed directly by the defoliation or they may become so weakened that they are killed by secondary insects or fungi. When trees are killed the financial cost of the primary insect damage can be estimated as the standing value of the trees lost. However, most insect outbreaks subside after causing only partial defoliation. In these cases, the economic costs of the damage are difficult to determine and require estimates of the reduction in tree growth rates and the effect this has on final timber yield.

The ideal approach to correlate insect damage with tree growth is to manipulate insect populations experimentally, to produce a range of infestation densities, and then to measure tree response under each infestation regime. However, although this method is being used for young trees, it is impractical on mature trees where estimation is best accomplished by analysing growth rings in relation to previous defoliation events. We are using this method to determine the effect of pine looper moth *(Bupalus piniaria)* on Scots pine in Tentsmuir Forest, Fife. Forty mature pines were felled in 1989 and cross-section discs cut from the stems. The rings on these discs show that growth was reduced substantially during, and immediately after, outbreaks of the moth in 1957, 1962, 1969, 1977 and 1984. Timber volume lost over the life of the crop is being calculated.

The experimental approach is being used successfully in studies on growth loss caused by pine shoot moth *(Rhyacionia buoliana),* pine sawfly *(Neodiprion sertifer)* and the green spruce aphid *(Elatobium abietinum). R. buoliana* and *N. sertifer* are typically pests of young plantations and have caused severe damage to bishop pine in Dorset and lodgepole pine in Scotland, respectively. Their population densities are relatively easy to manipulate by using insecticide sprays and larval transfers. A range of densities of *R. buoliana* has been maintained for 2 years in a stand of 6–9 year old bishop pine in Wareham Forest, Dorset, and preliminary results show that high infestation rates reduce mean annual leader growth by about 25%.

Work on *N. sertifer* follows previous studies of the impact on lodgepole pine by Hayes and Britton (1986) and Britton (1988), but extends the range of sawfly densities investigated. In addition, long-term field experiments were set up in 1991 to determine whether sawfly attack reduces the nursing properties of lodgepole pine when grown in mixture with Sitka spruce, and whether the susceptibility of trees to attack is influenced by fertiliser application at the time of planting.

The impact of *E. abietinum* is being studied in Hafren Forest, Powys, as part of a new experiment which also includes the effects of root-feeding aphids on the growth of Sitka spruce. The aim is to determine the independent and combined effects of these two types of aphid on the growth of spruce during the first 10 years following planting. Site selection and screening of candidate insecticides for controlling aphid populations were conducted in 1991, the main experiments commencing in 1992.

NIGEL STRAW, NICK FIELDING AND ALISDAIR HENDRY

REFERENCES

BRITTON, R.J. (1988). Physiological effects of natural and artificial defoliation on the growth of young crops of lodgepole pine. *Forestry* **61**, 165–175

HAYES, A.J. and BRITTON, R.J. (1986). Attacks of *Neodiprion sertifer* on *Pinus contorta*. EPPO Bulletin **16**, 613–620

THE USE OF AMBUSH 12ED TO PROTECT FOREST TRANSPLANTS FROM DAMAGE BY *HYLOBIUS ABIETIS*

Unless transplants are protected from attack by *Hylobius abietis*, plant losses can exceed 50%. A method of treating forest transplants using an Electrodyn Sprayer Conveyor (ESC), was introduced into the plant handling system at Newton nursery during 1986. Experiments undertaken between 1988 and 1990 showed that protection conferred was sometimes inadequate.

Replicated experiments set up in 1991 compared several ESC treatments for efficacy and possible phytotoxicity. They were planted at 24 different sites selected to ensure suitably high levels of insect damage and a variety of restocking conditions.

Efficacy experiment 1

Treatments were:

- Untreated
- Standard Electrodyn permethrin (Ambush 6 ED)
- Standard flow-rate 12% permethrin ED (Ambush 12 ED)
- Standard flow-rate lambda cyhalothrin (Karate ED)
- Dipped in 0.8% permethrin (Permit, EC).

Results are shown in Table 10. Analysis of the number of plants killed by *H. abietis* showed that all chemical treatments significantly reduced the number of deaths compared with no treatment ($P<0.001$). Ambush 12 ED and Permit treatments showed significantly less *H. abietis* damage than the other treatments ($P<0.001$). Chemical treatments also significantly reduced the incidence of non-fatal damage compared with no treatment ($P<0.001$), Ambush 12 ED and Permit giving the most significant reductions ($P<0.001$).

Efficacy experiment 2

Experiments were also set up to assess the level of protection provided by the ESC using Ambush 12 ED under normal forest conditions. Sites, each of at least 2 ha in area, were chosen to include areas where high levels of *H. abietis* attack was expected.

Treatments were:

- Untreated
- Standard flow-rate 12% permethrin (Ambush 12 ED).

Results are summarised in Table 11. Only two sites sustained sufficient damage to discern treatment differences. Survival of both treated and untreated trees was good, with less than 1% mortality from causes other than *H. abietis.* There were significantly more *H. abietis* killed trees in the untreated compared with the treated plots ($P<0.001$). In addition, there was significantly less non-lethal damage to the treated trees ($P<0.001$).

Phytotoxicity experiment

An experiment to assess possible phytotoxicity arising from insecticide application was also set up, based on two locations which were unlikely to have any *H. abietis* populations. Treatments were the same as in experiment 1. There were no significant differences in increment between any of the treatments for any of the species (Table 12). Differences in increment between the species was due to their intrinsic growth patterns.

Conclusions

Ambush 12 ED gave the same level of protection from H. *abietis* damage as dipping in an aqueous suspension of permethrin. Large-scale use of this treatment does not appear to have affected its efficacy or to have resulted in increased phytotoxicity.

STUART HERITAGE, TERRY JENNINGS AND DAVID JOHNSON

Table 10. Experiments to assess the efficiency of various electrodyn treatments for control of *Hylobius abietis*. Percentage of plants killed by *Hylobius*

Treatments	*Sites*														*Mean*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	
Untreated controls	20	35	38	40	51	51	51	67	70	71	76	84	89	89	60
Ambush 6ED (ESC)	1	7	28	3	5	30	10	8	53	7	13	49	74	60	25
Ambush 12ED (ESC)	0	4	10	2	2	10	2	1	4	8	7	28	77	45	14
Karate (ESC)	7	30	28	0	11	52	15	10	54	22	11	45	76	89	31
Perthmethrin dip 0.8%	0	2	5	0	0	3	3	1	9	5	1	24	24	35	8

Table 11. Tests of electrodyn treatments for control of *Hylobius abietis* under forest conditions

Treatments	Percentage of plants killed at two planting sites — Sites A	B	Mean
Untreated controls	72	65	68
Ambush 6ED (ESC)	4	1	3

Table 12. Assessments of potential phytotoxicity in plants treated with various insecticides

Treatments	Average first season height increment (cm) of each species per treatment — *Corsican pine (lowland)*	*Japanese larch (lowland)*	*Lodgepole pine (lowland)*	*Douglas fir (lowland)*	*Norway spruce (lowland)*	*Sitka spruce (lowland)*	*Sitka spruce (upland)*
Ambush 12ED	3	10	3	4	4	4	7
Untreated	3	11	3	4	5	4	6
Permit 0.8%	4	10	2	3	3	5	7
Ambush 6ED	4	10	2	4	4	5	7
Karate ED	3	10	4	5	5	5	8

WILDLIFE AND CONSERVATION

Technology transfer, consultancy and advisory work continues to increase in step with the rising demand for information on nature conservation. The Head of Branch participated in a review of the work of the upland research group of the former Nature Conservancy Council for Scotland (now Scottish Natural Heritage), in the steering group of a Scottish Office study into deer counting methodology, and in the Forestry Research Co-ordination Committee review group on forestry and nature conservation priorities. Additionally, he attends the newly formed Home-grown Timber Advisory Committee's environmental sub-committee.

The Branch continues to have a high input into the nature conservation management courses run by Forestry Practice Division, and new courses on roe deer management, following publication of *Roe deer biology and management* (Ratcliffe and Mayle, 1992), and integrated environmental management, with colleagues in Forestry Practice Division are in hand. Consultancy work to the Forestry Authority and Forest Enterprise has involved a number of topics including fox management, and advice on Woodland Grant Scheme applications.

The Anglia survival film, *Phantom of the forest*, which describes Steve Petty and David Anderson's work on goshawk conservation, was completed. It was broadcast in August 1992.

In-house research has continued to investigate edge management techniques. The selective use of certain herbicides and growth-retardants and grazing (goats and cattle) have all resulted in increased structural and/or plant diversity. The value of mechanical cutting continues to be studied.

Re-introduction of cattle to a riparian ecosystem at Strathrory in Easter Ross halted a deterioration in plant diversity, suggesting that cattle-grazing is a valuable management tool for maintaining an increasing diversity on forest edges and on open-space.

The monitoring of minimal intervention areas of windthrow, at Rendlesham, Suffolk, (*Report* 1991, p.49) is demonstrating high structural diversity which is providing valuable niches for wildlife. Birch, heather and bramble are regenerating in some areas, the large amount of woody debris providing protection from deer and rabbits.

Winter temperatures recorded inside artificial bat hibernacula constructed in 1991 at Pembrey Forest are within the required range for hibernating bats, and bats have used them during late summer.

The important work on red squirrel conservation is progressing, and trials of red-squirrel-only hoppers are proving promising. A private sector survey of grey and red squirrel distribution and damage has been completed. The commissioning of this work by Timber Growers UK has significantly advanced our knowledge of squirrels in this country.

New research includes projects on fallow deer ecology and management and carnivore ecology. A major programme on biodiversity is being led by Dr Ratcliffe which involves a multi-disciplinary approach with several branches participating. It is intended that the research programme will develop simultaneously with an evolving ethos in forest management policy and practice.

PHILIP RATCLIFFE

RIDE MANAGEMENT IN LOWLAND WOODS – VEGETATION SUCCESSION AND INVERTEBRATE RESPONSES

Ground flora and shrub vegetation development have been monitored for 5 years after creating or widening of forest rides in a range of lowland plantation woodland types. Changes in invertebrate numbers and diversity, particularly of butterflies, have also been recorded (Table 13, Figure 13).

The impact of mammalian herbivores on vegetation succession and tree regeneration in particular, has been assessed using exclosures, fenced against roe and muntjac deer, hares and rabbits.

A clear relationship exists between the increase in vegetation cover and butterfly numbers. An abundant nectar supply in the form of early successional plant species such as thistles, resulted in a dramatic increase in the

Table 13. Butterfly numbers recorded on the south-facing edge and north-facing edge of a 20 m wide E–W ride; Black Wood, Micheldever Forest, Hampshire (ratio S:N in parentheses)

	Year				
	1987	*1988*	*1989*	*1990*	*1991*
S-facing	32	341	494	405	455
N-facing	7	87	245	249	166
	(4.6)	(3.9)	(2.0)	(1.6)	(2.7)

numbers of butterfly species and individuals recorded. Butterfly activity was found to be greater on south-facing ride edges than those facing north. This is probably in response to the greater amount of sunlight received, although no clear differences in vegetation composition and structure have been detected between opposing aspects.

Particular plant communities showed a clear zonation with respect to the woodland edge. At Black Wood, Micheldever Forest, an area of P31–36 beech on a calcareous soil overlying chalk, the central portion of the new rides was characterised by an abundance of creeping thistle *(Cirsium arvense)* and wood sedge *(Carex sylvatica),* although the former has begun to decline in dominance after 4–5 years, with a more complete vegetation cover having formed. At the ride edge, the vegetation was primarily false brome *(Brachypodium sylvaticum),* dog's mercury *(Mercurialis perennis)* and regenerating ash seedlings. Smaller broadleaved herbs such as selfheal *(Prunella vulgaris),* bugle *(Ajuga reptans)* and wild strawberry *(Fragaria vesca)* were locally abundant.

The exclosure plots clearly demonstrated the influence that deer, rabbits and hares were having on the vegetation. Palatable herbs such as rosebay willowherb *(Chamaenerion angustifolium)* are largely absent in the unfenced areas but abundant within the exclosures. Luxuriant growth of brambles *(Rubus fruticosus)* and raspberry *(Rubus idaeus)* has occurred within the exclosures. Woody regeneration of goat willow and ash has occurred and the seedling density was shown to be significantly reduced outside of the fenced areas (P<0.01).

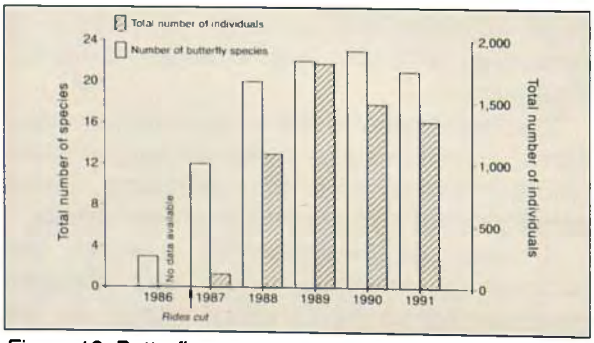

Figure 13. Butterfly responses to ride management in a P31–36 beech plantation, Micheldever Forest, Hampshire.

Further multivariate analyses of the data are planned, and the main findings of this work will be incorporated into new management guidelines.

RICHARD FERRIS-KAAN

TEMPORAL AND SPATIAL FLUCTUATION IN FIELD VOLE ABUNDANCE IN A PREDATOR/PREY STUDY

Field voles (*Microtus agrestis*) provide a major food resource for both avian and mammalian predators in upland forests. A long-term study in Kielder Forest District (Northumberland) had investigated relationships between the population ecology of tawny owls and field vole abundance (Petty, 1987 and 1989). Analysis of 928 pellets contain 2429 prey items showed that field voles were numerically (72%) and in biomass terms (78%) the most important prey (Figure 14). Tawny

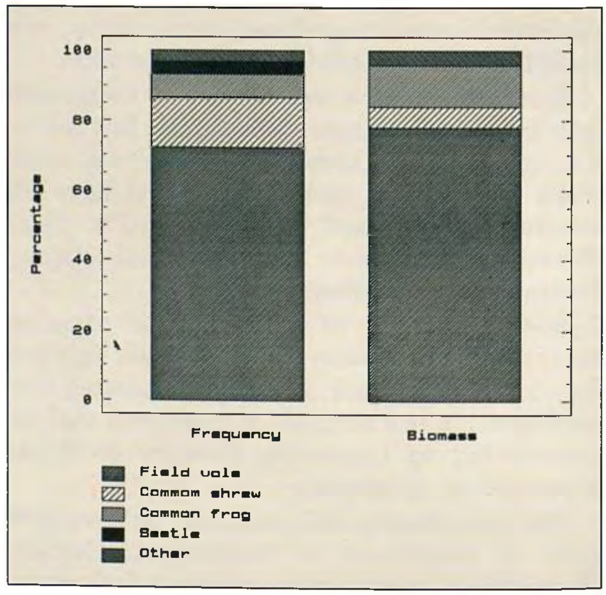

Figure 14. Diet of tawny owls in Kielder Forest determined from 2429 prey items in 928 pellets.

owls (*Strix aluco*) exhibited a functional response to variations in field vole abundance, with proportionally more taken when voles were plentiful.

Felled and replanted (restocked) areas develop a rank grassy vegetation 2 to 3 years after clear felling and provide a major field vole habitat until canopy closure (Petty, 1989). Work has concentrated on quantifying both small mammal community structure and temporal changes in field vole abundance on restocked sites, and latterly to model spatial fluctuations in vole abundance.

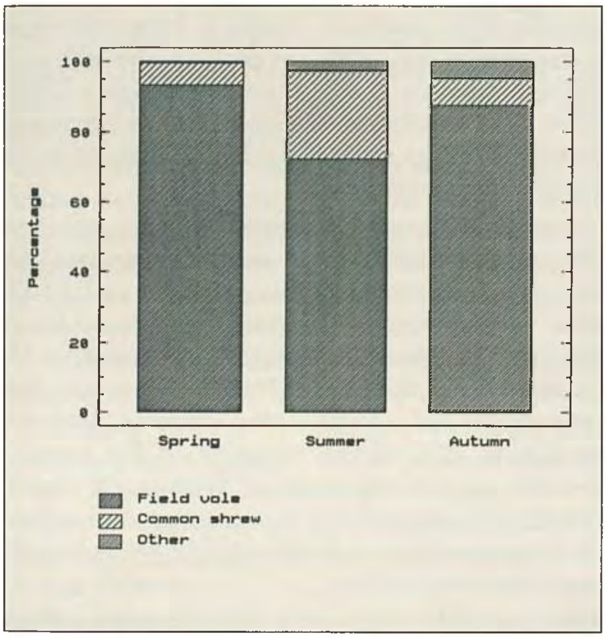

Figure 15. Seasonal changes in the small mammals caught on one restocked site in Kielder Forest. Pooled data from over 20 000 trap nights during 1984–1990.

The relative abundance and community structure of small mammal populations were determined at one trapping site. Trapping was done in March, May–June and September from 1984 to 1990 and spanned over 20 000 trap nights. Field voles were the most abundant small mammal caught, followed by common shrews *Sorex araneus* and with wood mice *Apodemus sylvaticus* and bank voles *Clethrionomys glareolus* caught infrequently. There were seasonal differences in the proportion of small mammals trapped (Figure 15). Field voles represented most of the captures in March and least in the summer, autumn was intermediate. The balance was made up largely by common shrews.

Within the trapping area, vole signs were also measured. An index using fresh grass clippings (Fresh Clippings Index – FCI) in vole runs gave the best correlation with the trapping index. This relationship changed over the three trapping seasons due to faster decay rates of grass clippings in the summer. Regression analysis was used to adjust seasonally the FCIs. The amplitude of annual changes in the relative abundance of field vole in Kielder indicated a 3-year cycle length (Figure 16). FCIs from widely scattered sites in the study area were then used to model spatial fluctuation in vole abundance throughout the study area

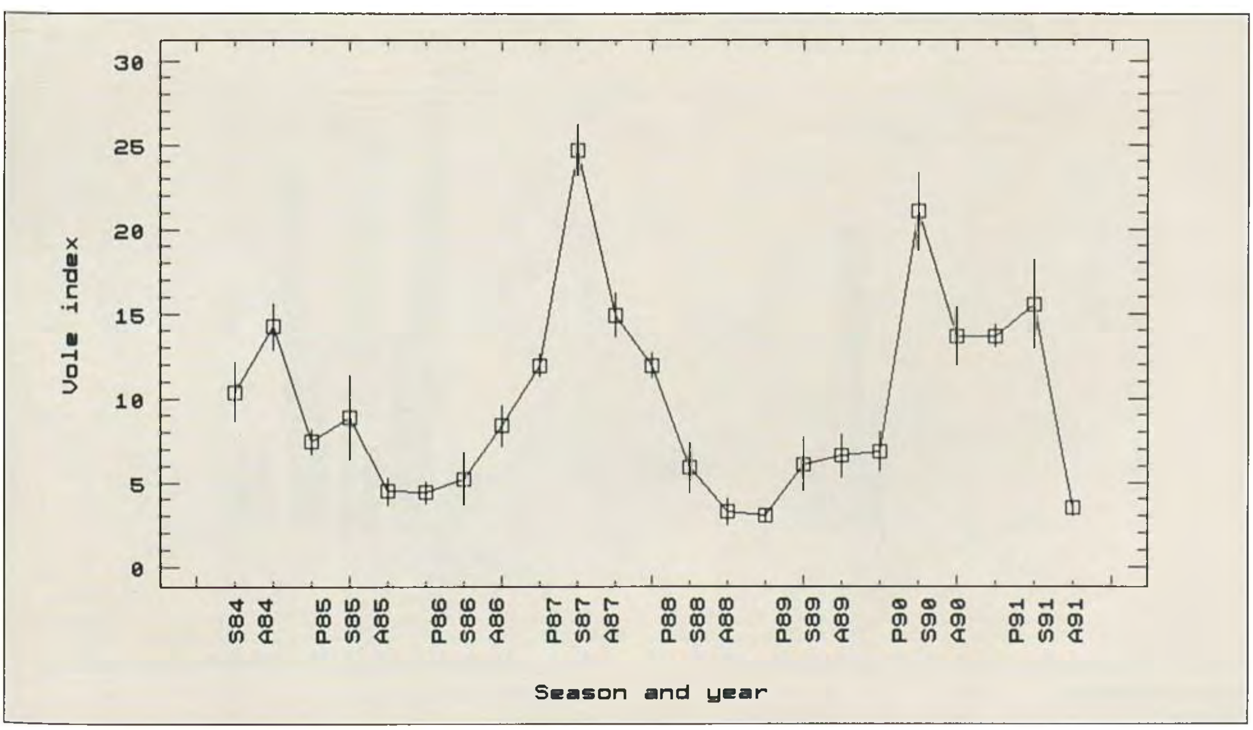

Figure 16. Temporal changes in field vole abundance from 1984–1991 in Kielder Forest (P = spring, S = summer and A = autumn). The data given are the means with standard error bars for a seasonal adjusted index based on fresh grass clippings in vole runs.

(Plate 8). This indicated that changes in vole abundance occurred in a wave-like manner throughout the study area.

As FCIs were collected from a wide but non-uniformly distributed number of sites throughout the study area it was necessary to apply an interpolation function to estimate a vole density index for the whole Kielder area. Using the method of Akima (1978) it has been possible to identify spatial changes in vole abundance across the study area (Plate 8).

STEVE PETTY AND ANDY PEACE

REFERENCES

AKIMA, H. (1978). A method of bivariate interpolation and smooth surface fitting for irregularly distributed data points. *ACM Transaction on Mathematical Software* **4**, 148–159.

PETTY, S.J. (1987). Breeding of tawny owls *Strix aluco* in relation to their food supply in an upland forest. In, *Breeding and management in birds of prey*, ed. D.J. Hill, 167–179. University of Bristol.

PETTY, S.J. (1989). Productivity and density of tawny owls *Strix aluco* in relation to the structure of a spruce forest in Britain. *Annales Zoologici Fennici* **26**, 227–233.

BAT ACTIVITY IN A MIXED LOWLAND WOODLAND IN RELATIONSHIP TO INSECT PREY AVAILABILITY

Little is known about the specific habitat requirements or preferences of woodland bats or of the relative importance of the different habitats found in woodlands to foraging bats. Walsh and Mayle (1991) showed that greatest bat activity occurred over ponds and in woodland rides in a mixed lowland woodland and suggested that this was probably due to an increase in insect species diversity and density at these sites.

Bat activity and insect availability were investigated in five habitats of a mixed lowland woodland in southern England from mid-May to the end of July 1991. At each site bat activity was recorded for 3 x 5 minutes through a QMC S200 Bat Detector on to a cassette tape recorder, and sticky traps were placed at 0, 2 and 4 m to sample nocturnal insects.

Bat activity was greatest in pond habitats (Figure 17). Significantly more insects (weight and species) were caught in felled and pond sites; most insects being caught at ground level (Figure 18). Insect biomass increased with increase in temperature. Habitat type and the proportion of 5–10 mm insects caught explained 37% of the variation in bat passes. Results support the views of Walsh and Mayle (1991) and suggest that the creation and sensitive management of ponds will improve woodlands for foraging bats.

BRENDA MAYLE

REFERENCE

WALSH, A.L. and MAYLE, B.A. (1991). Bat activity in different habitats in a mixed lowland woodland. *Myotis* **29**, 97–104.

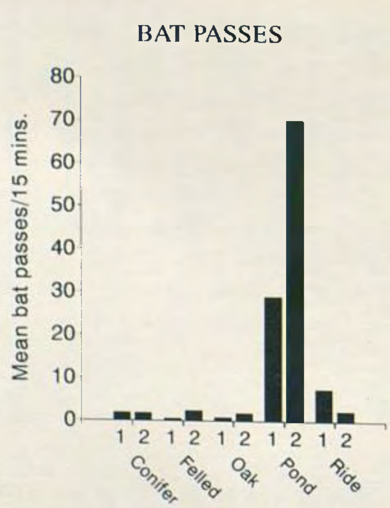

Figure 17. Bat activity in different mixed lowland woodland habitats.

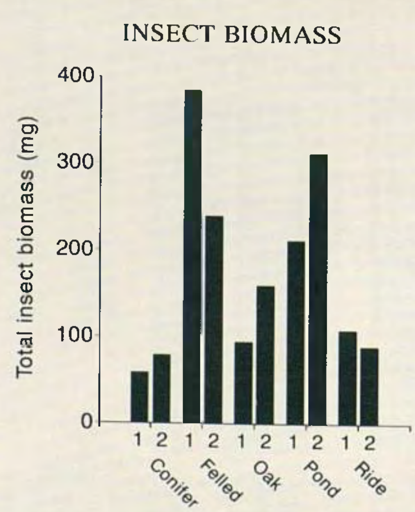

Figure 18. Insect biomass in different mixed lowland woodland habitats.

MENSURATION

Micropalm portable computers were successfully introduced into the 1991/92 sample plot measurement programme. A data collection program was written in TurboPASCAL for the Micropalm, and all field teams have been trained by the Branch. Field teams have welcomed the additional flexibility and robustness given by the new hardware and software. The sample plot measurement programme was one of the largest ever undertaken, with completion of over 145 full measurements and 57 partial measurements including the backlog of measurements in sample plots damaged in the gales of January 1990. In addition three temporary plots 0.25 ha in size, were established in Finn planted Corsican pine at Thetford at the request of the Forest District.

In collaboration with J.M. Christie provisional yield tables for poplar at 3, 4 and 8 m spacing, based on 8 m standard spacing, have been produced. Data from old silviculture poplar clonal trials, a new trial at Bedgebury, and measurements from Caen, France are being used to validate the models (see Figure 19).

A number of assortment tables covering a limited range of crop mean diameters and product top diameters have been constructed for typical plantations of unthinned Sitka spruce. They are compatible with the published tables, and although produced initially for Kielder Forest District, when fully extended they will be given wider distribution. A tariffing seminar was run by the Branch, in collaboration with Education and Training Branch, for North Scotland Conservancy. Course members included local staff and representatives from the timber trade. The Branch continues to represent the United Kingdom on the European Standards Committee CEN TC175 Working Group 1 'Methods of Measurement of Round Timber'.

A new tree ring measuring system has been purchased and installed in Mensuration Branch (Plate 9). Initially cores are being measured for a collaborative project with Site Studies

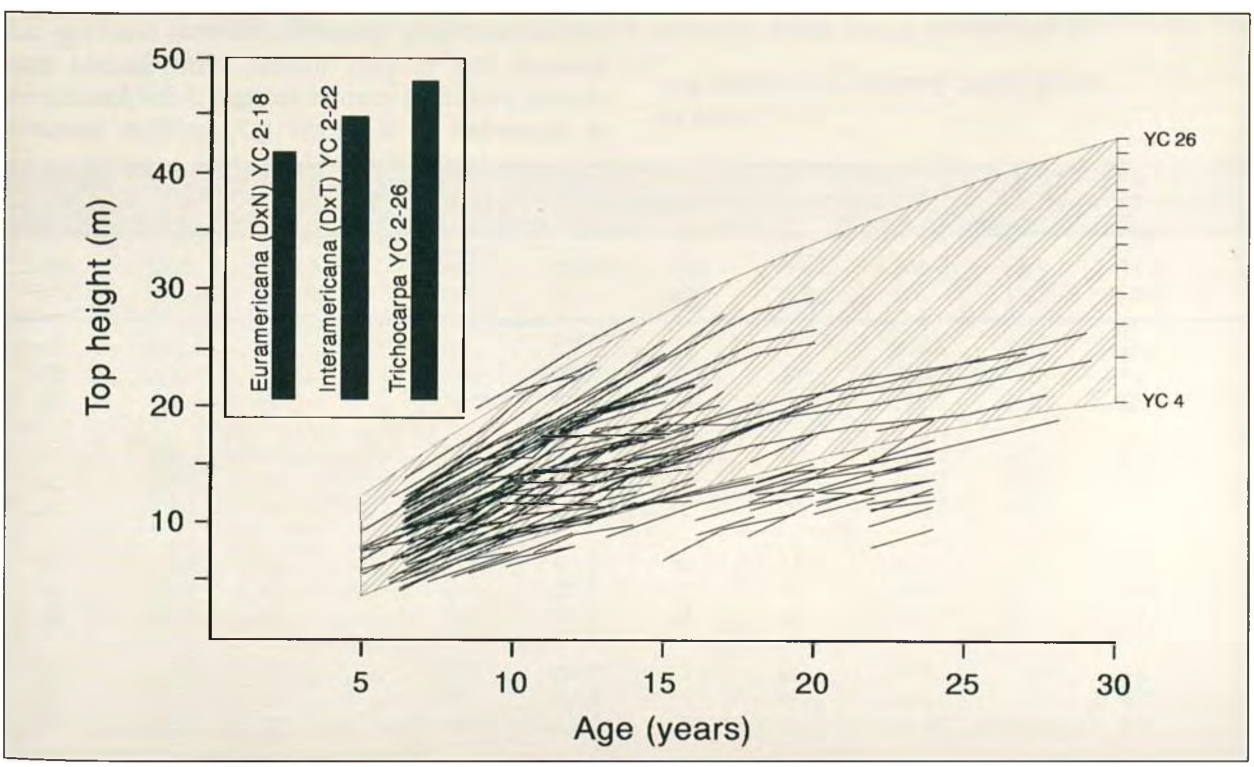

Figure 19. Validation data and extended top height age curves for poplar.

(South) Branch investigating the sensitivity of forest tree growth to environmental and management changes.

JANET METHLEY

SITE/YIELD

This is a joint research project funded by the Foresty Commission and the Ministry of Agriculture, Fisheries and Food. The objective is to design and calibrate a model that will enable growers to predict the potential yield of trees planted on their land from easily measured site factors. Soil group, soil moisture deficit and accumulated temperature have been identified as primary site factors affecting growth. A sampling scheme has been devised around these factors, taking into account data already collected from Forestry Commission permanent sample plots. Measurements from over 90 temporary plots of Corsican pine, Douglas fir, oak and beech have been recorded. Preliminary analysis of previously collected data has indicated that it may be necessary to include secondary site factors in the analysis and has confirmed the need for more data. Initially models are being developed for Corsican pine and Douglas fir, oak and beech. A 2-year extension of the project has been approved by MAFF during which models will be developed for ash, poplar, sycamore, hybrid larch and Norway spruce.

PETER JOKIEL, MELISSA ALEXANDER AND IAN SALISBURY

PROGRESS ON VALIDATION

As part of a strategy for incremental improvement and development of yield models, a flexible computer-based model has been developed for unthinned Sitka spruce, enabling models for planting spacings and yield classes not previously covered to be easily created. Table 14, for example, shows a complete model for Yield Class 12 unthinned Sitka spruce planted at 1.5 m spacing.

ROBERT MATTHEWS AND SUKHDEV SENCEE

CARBON STORAGE

Models for biomass accumulation and carbon storage by forests have been used to estimate the quantity of carbon locked up in British forests now and in the future. Figure 20 shows two alternative predictions of carbon storage by British forests over the next 50 years. It is estimated that the living, growing trees in British forests currently store 110 million tonnes of carbon. This estimate varies between 90 and 130 million tonnes, depending on how the forest area is defined. In this case the total forest area is taken to be 2.3 million hectares, as indicated in *Forestry facts and figures.* If the forest area is maintained but not expanded, carbon storage is predicted to rise slightly to 140 million tonnes by the year 2020 (solid line) before levelling out around 130 million tonnes. The dashed line shows predicted carbon storage if the forest area is expanded by a further 0.75 million hectares

Table 14. Yield table for Yield Class 12 unthinned Sitka spruce at 1.5m

Age (yrs)	Top height	Trees /ha	Mean dbh	B/A /ha	Mean vol	Vol /ha	Per cent mortality	MAI vol/ha	Age (yrs)
19	6.9	3841	9	27	0.02	64	0	3.4	19
24	9.5	3492	12	37	0.04	131	0	5.4	24
29	12.1	3098	14	45	0.07	211	0	7.3	29
34	14.6	2701	16	52	0.11	298	1	8.8	34
39	16.8	2339	18	57	0.16	382	2	9.8	39
44	18.9	2037	20	61	0.23	459	4	10.4	44
49	20.7	1801	21	64	0.29	527	7	10.8	49
54	22.2	1624	23	66	0.36	585	8	10.8	54
59	23.6	1494	24	68	0.42	635	10	10.8	59
64	24.7	1400	25	70	0.48	676	11	10.6	64
69	25.7	1330	26	71	0.53	710	13	10.3	69
74	26.5	1279	27	72	0.58	737	14	10.0	74
79	27.1	1241	27	73	0.61	759	15	9.6	79

over the next 50 years (Cunningham, 1991). The total quantity of carbon stored rises steadily, reaching 160 million tonnes by the year 2040. The forecasts assume that thinning, felling and replanting of commercially productive forests take place in the future at times and intensities indicated in the Forestry Commission's Management Tables (Edwards and Christie, 1981).

ROBERT MATTHEWS AND SUKHDEV SENCEE

REFERENCES

CUNNINGHAM, I, (1991). *Forestry expansion: Introduction, summary and conclusions.* Forestry Commission Occasional Paper 33. Forestry Commission, Edinburgh.

EDWARDS, P.N. and CHRISTIE, J.M. (1981). *Yield models for forest management.* Forestry Commission, Edinburgh.

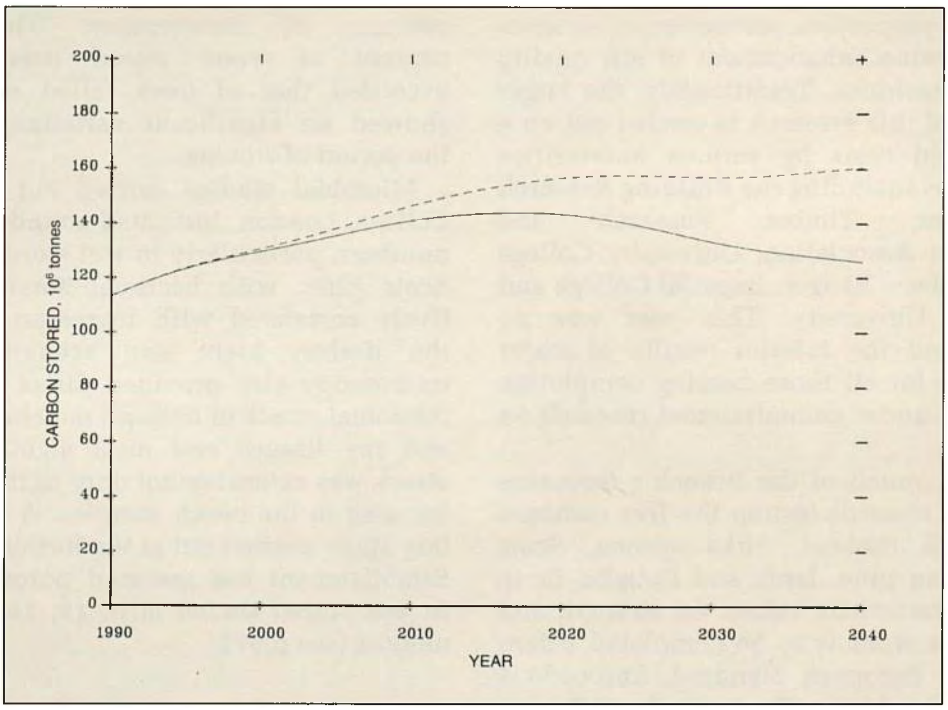

Figure 20. Alternative predictions for carbon storage by British forests over the next 50 years.

FOREST PRODUCTS

During 1991–92, the Branch continued research on a number of project areas spanning timber properties, prevention of deterioration and value enhancement of low quality timber and residues. Traditionally, the larger proportion of this research is carried out on a commissioned basis by various universities and institutes including the Building Research Establishment, Timber Research and Development Association, University College of North Wales – Bangor, Imperial College and Portsmouth University. This year was no exception and the interim results of major projects and for all those nearing completion are reported under commissioned research on pages 57–61.

Currently, much of the Branch's resources are directed towards testing the five common British-grown timbers, Sitka spruce, Scots pine, Corsican pine, larch and Douglas fir to provide characteristic values for strength and density. This work is to be completed before the issue of European Standard, Eurocode 5 (due in 1993), which will supersede all British Standards and contain grading rules for sawn and processed timber. Some testing of hardwood species is also underway in collaboration with the British Timber Merchants' Association.

Forest Products staff also continue to represent the Foresty 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-house' research commitments are mainly directed towards the preservation of home-grown species with particular emphasis on pine; individual projects are reported below.

WATER STORAGE OF TIMBER

Evaluation of long-term water storage over a 3-year period for the preservation of Corsican pine, Sitka spruce and European beech has been completed (see also earlier *Reports*). Consistent with earlier assessments, the logs sawed readily and cleanly and had minimal amounts of discoloration. The moisture content of water stored logs frequently exceeded that of fresh felled material and showed no significant variation throughout the period of storage.

Microbial studies carried out at Imperial College, London, indicated abundant bacterial numbers, particularly in wet stored beech and Scots pine, with bacterial abundance positively correlated with increased porosity of the timber. Light and scanning electron microscopy also provided direct evidence of microbial attack of both pit membrane systems and ray tissues and most significantly, pit attack was extensive not only in the softwoods but also in the beech samples. A complementary study carried out at the Building Research Establishment has assessed porosity changes in wet stored timber at 6, 12, 18, 24 and 36 months (see p.57).

JOAN WEBBER

PRESERVATION OF UTILITY POLES

Air seasoned British-grown Scots pine and Corsican pine are vulnerable to attack by wood rotting basidiomycetes during the necessary pre-treatment seasoning period. However, encouraging preliminary field trials suggested borates and certain fungal biological control agents could deter colonisation by the damaging basidiomycetes. As part of an SERC CASE studentship, the effectiveness of biological control fungi in utility poles is now being explored in greater detail.

In a large-scale experiment using Corsican pine and Scots pine, four potential biocontrol agents are under test: *Trichoderma viride, Cryptosporiopsis tarraconensis, Ascocoryne sarcoides* and *Potebnomyces coniferum*. These have been applied to the end grain of fresh felled logs and their protective action against wood rotting fungi is being assessed. As a more rapid method of screening the effectiveness of biocontrol fungi, lab based experiments will also challenge potential biocontrol fungi with a spectrum of white rot basidiomycete inocula on a substrate of irradiated pine discs.

JOAN WEBBER AND MAGNUS SCHOEMAN

ADVISORY SERVICE

Almost 200 enquiries from the public, schools and forestry industry were processed by the Branch during 1991/92. As usual requests for information were diverse, but queries about timber properties and uses, methods of preservation and use of chipped forest and timber residues were the most frequently encountered.

JOAN WEBBER AND CAROLE LISHMAN

STATISTICS AND COMPUTING

Introduction of the Local Area Network at Alice Holt has occupied much time but will greatly increase our computing capacity.

COMPUTING: NORTHERN RESEARCH STATION

Much of 1991 has been concerned with installing the new Sun workstations and Local Area Network. The Sun server is now the main central computer for all users and provides statistical, graphics, word-processing and data-base packages. Programs and data have been transferred from the Edinburgh University main-frames. The Experiment Register Database has also been moved and set up in Oracle. Micro users now have network access to files on the server and can use networked devices, such as laser printers, easily. We can also back up most micros to the central file storage on the server.

Some new notes for computer users have been written and all users have had at least basic training in the new system.

WAYNE BLACKBURN

STATISTICS: NORTHERN RESEARCH STATION

Ducts in spruce needles

Measuring the size of ducts in spruce needles produced interesting problems of analysis. Sections of needles were taken at fixed positions along the length of the needle and the area of the duct then measured (see p. 29). Ducts originate at the base of the needle, but extend to a variable length so a zero, or missing value, is obtained when a duct does not extend to a particular section. Rather than analysing the results for each section separately, then dealing with the problem of the large number of needles with no ducts reaching that section, inferences were made about the duct length, assuming a simple relationship between the measured area and the length of duct. A zero area was treated as a left-censored length measurement. The fitting process is particularly tractable if the duct length distribution is assumed to be logistic.

IAN WHITE

PROGRAMMING: ALICE HOLT

MicroPalms

In 1991, a program was written for MicroPalm users collecting the 1991 forest health survey data (see p. 17). It was based on a spreadsheet approach rather than on the 'question and answer' idea behind the programs for the 1990 survey.

The program was written in Turbo Pascal 6.0 (Borland) using object orientated programming techniques. There are two objects within the program, both of which are forms. The first form holds the details relating to the plot being surveyed. The second form holds the assessments for the plot.

The first form can be displayed in its entirety on the MicroPalm screen (which is 8 rows by 20 columns). The second form is represented by a virtual scrolling entry screen as it cannot all be visible on the MicroPalm screen.

Each entry is validated to ensure that it is within an allowable range and entries are cross-checked against other fields as appropriate. Entries for certain fields in the data are checked against the data collected in the previous survey. The new entry is queried if it is significantly different from the previous year's data, or if diameter (at breast height) is less.

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

At any stage during data collection, the user can call up a context sensitive help facility which displays information about the current entry field. The help contains an explanation of the data required and it lists the codes allowed as input for that field. Further help is available about using the program, moving about the screen, field editing capabilities and so on.

The data collected in the forest health survey is stored on a removable module within the MicroPalm. This module is sent to Alice Holt where it is copied on to micro-computer for analysis. New versions of the program can be returned to the surveyor on the module as upgrades are required.

The data capture program has been used as the core of a second MicroPalm program, for entering the proportion of the surface of a rod that has been rusted. This involved adding an extra section to the program to allow many rods within the file. From a programming point of view, a single rod is the equivalent of a forest health survey plot.

The program has application to similar hand-held data loggers.

Forest Surveys

Work began in September 1991, to transfer the Subcompartment Database and its associated programs to the computing facilities at Forestry Commission HQ. The system would be run on a VAX under the VMS operating system. The ORACLE database and many of the Pascal and FORTRAN programs have been converted to run under VMS. The job control system (which was written in PRIME CPL) is being rewritten in VAX DCL.

Plant Production

Delta-T loggers are used to monitor germination experiments. Users have to be alerted when a sensor goes out of range. The old system generated huge amounts of paper which had to be inspected, when all that was required was a record of readings leading up to the problem and an alarm to alert personnel. A program has now been written as a terminate-and-stay-resident (TSR) program for a PC. The records of all readings are written to a file and personnel are alerted when a sensor goes out of the range specified in an ASCII file. The program will be used in the lab when a new 45 channel system is installed.

JOHN HALL AND LESLEY HALSALL

STATISTICS: ALICE HOLT

The SILVAN data analysis system

The SILVAN system is a Fortran shell that can be used to set up and run GENSTAT analyses for a large number of experiments from Silviculture (South) Branch, using recent or previously assessed data. It achieves this by displaying simple questions on a terminal and turning the user's responses into options and parameters of a GENSTAT procedure. Although the procedure is unique to each experiment, only a few lines of code differ between experiments. These give details of the number of units in each plot, the experimental design, and text to enhance the output.

The GENSTAT procedure is the key to the system and was designed to be easy to use, with the minimum number of options and parameters. Thus, by supplying text to describe the variate being analysed, the identifier of the variate to be used in the GENSTAT program, the date of the assessment and the name of the data-file, a very simple program can be written to give the appropriate ANOVA and tables of means. For example:

```
GENAN 'Height' ; ht587 ; 'May 1987' ; 'my87ht'
```

If a second variate name is specified, together with date and file, analyses of covariance and increments are carried out, using data from the first set as the initial measurements.

One option gives the ANOVA for percentage survival (transformed to angles) when more than one unit was measured in each plot. Other options of output include a line-printer display of plot means against treatment combination (annotated individually for each experiment), and a file of re-randomised plot means with all associated factor levels. Tests are built in to inhibit inappropriate selections and warn of large numbers of missing plots or poor overall survival levels. Covariance analyses can be disabled for both final assessment data or increment analyses.

When using SILVAN the user can interactively identify experiments that can be analysed using the system, and find which data files are available. Using the information provided, the system expands file names to create appropriate parameters, while user-choices are translated into the required options. The user can abandon the process at any stage, or run the created GENSTAT program as a batch job. The output is presented without the GENSTAT source code in a file named after the experiment identifier.

ROGER BOSWELL AND TRACY HOUSTON

COMMUNICATIONS

Several staff changes occurred during the year, including the departure of the former Head of Branch, B.G. Hibberd, on promotion to the Forestry Authority's national office for England. Prior to his transfer Mr Hibberd saw the publication of the 11th edition of *Forestry practice* which he had edited and which forms part of a trilogy of silvicultural practice handbooks along with *Farm woodland practice* and *Urban forestry practice*. Planning for the 'Trees for Tomorrow' Open Days at Alice Holt (June 1992) was well advanced by the year end.

Additional information technology equipment in the Library and in Photography Section, together with the benefit to Forestry Commission technical publications that has been gained from the use of new computer graphics facilities in HMSO's Graphics Design Section, mean that the Branch is able to maintain a high quality of output for its various products and services while responding to an increasing quantity of requests for forestry research information.

JOHN PARKER

LIBRARY AND INFORMATION SERVICE

The Library has continued to provide a wide ranging service in support of the work of Research Division in particular and of the Forestry Commission in general, as well as to external enquirers, especially students of forestry and environmental sciences. The number of book and report loans has increased and there has been substantial use of our photocopying service generated by our Current Awareness listing of selected periodical articles. The number of individual visits to the Library more than doubled to over 200; we also had a special visit from Romanian forestry students.

We have been very pleased with the acquisition of a CD-ROM. This has proved a popular and useful service in the Library, allowing researchers to access summaries of forestry articles at a moment's notice. At present we have TREECD for forestry material from 1939 to 1992, and two editions of CAB Abstracts for the years 1984 to 1989. We have also extended our use of Current Contents on diskette to include abstracts.

CATHERINE OLDHAM

PHOTOGRAPHY

Design advice and preparation of display material were provided for the Open Days at the Northern Research Station in May 1991 to mark the Station's 21st Anniversary. Also in May, a Photographer was appointed at the Northern Research Station to provide photographic and computer graphic services for staff there. At Alice Holt, a thermal wax printer was purchased, which allows for the fast production of colour computer-generated images as prints or overhead transparencies. Just before the year end the Graphics Officer post was transferred from Publications Section to Photography Section.

GEORGE GATE

PUBLICATIONS

The following titles were published during the year ending 31 March 1992:

Reports

Report on forest research 1990 (£15).
Report on forest research 1991 (£15).

Bulletins

95 Forest fertilisation in Britain, by C.M.A. Taylor (£5.75).

96 Sawmilling accuracy for bandsaws cutting British softwoods, by J.N. Smithies (£3).

97 Research for practical arboriculture, edited by S.J. Hodge (£17.50).

98 Monitoring of forest condition in Great

Britain 1990, by J.L. Innes and R.C. Boswell (£7.50).

99 Urban trees – a survey of street trees in England, by S.J. Hodge (£3.50).

100 Honey fungus, by B.J.W. Greig, S.C. Gregory and R.G. Strouts (£3).

101 De-icing salt damage to trees and shrubs, by M.C. Dobson (£6.75).

102 Forest fencing, by H.W. Pepper (£5).

104 Valuing informal recreation on the Forestry Commission estate, by J.F. Benson and K.G. Willis (£7.50).

Guidelines

Forests and water guidelines (£5.25).
Community woodland design guidelines (£9.75).

Handbooks

6 Forestry practice, edited by B.G. Hibberd (£14.95).

7 Treeshelters, by M.J. Potter (£5.30).

Occasional Papers

29 The supply and demand for wood in the United Kingdom, by A. Whiteman (£2.50).

30 The impact of government intervention on private forest management in England and Wales, by J.A. Johnson and D.C. Nicholls (£2.50).

31 Factors affecting the natural regeneration of oak in upland Britain – a literature review, by R. Worrell and C.J. Nixon (£2).

32 Price-size curves for broadleaves, by A. Whiteman, H. Insley and G. Watt (£2).

The following 15 Occasional Papers were originally issued in July 1991 as a series of invited papers under the overall title 'Forestry expansion: a study of technical, economic and ecological factors'. Price £25 the set inclusive of postage.

33 Introduction, summary and conclusions (free).

34 British forestry in 1990 (£2).

35 International environmental impacts: acid rain and the greenhouse effect (£2).

36 The long term global demand for and supply of wood (£2).

37 UK demand for and supply of wood and wood products (£2).

38 Development of the British wood processing industries (£2).

39 The demand for forests for recreation (£2).

40 Forests as wildlife habitat (£2).

41 Forestry and the conservation and enhancement of landscape (£2).

42 The impacts on water quality and quantity (£2).

43 Sporting recreational use of land (£2).

44 The agricultural demand for land: its availability and cost for forestry (£2).

45 Forestry in the rural economy (£2).

46 New planting methods, costs and returns (£2).

47 Assessing the returns to the economy and to society from investments in forestry (£2).

Miscellaneous

Successful tree establishment (free).

Research Information Notes

200 Vegetative propagation of aspen.

201 Herbicides for farm woodlands and short rotation coppice.

202 Appraisal of charcoal production.

203 Methods of grass control in the uplands.

204 Management of Sitka spruce natural regeneration.

205 Conserving the red squirrel (colour).

206 Electric fencing against deer.

207 Shoot dieback of lodgepole pine caused by *Ramichloridium pini.*

208 Air quality and tree growth in open-top chambers (colour).

209 Forest monitoring programme – 1991 results (colour).

210 Electrolyte leakage: a rapid index of plant vitality.

211 Planting and establishment success of Corsican pine raised in JPPs.

212 Sitka spruce for construction timber: the relationship between wood growth characteristics and machine grade yields of Sitka spruce.

213 Ecology of nightjars in Thetford Forest and the national nightjar survey in 1992.

214 Occurrence of decline and dieback of oak in Great Britain.

215 Nestboxes for kestrels (colour).

216 Physical site evaluation for community woodland establishment.

217 Forest management practice to minimise the impact of the pine beauty moth.

JOHN PARKER

PART II

Work Done for the Forestry Commission by Other Agencies

HERBICIDE EVALUATION ON FOREST WEEDS AND CROPS

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In this project improved herbicide treatments are sought for forest nurseries, newly-planted forest trees and certain problem weeds using experiments on container-grown plants.

Emerged weeds are often a severe problem on nurseries requiring expensive hand-weeding. In a search for possible contact herbicides, 13 were tested for tolerance on birch, Japanese larch and Sitka spruce seedlings. Clopyralid and haloxyfop at doses needed for weed control had no adverse effects on any species. Cyanazine, cyanazine + clopyralid, fluoroglycofen-ethyl, formesafen, thifensulfuron-methyl and tribenuron-methyl generally had no adverse effect on larch and spruce at recommended doses. Other herbicides tested were very damaging.

Rhododendron ponticum is a serious weed problem in many forests. Treatment with glyphosate or triclopyr may not give long-term control. Earlier work in this project showed that imazapyr was a promising control agent. Factors affecting imazapyr activity on *R. ponticum* have been investigated. Applications of imazapyr at all times of year were effective, although lower doses applied in winter had reduced activity. There was greater effect from foliage applications compared with root drenches. Spraying imazapyr just on parts of the foliage caused damage throughout the bushes indicating considerable translocation from sprayed parts (Figure 21). On small plants imazapyr applied to older leaves was more damaging than treatment of young leaves.

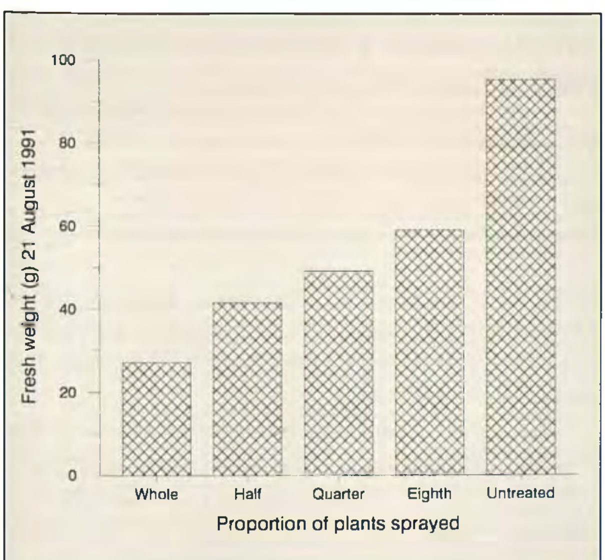

Figure 21. The effect on shoot fresh weight of imazapyr (400 g a.e./ha) applied on 24 April 1991 to different proportions of the shoots of Rhododendron ponticum *bushes.*

Imazapyr is very slow acting; addition of a contact herbicide to indicate rapidly the position of sprayed bushes could be useful. Addition of sodium monochloroacetate to imazapyr spray solutions caused rapid leaf kill but there was some reduction of imazapyr toxicity at lower doses.

Certain sulfonyl urea herbicides are of potential value for the control of bracken *(Pteridium aquilinum).* Thifensulfuron-methyl and tribenuron-methyl applied over young Sitka spruce at different dates during the summer generally had no adverse effect on tree growth after treatment or in the following year.

REFERENCES

CLAY, D.V., GOODALL, J.S. and WILLIAMSON, D.R. (1992). Evaluation of post-emergence herbicides for forestry seed beds. *Aspects of Applied Biology* **29**, *Vegetation management in forestry, amenity and conservation areas*, 139–148.

CLAY, D.V., GOODALL, J.S. and NELSON, D.G. (1992). The effect of imazapyr on *Rhododendron ponticum*. *Aspects of Applied Biology* **29**, *Vegetation management in forestry, amenity and conservation areas*, 287– 294.

CYCLIC LOADING OF SITKA SPRUCE ROOTS AND SOIL – ROOT SYSTEMS

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The response of trees and their root systems to dynamic loads is an important feature of their resistance to windthrow. In most studies, however, the relevant mechanical properties of soil–root systems have been measured in static tests because of the difficulties involved in dynamic testing.

Equipment was designed and built to enable cyclic loading tests to be made on the soil–root systems of trees, and on tree roots, at frequencies close to the natural frequencies of fully-grown Sitka spruce (*Report* 1990, p.92 and Report 1991, p.66). Soil–root systems were tested by imposing cyclic displacements on the stumps of Sitka spruce trees which had been felled at about 1.5 m, while measuring overturning moment and root plate displacement. Individual roots were tested by applying cyclic loads to severed root ends *in situ*, while measuring extraction force and the displacement of the severed ends. Isolated sections of bare root, from 4 mm to 20 mm diameter over bark, were also tested in the laboratory to allow measurement of the elastic modulus of roots under conditions of cyclic loading. Some static loading tests were also made in the laboratory.

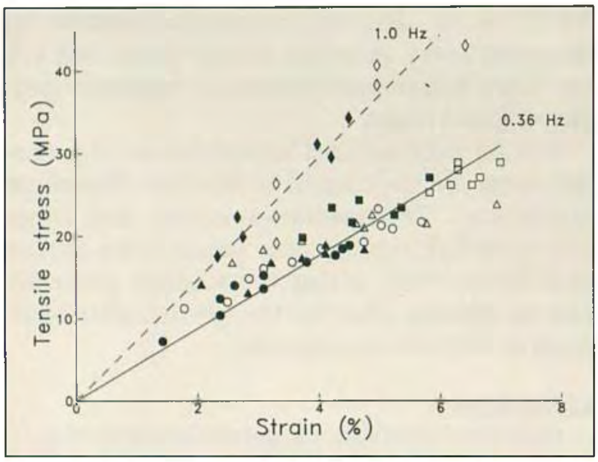

Figure 22. Results of laboratory tests on bare roots at two frequencies. The different symbols represent different specimens. Open and filled symbols represent results at the start and end of each loading episode, respectively.

Cyclic loading of soil–root systems had two opposing effects. There was progressive failure of the anchorage with successive load applications up to about 25 cycles. This tendency increased with stem displacement and would tend to reduce the stability of trees. The size of the reduction in anchorage strength was in the order of 25%. The other effect was that a larger load was required to produce a given root plate displacement with cyclic than with static loading. This was a result of energy dissipation within the system and so this phenomenon would tend to increase tree stability. About 10% to 20% of the input energy was dissipated in this way. The displacement of soil–root systems under the action of wind in the forest does not follow such a simple, repetitive pattern and, thus, more work is required to estimate the sizes and relative importance of these effects in representative forest conditions.

When tested *in situ*, the roots withdrew from the soil appreciably on the first loading cycle and then by successively smaller amounts with each cycle, up to about 25 cycles. The roots also stretched elastically, with an approximately linear relationship between force and elastic elongation.

In the laboratory, the apparent elastic modulus of bare roots depended on loading frequency. The use of a simple mathematical model allowed the results to be expressed in terms of a storage modulus, independent of frequency, and a loss modulus. This showed that, at a loading frequency of 0.36 Hz, about 33% of the input energy was dissipated in these roots.

THE STATUS OF BIRCH IN SITKA SPRUCE RE-STOCKED PLANTATIONS

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Downy birch decreased dramatically at distances greater than 200 m from seed sources. The corresponding distance was 150 m for silver birch. The number of source trees declined with increasing altitude with little regeneration occurring over 200 m. This altitudinal limit reflects past land-use impacts rather than the natural distribution of either species.

Initial recruitment of downy birch was higher on podzols and deeper peats with a vegetation of sub-shrubs and wavy-hair grass *(Deschampsia flexuosa)*. However, mortality on these sites was higher than on brown earths, which supported large numbers of birch of 1–5 m. Silver birch performed best on podzols.

Few birch survived beyond the thicket stage even though mean cover of Sitka spruce was no higher than 40%.

THE GROUND FLORA OF CONIFER-BROADLEAF PLANTATIONS

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In Norway spruce/oak mixtures, high densities of spruce depressed vascular plant cover and species number, as did the beech component in pine/beech mixtures.

The number of seeds of vascular plants in the soil of spruce/oak mixtures was positively correlated with oak growth and the diversity of ground vegetation, and negatively correlated with the amount of spruce present. The roles of the broadleaf and conifer components were reversed in seedbanks of pine/beech stands.

A significant increase in ground flora species occurred following the removal of the spruce canopy and leaf litter in a spruce/oak mixture growing on an ancient woodland site.

There was little correspondence between the seedbank species and those in the above-ground vegetation. Commonest seedbank species were *Rubus fruticosus*, *Juncus effusis*, *Hypericum* spp. and *Epilobium* spp. The limited seedbank of grasses typical of ancient woodland such as *Milium effusum* and *Poa nemoralis* will result in their replacement by such species as *Poa trivialis* and *Holcus lanatus* if they are lost from the above ground vegetation.

RESEARCH ON BRITISH-GROWN TIMBER

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Water-stored timber

Evaluation of changes in strength and porosity of timber held under long-term water storage has almost been concluded. For Corsican pine and Sitka spruce measurements of porosity, using a specially developed 'air leakage' method, have now been completed on kiln dried planks measuring 50 x 100 mm cut from fresh-felled logs for controls and from logs stored under continuous water-spray for 6, 18, 24 and 36 months. In addition, the porosity of fresh felled versus logs stored for 18 months has also been compared for Scots pine, larch, Douglas fir and Norway spruce. Overall, 2260 battens have been processed. The final stages of the study currently involve measurements on the beech control material and on the beech planks cut from logs stored for 36 months.

Analysis of all data is still in progress but preliminary results confirm expectations that

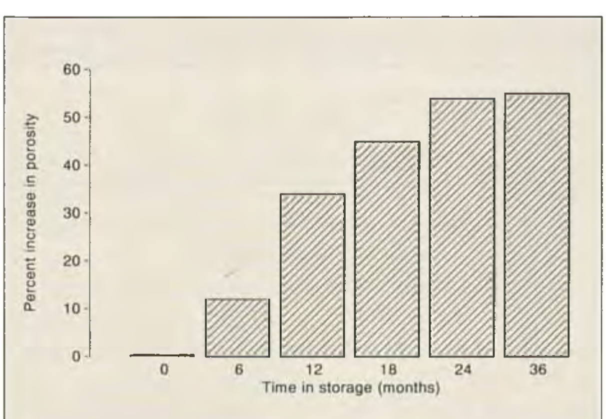

Figure 23. Percentage change in porosity of Corsican pine during water storage.

porosity increases with time under water storage. The effect is particularly marked in Corsican pine (Figure 23) where progressive increases in porosity were detected through to 24 months, after which time there was no further significant increase. With Sitka spruce, increases in porosity occurred in the first 12 months and then remained unchanged. Increased porosity in beech was detected between 12 and 18 months but the true magnitude and significance of this cannot be confirmed until results with the control material have been completed and analysed.

All the softwood material has also been stress-graded and results indicate no significant deterioration in strength with increasing storage time up to 24 months; data for 36 months have yet to be analysed. Some changes in structural classification yields occurred, but they were small and inconsistent.

Grading rules for Eurocode 5

The programme of testing to ensure compliance of British-grown timber with Eurocode 5 is now well advanced. Altogether five species are under test: Sitka spruce, Scots pine, Corsican pine, larch and Douglas fir. All testing and analysis for Sitka spruce is complete, including extra data to refine earlier results and allow for possible future improvements in machine grading procedures.

The test data indicated that the old settings used for machine stress grading over-optimised the Strength Class (SC) yields, particularly for higher grades, when timber from current production was graded. This resulted in reduced safety levels when the graded timber was used for construction purposes. When normal analytical procedures were used to determine new settings, the result was a large drop in yields, necessitating the development of a more refined procedure to achieve the optimum machine settings for commercial sawmill grading. On the basis of these data, trial machine settings were then issued to five co-operating sawmills for grading trials and yield assessments. The results of these trials have been analysed and used to issue revised machine settings. The changes in yields for various Strength Classes are shown in Table 15.

Although the new European CEN strength classes cannot be exactly equivalent to those used in the UK, CEN classes C22 and C16 are roughly equivalent to SC4 and SC3 respectively. Table 15 shows that although there will be some loss of yield for SC4, there will be little change for SC3, the most popular class currently used for construction purposes, even

Table 15. Machine grade yields of Sitka spruce construction timber in SC3 and SC4 strength classes

Settings	*UK strength*	*CEN strength*	*Yield %*
Old	SC4		49
New	SC4		40
New		C22	30
Old	SC3		91
New	SC3		90
New		C16	89
New		C18	75

when C16 has to be adopted from the European CEN standard. There is also the advantage of a higher strength class C18, which clearly gives acceptable yields. The project has, however, shown the need for further work to investigate apparent variations in Sitka spruce from forest to forest in the relations between certain timber properties.

Testing and data analysis with Scots pine is not yet complete but correlation co-efficients between bending strength and Modulus of Elasticity do suggest further testing may be necessary. So far only a quarter of the data required for Corsican pine has been obtained and as yet none of the larch and Douglas fir material is available for testing.

Work to derive grading rules and strength properties for British-grown oak has commenced and testing work is complete on the small sized timber samples (50 x 100 mm) after kiln drying. Preliminary findings suggest despite indications of some slight embrittlement in the timber, possibly caused by kiln drying, that a relationship exists between the extent of visual defects in the timber and timber strength. This will allow the determination of visual grading rules and characteristic values to be derived and incorporated into British Standard 5268 and the new CEN Standard.

Sitka spruce provenance comparison

This project seeks to determine the structural classification, Modulus of Elasticity (MoE) and Modulus of Rupture (MoR), of sawn Sitka spruce from six different provenances (five Washington provenances and one, QCI, from British Columbia). The results have indicated no significant differences between the graded yields within or between the provenances, while determinations of MoE and MoR for each provenance have been carried out on 40% of the sawn battens but have yet to be fully analysed. However, the indications are that there is no significant difference in MoE values between Washington and QCI provenances, except for the Washington material designated Hoh which had a lower mean MoE. In general, this provenance also gave poorer yields of stress-graded material. Provisional analyses of MoR values have shown a significant difference between the two QCI samples, with the Washington samples for Copalis and Hoh also returning low values (Table 16).

Table 16. Mean values from static bending tests of Sitka spruce from six different provenances

		Strength values	
Area	*Provenance*	*Mean MoR (N/mm²)*	*Mean MoE (N/mm²)*
QCI	Sample 1	10900	48
		10400	45
	Sample 2	9800	42
Washington	Columbia	10000	44
	Copalis	9600	41
	Greys	10200	45
	HOH	9100	42
	Nemah	10100	43

DEVELOPMENT OF BRITISH-GROWN TIMBER

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Laminated veneer lumber from European species

This project has been devised to evaluate the technical and economic benefits, and viability of manufacturing Laminated Veneer Lumber (LVL) using wood grown within the European Community. It has progressed, with Forestry Commission support, to the stage at which the two main types of experimental LVL have been manufactured successfully on an industrial scale, using British-grown Sitka spruce and French-grown poplar. These timbers are also included in laboratory-scale manufacturing trials, and there are also plans to include British-grown poplar and Danish Sitka spruce in this lab-scale work.

Using samples from the full-sized experimental production, quality control tests have been carried out on the LVL to assess the bending strength in two directions, and to evaluate glueline quality. This has proven satisfactory. The source materials for both the full scale, and the lab-scale LVL are also being characterised with respect to various wood-structural and mechanical properties. These include number, location and width of growth rings; grain angle; compression strength of small clear sample pieces; wet density and drilling resistance. For the British and Danish Sitka spruce, this work has been completed but is still continuing on the discs of poplar. In addition to these characterisation tests using very small specimens taken from tree discs, planks have been sampled from similar logs to those used for the veneer peeling. These planks have been converted to small test beams intended to represent the material as normal sawn structural wood. They will be tested for stiffness and loaded to failure, using full-sized specimens test procedures.

Using the full-sized experimental LVL material, and with normal production LVL for comparison, many physical and mechanical properties are to be evaluated. In this work, structural-sized tension tests are to be included on the British Sitka spruce LVL, and on the French poplar material. Manufacture and conditioning of these specimens has been started. Creep and duration of load tests are also to be included, and some of the initial testing for these has commenced.

Important aspects of the laboratory-scale manufacture and testing are to include evaluation of alternative adhesive systems, and to assess alternative layup procedures to obtain beneficial and competitive properties. For example, one variation being examined in poplar is the use of thicker veneers compared with those recommended for softwood LVL production. In addition, a study has been initiated on the feasibility and economics of LVL production in selected locations within the European Community. Aspects such as actual and potential wood species used in LVL production, types, sizes and capacity of production lines, and comparisons with other structural materials have been discussed with the industry.

Small dimension hardwood blanks

The aim of this small market research project was to assess the commercial prospects for a wider trade in small, essentially defect-free wood blanks in a range of standard sizes cut from larger defective timber pieces. This would have particular relevance for the effective utilisation of low-grade hardwoods. The consumers of such blanks were foreseen as the furniture and joinery manufacturing industries who would lay down specification for their requirements in terms of species, size, moisture content, quality and other factors for manufacture into components.

Information was obtained by face to face interviews with selected sawmillers and potential customers. Survey results suggested that it was unlikely that there would be scope for producing and marketing such blanks in advance of creating specific markets. The main reason was the variety of sizes and specifications likely to be required by different potential customers. Potential customers were very protective of their buying policy which allowed flexibility of supply and conversion to meet changing demands.

Currently, demand and supply arrangements for blanks of various types are already established, but they are limited. The survey did not, however, reveal much encouragement for widespread expansion of this type of added value conversion for low-grade hardwoods.

FUNGAL STAIN AND MOULDS ON UNSEASONED TIMBER

BY ROD EATON AND MICHAEL POWELL
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The establishment of sapstain fungi and moulds on Corsican and Scots pine before, during and after processing at the sawmill is being investigated. Spores of sapstain fungi are disseminated by bark beetle vectors and it is probable that this is a major infection route into freshly felled logs during storage. Alternatively, sapstain infection of exposed green timber may occur through spore transmission in rain or mist droplets, mite and microarthropod infestation of logs or sawn timber in close contact with soil or via dissemination of infected sawdust particles released from the saw blade. The possibility also exists that infection of sawn surfaces may occur directly from the blade.

One of the main objectives of this study is to define more precisely the source of fungal infection throughout the year. This is being investigated by sampling stored logs and stacked sawn timber, collecting associated insects and by air-sampling at sawmills. A further element of the work deals with the susceptibility of wet-stored timber to stain and mould fungi.

First results indicated more intense internal fungal staining in Scots pine logs removed from the upper part of the tree and stored for 6 months. The greater degree of stain may be related to a lower moisture content in the wood, but the relationship between wood moisture content, speed of drying and log diameter, and the rate of fungal infection is being studied further.

Field trials have been set up to monitor sapstain and mould growth in Corsican and Scots pine sawn boards cut from freshly felled logs and logs maintained in wet storage for 3 years. Wet-stored boards of both species were less disfigured than freshly felled wood. The levels of surface stain on boards from wet-stored logs was <10% after 3 months close-stacked storage whilst more than 50% of the surface of freshly felled boards was infected. The nutritional state of wet-stored timber and the presence of a large bacterial population plus bacterial extracellular metabolites may contribute towards lower infection and growth rates by moulds and sapstain fungi. Preliminary studies indicate that bacteria isolated from wet-stored wood are antagonistic to selected sapstain fungi and this will be investigated further.

TIMBER PRESERVATION

BY RICHARD MURPHY
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Research on the preservative treatment and durability of British-grown timber and timber products has been undertaken in several areas through the sponsored lectureship in Forest Products at Imperial College. These range from fundamental studies at the molecular level into the effects of decay on wood cell wall polymers and the interaction of preservative compounds with these polymers, to studies on the efficacy and suitability of preservative treatments and materials for British and European building timbers and timber products.

Fourier Transform Infra Red spectroscopy (FTIR) coupled with FTIR microscopy has been used to investigate molecular changes in the cell wall polymers of wood after decay by different fungi. The technique has been developed to a level where thin sections of wood can be used for FTIR studies with resolutions of approximately 50 μm^2. The technique is now being applied to investigate aspects of wood decay by brown rot fungi, lignin distribution in wood and its modification by these fungi and the distribution of various preservative compounds. In another study, Electron Paramagnetic Resonance spectroscopy (EPR) is being applied to elucidate the mechanisms by which several copper-based preservatives are bonded in wood. This is a co-operative study with a major British wood preservation company, and it has already demonstrated that copper will interact with wood in several ways depending on the preservative formulation. It is the overall objective of the programme to provide a fundamental basis, in association with biological data, for the development of future wood preservatives.

Co-operative work on home grown timbers has developed in two major areas with the Building Research Establishment. In the first, the effect of different treatment processes on the distribution of copper-chrome-arsenate preservatives in Corsican pine has been studied. It has been found that the use of empty-cell processes leads to some preservative disproportionation in wood in comparison with full-cell methods; the implications of these differences for preservative efficacy are currently being evaluated.

These investigations will be extended in the near future to include British-grown poplar species. The second major area of co-operation with the Building Research Establishment is a study of vapour boron treatment method for the preservative and flame retardant treatment of British manufactured panel products. A full investigation of the physical and mechanical effects of this novel process on Oriented Strandboard, Medium Density Fibreboard and chipboard has been conducted. The treatment has been shown to cause only minor effects on board properties and has considerable potential for extending the uses of these materials.

Co-operative research is also in progress with support from the EC on an evaluation of the potential of boron based preservatives for the treatment of building timbers, including Scots pine and Sitka spruce. Earlier work at Imperial College on the boron treatment of Sitka spruce provided the background for this study. Finally, a research programme has been initiated to develop the methods for undertaking and conducting a full environmental life-cycle analysis of preservative treated timber, in co-operation with the Imperial College Centre for Environmental Technology in a programme supported by members of the Electricity Association and companies in the timber treatment industry. The study will consider all aspects of the life-cycle of selected treated timber products (overhead line poles, construction timber) in Britain, including aspects of wood production, recycling and product performance. It is the intention of the programme to develop the fundamentals for the life-cycle analysis methodology with special reference to this and other timber products.

APPENDIX I

PUBLICATIONS BY RESEARCH DIVISION STAFF

BEATON, A., THOMPSON, D.A. & WEBBER, J.F. (1991). British poplar: a 21st century challenge. *Forestry and British Timber* **20**(8), 19–21.

BENDING, N.A.D., MOFFAT, A.J. & ROBERTS, C.J. (1991). Site factors affecting tree response on restored opencast ground in the South Wales coalfield. In, *Land reclamation: an end to dereliction?* Edited by Davies, M.C.R.; 347–356.

[BLYTH, J.,] EVANS, J., [MUTCH, W.E.S. & SIDWELL, C.] (1991). *Farm woodland management.* 2nd edtn. 196 pp. Farming Press, Ipswich.

BRASIER, C.M. (1991). Current questions in *Phytophthora* systematics: the role of the population approach. In, *Phytophthora.* Edited by Lucas, J.A., Shattock, R.C., Shaw, D.S. & Cooke, L.R.; 105–128.

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

CAHALAN, C.M. (1991). Seeds of success. *Timber Grower* No. 121, Winter 1991, 14, 16.

CARTER, C.I. (1992). *Lime trees and aphids.* 5 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 104/92/ENT).

CARTER C.I. [& WATSON, G.] (1991). The ecology of conifer aphids and its bearing on forest establishment and productivity. In, *Exotic aphid pests of conifers: a crisis in African forestry.* Proceedings of a seminar held at Kenya Forestry Research Institute, Muguga, Kenya, 3–6 June 1991; 23–32.

COLDERICK, S.M. & HODGE, S.J. (1991). A study of urban trees. Paper 9 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 63–73.

COUTTS, M.P. & NICOLL, B.C. (1991). Orientation of the lateral roots of trees 1: upward growth of surface roots and deflection near the soil surface. *New Phytologist* **119,** 227–234.

CROWTHER, R.E., LOW, A.J. & TABBUSH, P.M. (1991). Establishment and tending. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 41–80.

[DAY, K.R.,] LEATHER, S.R. & LINES, R. (1991). Damage by *Zeiraphera diniana* (Lepidoptera: Tortricidae) to lodgepole pine *(Pinus contorta)* of various provenances. *Forest Ecology and Management* **44** (2–4), 133–145.

DOBSON, M.C. (1991). *De-icing salt damage to trees and shrubs.* 64 pp. HMSO, London. (FC Bulletin 101).

DOBSON, M.C. (1991). De-icing salt damage to trees and shrubs and its amelioration. Paper 18 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 141–151.

DOBSON, M.C. (1991). *Diagnosis of de-icing salt damage to trees.* 3 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 96/91/PATH).

DOBSON, M.C. (1991). *Tolerance of trees and shrubs to de-icing salt.* 3 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 99/91/PATH).

DOBSON, M.C. (1991). *Prevention and amelioration of de-icing salt damage to trees.* 4 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 100/91/PATH).

DURRANT, D.W.H., WADDELL, D.A., BENHAM, S.E. & HOUSTON, T.J. (1992). *Air quality and tree growth in open-top chambers.* 4 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 208).

EVANS, J. (1991). Forestry in Britain. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 1–9.

EVANS, J. (1991). Future forests: lessons from experience. In, *Future forests: lessons from experience.* Proceedings of a symposium held at Wolverhampton Polytechnic on 16 March 1991 by the Wolverhampton Woodland Research

Group with the support of the Arboricultural Association; (Wolverhampton Woodland Research Group Symposium 3). Edited by Packham, J.R.; 71–75.

FIELDING, N.J., EVANS, H.F., [WILLIAMS, J.M. & EVANS, B.] (1991). Distribution and spread of the great European spruce bark beetle, *Dendroctonus micans*, in Britain: 1982 to 1989. *Forestry* **64**(4), 345–358.

FLETCHER, A.M. (1991). Seed selection. In, *Tree breeding and improvement.* Proceedings of a symposium held at Edgbaston, (Birmingham), 8 March 1991. Royal Forestry Society of England, Wales and Northern Ireland. Edited by Jackson, J.E.; 3–11.

FLETCHER, A.M. [& NANSON, A.] (1991). *Douglas fir seed sources field inspection, northern Washington.* 2 vols. v.p. FC Research Division, Roslin, Midlothian. (CEC-DG-6-91-EN-REV).

FREER-SMITH, P.H. (1991). Review of integrated effects (forests), soil acidification/N cycling. In, *Acidification research in the Netherlands.* Final report of the Dutch Priority Programme on Acidification. Edited by Heij, G.J. & Schneider, T.; 639–642, 650–653.

GARDINER, B.A. (1991). Observations of airflow above and within conifer plantations. In, *Proceedings of the 20th Agricultural and Forest Meteorology Conference,* Salt Lake City, Utah, USA, September 1991; 68–71.

GARDINER, B.A. (1992). Mathematical modelling of the static and dynamic characteristics of plantation trees. In, *Mathematical modelling of forest ecosystems.* Edited by Franke, J. and Roeder, A.; 40–51.

GARDINER, B.A. & QUINE, C.P. (1991). Wind studies in the Forestry Commission. *Wind Engineering Society Newsletter* 4, December 1991.

[GHANI, A.K.M.O. &] CAHALAN, C.M. (1991). Propagation of *Prunus avium* from root cuttings. *Forestry* **64**(4), 403–409.

GIBBS, J.N. (1991). Survey of parkland trees in southern England after the gale of October 1987. Paper 12 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 91–93.

GIBBS, J.N. [& INMAN, I.] (1991). The pine shoot beetle *Tomicus piniperda* as a vector of blue stain fungi to windblown pine. *Forestry* **64**(3), 239–249.

GIBBS, J.N. & STROUTS, R.G. (1991). Diseases and disorders. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 81–100.

GILL, R.M.A. (1992). A review of damage by mammals in north temperate forests: 1. deer. *Forestry* **65**(2), 145–169.

[GORDON, A.G.,] GOSLING, P.G. [& WANG, B.S.P.] (1991). *Tree and shrub seed handbook.* ISTA, Zurich, Switzerland.

GOSLING, P.G. (1991). Seed. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 11–16.

GREGORY, S.C. (1991). Armillaria root rot. In, *Compendium of raspberry and blackberry diseases and insects.* Edited by Ellis, M.A., Converse, R.H. Williams, R.N. & Williamson, B.; 37–38.

GREGORY, S.C., [RISHBETH, J.R. & SHAW, C.G.] (1991). Pathogenicity and virulence. In, *Armillaria root disease* (USDA Agriculture Handbook 691); 76–87.

GREIG, B.J.W. (1991). Stump fumigation as a control measure against honey fungus. Paper 23 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 188–196.

GREIG, B.J.W. (1992). Decline and dieback of oak in Great Britain. In, *National Hardwoods Programme.* Report of ninth meeting, Oxford Forestry Institute, 2 October 1991; (OFI Occasional Papers 41). Edited by Savill, P.S.; 31–33.

GREIG, B.J.W. (1992). Oak decline and dieback. *Timber Grower* No. 122, Spring 1992, 16.

GREIG, B.J.W. (1992). *Occurrence of decline and dieback of oak in Great Britain.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 214).

GREIG, B.J.W. (1992). *Occurrence of decline and dieback of oak in Great Britain.* 4 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 105/92/PATH).

GREIG, B.J.W. & SHARPE, A.L. (1991). Pine stem rust *(Peridermium pini)* in a Scots pine provenance trial at Teindland Forest. *Scottish Forestry* **45**(3), 169–174.

GREIG, B.J.W, GREGORY S.C. & STROUTS, R.G. (1991). *Honey fungus.* 11 pp. HMSO, London. (FC Bulletin 100).

[GURNELL, J. &] PEPPER, H.W. (1991). *Conserving the red squirrel.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 205).

[HANNAH, P.J., PALUTIKOF, J.P.,] QUINE, C.P. [& GUO, X.] (1991). Reconstruction of time-series in complex terrain. In, *Wind energy* *conversion 1991.* Proceedings of the 13th British Wind Energy Association Conference, Swansea, April 1991. Edited by Quarton, D.C. & Fenton, V.C.; 281–288.

HARMER, R. (1991). The effect of bud position on branch growth and bud abscission in *Quercus petraea* (Matt.) Liebl. *Annals of Botany* **67**, 463–468.

HARMER, R. (1992). Relationships between shoot length, bud number and branch production in *Quercus petraea* (Matt.) Liebl. *Forestry* **65**(1), 61–72.

HIBBERD B.G. (ed.) (1991). *Forestry practice.* 11th edtn. (supersedes FC Bulletin 14). 239 pp. HMSO, London. (FC Handbook 6).

HODGE, S.J. (1991). BS 3936 Part 1: take 2. In, *A seed in time.* The second UK/International conference on urban forestry, Dudley campus of Wolverhampton Polytechnic, 18–20 June 1991. Edited by Field, C.; 45–53.

HODGE, S.J. (1991). *Amenity tree planting with bare-root stock.* 4 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 97/91/ARB).

HODGE, S.J. (1991). *Cell grown broadleaved stock.* 4 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 98/91/ARB).

HODGE, S.J. (1991). *Improving the growth of established amenity trees: site physical conditions.* 4 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 102/91/ARB).

HODGE, S.J. (1991). *Improving the growth of established amenity trees: fertiliser and weed control.* 4 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 103/91/ARB).

HODGE, S.J. (1991). Trees on the farm 2: how to get 'em off to a good start. *Farmers Weekly* **115**(5), 2 August 1991, 38–41.

HODGE, S.J. (ed.) (1991). *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; organised by the Forestry Commission, Arboricultural Association and the Department of the Environment. 222 pp. HMSO, London. (FC Bulletin 97).

HODGE, S.J. (1991). Use of water-retentive materials in planting pits for trees. Paper 5 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 29–37.

HODGE, S.J. (1991). *Urban trees: a survey of street trees in England.* 19 pp. HMSO, London. (FC Bulletin 99).

HODGE, S.J. (1992). *Planting and establishment success of Corsican pine raised in JPPs.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 211).

HODGE, S.J. & KERR, G. (1991). Trees on the farm 3: young trees need to be freed from weed. *Farmers Weekly* **115**(9), 30 August 1991, 69–72.

HODGE, S.J. & KERR, G. (1991). Trees on the farm 4: the early experts get them growing. *Farmers Weekly* **115**(12), 20 September 1991, 70–71.

HOLLINGSWORTH, M.K. & MASON, W.L. (1991). *Vegetative propagation of aspen.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 200).

[HOOD, I.A.,] REDFERN, D.B. [& KILE, G.A.] (1991). *Armillaria* in planted hosts. In, *Armillaria root disease.* (USDA Agriculture Handbook 691); 122–149.

HULL, S.K. (1991). A study undertaken in southern Britain to investigate the late-flushing of hedgerow ash in Spring 1987. *Forestry* **64**(2), 189–197.

[INESON, P.,] DUTCH, J. [& KILLHAM, K.S.] (1991). Denitrification in a Sitka spruce plantation and the effect of clear-felling. *Forest Ecology and Management* **44**(1), 77–92.

INNES, J.L. (1989). The assessment of patterns of tree condition in Great Britain with particular reference to North Wales. In, *Proceedings of acid deposition in Gwynedd conference,* Plas Tan-y-Bwlch, Maentwrog, 16–18 March 1989. Edited by Gritten, R.H.; 143–146.

INNES, J.L. (1991). Acid rain: tree health surveys. Paper 16 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 120–128.

INNES, J.L. (1991). How the forest health survey is streamlined. *Forestry and British Timber* **20**(6), June 1991, 25, 27.

INNES, J.L. (1991). The application of cause-effect criteria to the relationship between air pollution and forest decline in Europe. In, *Acid deposition: origins, impacts and abatement strategies.* Edited by Longhurst, J.W.S.; 63–73.

INNES, J.L. (1992). Forest decline. *Progress in Physical Geography* **16**(1), 1–64.

INNES, J.L. (1992), Observations on the condition of beech *(Fagus sylvatica* L.*)* in Britain in 1990. *Forestry* **65**(1), 35–60.

INNES, J.L. & BOSWELL, R.C. (1991). *Forest* *monitoring programme: 1991 results.* 4 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 209).

INNES, J.L. & BOSWELL, R.C. (1991). *Monitoring of forest condition in Great Britain 1990.* 54 pp. HMSO, London. (FC Bulletin 98).

INNES, J.L. [& NEUMANN, H.] (1991). Past growth variation in *Picea sitchensis* with differing crown densities. *Scandinavian Journal of Forest Research* **6**(3), 395–405.

JONES, S.K., SAMUEL, Y.K. & GOSLING, P.G. (1991). The effect of soaking and prechilling on the germination of noble fir seeds. *Seed Science and Technology* **19**, 287–293.

KERR, G. (1991). Broadleaves: the vital initial spacing decision. *Forestry and British Timber* **20**(9), 20–21.

KERR, G. (1991). Trees on the farm 1: experts say, money can grow on trees. *Farmers Weekly* **115**(1), 5 July 1991, 63–65.

KERR, G. (1992). Treeshelters: uses and abuses. *Tree News,* February 1992, 16–17.

KERR, G. & HODGE, S.J. (1991). Trees on the farm 5: don't let trees spoil the wood. *Farmers Weekly* **115**(6), 18 October 1991, 64–66.

KERR, G. & WILLIAMSON, D.R. (1991). Trees on the farm 6: money to take for granted. *Farmers Weekly* **115**(22), 29 November 1991, 67.

KERR, G., NIXON, C.J. & MATTHEWS, R.W. (1992). Silviculture and yield of mixed-species stands: the UK experience. In, *The ecology of mixed-species stands.* Proceedings of a symposium held at Heriot-Watt University, 2–6 September 1990. (British Ecological Society Special Publication 11). Edited by Cannell, M.G.R., Malcolm, D.C. & Robertson, P.S.; 35–51.

[KIRBY, K.J. &] PATTERSON, G. (1992). Ecology and management of semi-natural species mixtures. In, *The ecology of mixed-species stands.* Proceedings of a symposium held at Heriot-Watt University, 2–6 September 1990. (British Ecological Society Special Publication 11). Edited by Cannell, M.G.R., Malcolm, D.C. & Robertson, P.S.; 189–209.

[KUIPER, L.C. &] COUTTS, M.P. (1992). Spatial disposition and extension of the structural root system of Douglas-fir. *Forest Ecology and Management* **47**(1–4), 111–125.

LEATHER, S.R. (1991). Feeding specialisation and host distribution of British and Finnish *Prunus*-feeding macrolepidoptera. *Oikos* **60**(1), 40–48.

LEATHER, S.R. (1992). *Forest management practice to minimise the impact of the pine beauty moth.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 217).

LEE, S.J. (1991). Tree breeding in Britain. In, *Proceedings of the eleventh meeting of Forest Research Working Group 1 (Forest Genetics),* Coonawara, South Australia; 178–180.

LEE, S.J. (1991). Tree improvement. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 25–40.

LONSDALE, D. (1991). Pollarding success or failure: some principles to consider. In, *Pollard and veteran tree management.* Proceedings of the meeting hosted by the Corporation of London at Burnham Beeches, Bucks, on 6 March 1991. Edited by Read, H.J.; 57–58.

LONSDALE, D. (1991). Tree decay in relation to pruning practice and wound treatment: a progress report. Paper 22 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990. (FC Bulletin 97). Edited by Hodge, S.J.; 177–187.

LONSDALE, D. (1991). Use of the word "callus" (Letters to the editor). *Arboricultural Journal* **15**(2), 183–184.

MASON, W.L. (1991). *A survey of research on trees being funded in Scotland.* 43 pp. FC Research Division, Roslin, Midlothian.

MASON, W.L. (1991). Commercial development of vegetative propagation of genetically improved Sitka spruce *(Picea sitchensis* Bong.Carr.) in Great Britain. In, Efficiency of stand establishment operations. *(New Zealand Forest Research Institute Bulletin* 156, 35–41).

MASON, W.L. (1992). Forestry research in Scotland: extent, collaboration and technology transfer. *Scottish Forestry* **46**(1), 1–26.

MASON, W.L. (1992). Silvicultural research for the 1990s and beyond. In, *Whither silviculture?* Proceedings of Institute of Chartered Foresters, Wales and Marches Regional Group, Discussion Meeting, November 1991. Edited by Stumbles, R.E.; 30–39.

MASON, W.L. & WILLIAMSON, D.R. (1992). Alternatives to triazines for weed control in forest nurseries. In, Vegetation management in forestry, amenity and conservation areas. *(Aspects of Applied Biology* **29**, 149–155).

MATTHEWS, R.W. (1991). Biomass production and carbon storage by British forests. In, *Wood for energy: the implications for harvesting, utilisation and marketing.* Proceedings of a discussion meeting, Heriot-Watt University, Edinburgh, 5–7 April 1991. Edited by Aldhous, J.R.; 162–177.

MATTHEWS, R.W. (1991). Forestry and the carbon cycle. *Rural Wales,* Summer 1991, 14–15.

MATTHEWS, R.W. (1991). Forests and arable energy crops in Britain: can they help stop global warming? In, *Wood: fuel for thought.* Proceedings of the first international wood fuel conference, Bristol, 23–25 October 1991. Edited by Richards, G.E.; 39–62.

MATTHEWS, R.W., [MATTHEWS, G.A.R., ANDERSON, R.A. & SENCEE, S.S.] (1991). Construction of yield tables for woody biomass production and carbon storage by British plantation species. In, *World Forestry Congress, 10th,* Paris, France, 17–26 September 1991. Proceedings, volume **2,** 87–97.

MAYLE, B.A. (1992). Deer control 1: how to spot the difference...*Farmers Weekly* **116**(5), 31 January 1992, 52–55.

MAYLE, B.A. & PEPPER, H.W. (1992). Deer control 2: too dear to guard? Foil 'em by fencing! *Farmers Weekly* **116**(7), 14 February 1992, 60–62.

McKAY, H.M. (1991). *Electrolyte leakage: a rapid index of plant vitality.* 2 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 210).

McKAY, H.M. & MASON, W.L. (1991). Physiological indicators of tolerance to cold storage in Sitka spruce and Douglas-fir seedlings. *Canadian Journal of Forest Research* **21**(6), 890–901.

MILLER, K.F. & QUINE, C.P. (1991). Wind. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 139–146.

MOFFAT, A.J. (1991). Forestry and soil protection in the UK. *Soil Use and Management* **7,** 145–151.

MOFFAT, A.J. (1991). The importance of pedology in modern forestry. *Forestry* **64**(3), 217–238.

MOFFAT, A.J. (1992). Trees please. *Sand and Gravel Association Bulletin* **24,** 13.

MOFFAT, A.J. & BENDING, N.A.D. (1992). *Physical site evaluation for community woodland establishment.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 216).

MOFFAT, A.J. & WILLIAMSON, D.R. (1991). Review of fertiliser and herbicide use in UK tree crop systems. *Journal of the Science of Food and Agriculture* **57,** 1–18.

MOFFAT, A.J., BENDING, N.A.D. & ROBERTS, C.J. (1991). The use of sewage sludge as a fertiliser in the afforestation of opencast coal spoils in South Wales. In, *Land reclamation: an end to dereliction?* Edited by Davies, M.C.R., 391–392.

MOFFAT, A.J., MATTHEWS, R.W. [& HALL, J.E.] (1991). The effects of sewage sludge on growth and foliar and soil chemistry in pole-stage Corsican pine at Ringwood Forest, Dorset, UK. *Canadian Journal of Forest Research* **21**(6), 902–909.

MORGAN, J.L., CAMPBELL, J.M. & MALCOLM, D.C. (1992). Nitrogen relations of mixed-species stands on oligotrophic soils. In, *The ecology of mixed-species stands.* Proceedings of a symposium held at Heriot-Watt University, 2–6 September 1990; (British Ecological Society Special Publication 11). Edited by Cannell, M.G.R., Malcolm, D.C. & Robertson, P.S.; 65–85.

NELSON, D.G. (1991). Developing an efficient restocking system for conifers in the uplands of Great Britain. In, Efficiency of stand establishment operations. *(New Zealand Forest Research Institute Bulletin* 156, 115–124).

NELSON, D.G. (1991). *Management of Sitka spruce natural regeneration.* 5 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 204).

NELSON, D.G. & DUTCH, J.C. (1991). The silvicultural implications of utilising harvesting residues for energy, etc. In, *Wood for energy: the implications for harvesting, utilisation and marketing.* Proceedings of a discussion meeting, Heriot-Watt University, Edinburgh, 5–7 April 1991. Edited by Aldhous, J.R.; 148–161.

NELSON, D.G. & NIXON, C.J. (1992). Management of Sitka spruce natural regen(eration). *Forestry and British Timber* **21**(2), February 1992, 30, 32, 34.

[NISBET, A.F. &] NISBET, T.R. (1992). Interaction between rain, vegetation and soils. In, *Restoring acid waters: Loch Fleet 1984–1990.* Edited by Howells, G. & Dalziel, T.K.R.; 135–148.

[O'CONNOR, J.P.,] WINTER, T.G. [& GOOD, J.A.] (1991). A review of the Irish Scolytidae (Insecta:Coleoptera). *Irish Naturalist's Journal* **23**(10), 403–409.

PATCH, D. (1991). Some thoughts on the physiology of pollarding. In, *Pollard and veteran tree management.* Proceedings of the meeting hosted by the Corporation of London at Burnham Beeches, Bucks, on 6 March 1991. Edited by Read, H.J.; 56.

PATERSON, D.B. (1990). The potential to apply different silvicultural systems to upland British forests, predominantly of Sitka spruce. In, *Silvicultural systems.* Proceedings of a discussion meeting held at University of York, 6–8 April 1990, by Institute of Chartered Foresters. Edited by Gordon, P.; 120–138.

[PEI, M.H. &] GIBBS, J.N. (1991). Cultural variation in *Peridermium pini* from two parts of the United Kingdom. *European Journal of Forest Pathology* **21**(3), 164–167.

[PEI, M.H. &] GIBBS, J.N. (1991). *Peridermium pini* (Pers.) Lev.: axenic culture and inoculation of pine seedlings and callus cultures. In, *Rusts of pine.* Proceedings 3rd IUFRO Rusts of Pine Working Party Conference, Banff, Alberta, 18–22 September 1989. Forestry Canada Northwest Region, Northern Forestry Centre, Edmonton, Alberta, Information Report NOR-X-317. Edited by Hiratsuka, Y., Samoil, P.V., Blenis, P.V., Crane, P.E. & Laishley, B.L.

[PEI, M.H. &] GIBBS, J.N. (1992). Axenic culture of *Peridermium pini* from single aeciospores. *Plant Pathology* **41**(1), 91–94.

PEPPER, H.W. (1992). *Forest fencing.* 3rd edtn. (supersedes FC Leaflet 87). 42 pp. HMSO, London. (FC Bulletin 102).

PEPPER, H.W., CHADWICK, A.H. & BUTT, R. (1992). *Electric fencing against deer.* 5 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 206).

PETTY, S.J. (1992). *Ecology of nightjars in Thetford Forest and the National Nightjar Survey.* 2 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 213).

POTTER, C.J. & TABBUSH, P.M. (1991). The cultivation of poplar as an energy crop. In, *Wood for energy: the implications for harvesting, utilisation and marketing.* Proceedings of a discussion meeting, Heriot-Watt University, Edinburgh, 5–7 April 1991. Edited by Aldhous, J.R.; 206–217.

[PREST, G.I.] QUINE, C.P. [& CAMERON, A.D.] (1991). Windthrow of five-year-old Sitka spruce on an upland restocking site. *Scottish Forestry* **45**(2), 120–128.

QUINE, C.P. (1991). Recent storm damage to trees and woodlands in southern Britain. Paper 11 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990; (FC Bulletin 97). Edited by Hodge, S.J.; 83–89.

QUINE, C.P. (1992). Windthrow as a constraint on silviculture. In, *Whither silviculture?* Proceedings of Institute of Charterted Foresters, Wales and Marches Regional Group Discussion Meeting, November 1991. Edited by Stumbles, R.E.; 21–29.

QUINE, C.P. & BURNAND, A.C. (1991). Early growth and root architecture of Sitka spruce in relation to cultivation of a peaty ironpan afforestation site. *Scottish Forestry* **45**(3), 175–182.

QUINE, C.P. & GARDINER, B.A. (1991). Storm damage to forests: a major abiotic threat with global occurrence. In, *World Forestry Congress, 10th,* Paris, France, 17–26 September 1991. Proceedings, volume **2**, 339–345.

QUINE, C.P. & MILLER, K.F. (1990). Windthrow: a factor influencing the choice of silvicultural system. In, *Silvicultural systems.* Proceedings of a discussion meeting held at University of York, 6–8 April 1990, by Institute of Chartered Foresters. Edited by Gordon, P.; 71–81.

QUINE, C.P., BURNAND, A.C, COUTTS, M.P. & REYNARD, B.R. (1991). Effects of mounds and stumps on the root architecture of Sitka spruce on a peaty gley restocking site. *Forestry* **64**(4), 385–401.

RATCLIFFE, P.R. (1991). Wildlife management. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 113–128.

RATCLIFFE, P.R. (1991). The deer of Alice Holt. *The Crondall Society News,* Autumn 1991, 24–26.

RATCLIFFE, P.R. (1992). The interaction of deer and vegetation in coppice woods. In, *Ecology and management of coppice woods.* Edited by Buckley, G.P.; 233–246.

RATCLIFFE, P.R. & GILL, R.M.A. (1991). The influence of mammals on the regeneration of forest communities. In, *Future forests: lessons from experience.* Proceedings of a symposium run at Wolverhampton Polytechnic on 16 March 1991 by the Wolverhampton Woodland Research Group with the support of the Arboricultural Association; (Wolverhampton Woodland Research Group Symposium 3). Edited by Packham, J.R.; 54–70.

REDFERN, D.B. (1991). *Melanotus proteus:* a newly recorded colonist of Sitka spruce stumps in Britain and a potential competitor for *Heterobasidion annosum. Plant Pathology* **40,** 483–486.

REDFERN, D.B. [& FILIP, G.M.] (1991). Inoculum and infection. In, *Armillaria root disease* (USDA Agriculture Handbook 691), 48–61.

ROOK, D.A. (1991). Seedling development and physiology in relation to mineral nutrition. Chapter 4 in, *Mineral nutrition of conifer seedlings.* Edited by van den Driessche, R.; 85–111.

ROOK, D.A. (1992). Possible implications of climatic change on broadleaved forestry in

Britain. In, *National Hardwoods Programme.* Report of ninth meeting, Oxford Forestry Institute, 2 October 1991; (OFI Occasional Paper 41). Edited by Savill, P.S.; 1–7.

ROOK, D.A. & FLETCHER, A.M. (1991). Research on the genetics of birch in Britain. In, *The commercial potential of birch in Scotland.* Edited by Lorrain-Smith, R. & Worrall, R.; 43–54.

ROSE, D.R. (1991). *Shoot dieback of lodgepole pine caused by Ramichloridium pini.* 3 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 207).

SAMUEL, C.J.A. (1991). Conventional tree breeding techniques. In, *Tree breeding and improvement.* Proceedings of a symposium held at Edgbaston, (Birmingham), 8 March 1991. Royal Forestry Society of England, Wales and Northern Ireland. Edited by Jackson, J.E.; 12–19.

SAMUEL, C.J.A. (1991). The estimation of genetic parameters for growth and stem-form over 15 years in a diallel cross of Sitka spruce. *Silvae Genetica* **40**(2), 67–72.

[SCHULZE, E-D. &] FREER-SMITH, P.H. (1991). An evaluation of forest decline based on field observations focussed on Norway spruce, *Picea abies.* In, *Acidic deposition: its nature and impacts.* Proceedings of the International Symposium held in Glasgow, Scotland, 16–21 September 1990, organised by the Royal Society of Edinburgh. Edited by Last, F.T. & Watling, R.; 155–168.

[SOUTH, D.B. &] MASON, W.L. (1991). Using distribution-modifying functions to predict variation in frequency distributions of tree heights during plantation establishment. *Forestry* **64**(3), 303–319.

STOAKLEY, J.T. & EVANS, H.F. (1991). Insect pests. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 101–112.

STROUTS, R.G. (1991). *Anthracnose of London plane (Platanus x hispanica).* (Supersedes Arboriculture Research Note 46/83/PATH). 3 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 46/91/PATH).

STROUTS, R.G. (1991). Recognition and investigation of unexplained disorders of trees. Paper 20 in, *Research for practical arboriculture.* Proceedings of a seminar held at the University of York, 2–4 April 1990. (FC Bulletin 97). Edited by Hodge, S.J.; 161–167.

TAYLOR, C.M.A. (1991), *Forest fertilisation in Britain.* 45 pp. HMSO, London. (FC Bulletin 95).

TRACY, D.R. & NELSON, D.G. (1991). *Methods of grass control in the uplands.* 4 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 203).

WAINHOUSE, D., [WYATT, T., PHILLIPS, A., KELLY, D.R., BARGHIAN, M., BEECH-GARWOOD, P., CROSS, D. &] HOWELL, R.S. (1991). Response of the predator *Rhizophagus grandis* to host plant derived chemical in *Dendroctonus micans* larval frass in wind tunnel experiments (Coleoptera:Rhizophagidae, Scolytidae). *Chemoecology* **2**, 55–63.

[WALSH, A.L. &] MAYLE, B.A. (1991). Bat activity in different habitats in a mixed lowland woodland. *Myotis* **29**, 97–104.

[WANG, Y.P., JARVIS, P.G. &] TAYLOR, C.M.A. (1991). PAR absorption and its relation to above-ground dry matter production of Sitka spruce. *Journal of Applied Ecology* **28**, 547–560.

WARD, E. & DUTCH, J.C. (1991). Does your forest need foliar analysis? *Forestry and British Timber* **20**(11), November 1991, 17, 19.

[WATSON, C.A., BODEUX, C., BIRLEY, M.A., NEWBOULD, P., HOOKER, J.E., ATKINSON, D. &] NIXON, C.J. (1991). Effect of ground vegetation management in agro-forestry systems on tree growth and environmental impact. *Brighton Crop Protection Conference* **5C**(3), 631–638.

[WATT, A.D.,] LEATHER, S.R. & EVANS, H.F. (1991). Outbreaks of the pine beauty moth on pine in Scotland: influence of host plant species and site factors. *Forest Ecology and Management* **39**(1–4), 211–221.

[WATT, A.D.,] LEATHER, S.R. & FORREST, G.I. (1991). The effect of previous defoliation of pole-stage lodgepole pine on plant chemistry, and on the growth and survival of pine beauty moth *(Panolis flammea)* larvae. *Oecologia* **86**(1), 31–35.

[WHEELER, C.T.,] HOLLINGSWORTH, M.K., [HOOKER, J.E.,] McNEILL, J.D., MASON, W.L., MOFFAT, A.J. [& SHEPPARD, L.J.] (1991). The effect of inoculation with either cultured *Frankia* or crushed nodules on nodulation and growth of *Alnus rubra* and *Alnus glutinosa* seedlings in forest nurseries. *Forest Ecology and Management* **43**(1–2), 153–166.

WHITE, J.E.J. (1991). Suggestions for re-pollarding oaks at Markshall, Essex. In, *Pollard and veteran tree management.* Proceedings of the meeting hosted by the Corporation of London at Burnham Beeches, Bucks, on 6 March 1991. Edited by Read, H.J.; 46–47.

WILLIAMSON, D.R. (1991). *Herbicides for farm woodlands and short rotation coppice.* 7 pp. FC Research Division, Farnham, Surrey. (FC Research Information Note 201).

WILLIAMSON, D.R. & MASON, W.L. (1991). Nursery practice. In, *Forestry practice* (FC Handbook 6). Edited by Hibberd, B.G.; 17–23.

WINTER, T.G. (1991). Interceptions of exotic bark beetles (Col., Scolytidae) on timber imports into Great Britain, 1980 to 1988. *Entomologist's Monthly Magazine* No. 127, 13–17.

WINTER, T.G. (1991). *Pine shoot beetles and ball-rooted semi-mature pines.* 3 pp. DOE Arboricultural Advisory & Information Service, Farnham, Surrey. (Arboriculture Research Note 101/91/ENT).

WINTER, T.G. (1992). Are your logs safe? *Timber Grower* No. 122, Spring 1992, 27–28.

[WORRELL, R. &] NIXON, C.J. (1991). *Factors affecting the natural regeneration of oak in upland Britain: a literature review.* 28 pp. FC, Edinburgh. (FC Occasional Paper 31).

APPENDIX II

RESEARCH DIVISION ORGANISATION

Director

- **Chief Research Officer (North)**
  - Silviculture (North) Branch
  - Site Studies (North) Branch
  - Tree Improvement Branch‡
  - Physiology Branch
  - Statistics and Computing (North) Branch
  - Administration – Instrumentation (North) Section
- Mensuration Branch
- Forest Products Branch
- Communications Branch
  - *Library and Information Section*
  - *Photography Section*
  - *Publications Section*
- Administration
- **Chief Research Officer (South)**
  - Plant Production Branch
  - Silviculture (South) Branch
  - Site Studies (South) Branch – Instrumentation (South) Section
  - Pathology Branch*
  - Entomology Branch*
  - Wildlife and Conservation Research Branch*
  - Statistics and Computing (South) Branch

‡Branch with Section at Alice Holt.

*Branches with Sections at the Northern Research Station.

APPENDIX III

RESEARCH DIVISION BRANCHES AND THEIR PROJECT GROUPS ‡

	Project leader(s) at 31/3/92
Plant Production	
Research	P.G. Gosling, S.K. Jones
Service	P.G. Gosling
Nursery	R.L. Jinks
Silviculture (South)	
Arboreta	J.E.J. White
Establishment	G. Kerr, D.R. Williamson, S.J. Hodge
Silviculture operations	G. Kerr
Arboriculture	
Advice	D. Patch
Urban and community forestry	S.J. Hodge
Farm forestry	D.R. Williamson
Short rotation coppice	P.M. Tabbush
Poplars	A. Beaton
Silviculture (North)	
Plant production	W.L. Mason
Species	C.J. Nixon
Planting (including weed control)	D.G. Nelson
Nutrition	J.C. Dutch
Cultivation	D.G. Nelson, C.P. Quine
Stability	B.A. Gardiner, C.P. Quine
Farm forestry	C.J. Nixon
Reclamation (N)	J.D. McNeill
Site Studies (South)	
Effects of trees on sites	A.J. Moffat, T.R. Nisbet
Lowland production forestry	A.J. Moffat
Reclamation	A.J. Moffat
Hydrology: water quality	T.R. Nisbet
Air pollution	P.H. Freer-Smith, J. L. Innes, D.W.H. Durrant
Chemical analysis	E. Ward
Instrumentation	T.R. Nisbet

	Project leader(s) at 31/3/92
Forestry and environmental change	P.H. Freer-Smith, J.L. Innes
Site Studies (North)	
Clay soils	D. Ray
Deep peats	D.G. Pyatt
Ironpan soils	A.R. Anderson
Loamy gleys	A.R. Anderson, D. Ray
Hydrology	D.G. Pyatt
Tree Improvement	
Forest reproductive material regulations	A.M. Fletcher
Testing progeny and clones	S.J. Lee
Origin	A.M. Fletcher, C.J.A. Samuel
Production: clone banks and orchards	A.M. Fletcher, W. Brown
Biochemical variation	G.I. Forrest
Biometrical studies	C.J.A. Samuel
Flowering	J.J. Philipson
Micropropagation	A. John
Rejuvenation	A. John
Improvement and propagation of broadleaves	R. Harmer
Improvement and propagation of farm forestry broadleaves	C.M. Cahalan
Physiology	
Root growth and form	M.P. Coutts
Bent top	M.P. Coutts
Planting stock quality	H.M. McKay
Mycorrhizas	C. Walker
Development of rooting patterns	C. Walker
Pathology	
Disease diagnosis, damage monitoring and risk assessment	D.B. Redfern, S.C. Gregory, R.G. Strouts, J.N. Gibbs
Dutch elm disease	C.M. Brasier, B.J.W. Greig

Fomes root rot	D.B. Redfern, B.J.W. Greig
Stem decays	D. Lonsdale
Poplar diseases	D. Lonsdale
Special investigations	J.N. Gibbs, B.J.W. Greig, D.R. Rose

Entomology

Dendroctonus micans	H.F. Evans, D. Wainhouse
Panolis flammea	S.R. Leather
Beech bark disease	D. Wainhouse
Elatobium abietinum	C.I. Carter
Hylastes and *Hylobius*	S.G. Heritage, S.R. Leather
Advisory and taxonomic	T G. Winter
Genetic variations	M.R. Jukes
Impact	N.A. Straw
Stress	D. Wainhouse

Wildlife and Conservation

Deer	P.R. Ratcliffe
Squirrels, rabbits	H.W. Pepper
Birds	S.J. Petty
Damage	R.M.A. Gill
Tree protection	H.W. Pepper
Bats, roe and fallow deer	B.A. Mayle
Vegetation management	R. Ferris-Kaan, G.S. Patterson
Streams and riparian vegetation	G.S. Patterson

Mensuration

Sample plots	J.M. Methley
Measurement studies	J.M. Methley
Yield modelling	R.W. Matthews
Management services	J.M. Methley
Site yield	P.C. Jokiel

Forest Products

Quality and value enhancement	J.F. Webber
Preservation	J.F. Webber
Wood and timber properties	J.F. Webber

Statistics and Computing (South)

Forest growth modelling	A.R. Ludlow

‡'Advisory' is distinguished as a separate project group in certain Branches but is an activity in all.

APPENDIX IV

NET EXPENDITURE OF RESEARCH DIVISION 1991/92

				£000
Branch[a]	*Expenditure by Branch direct*[b]	*Net value of in-house services received less than those provided*[c]	*Commissioned*[d] *research*	*Expenditure attributable to Branch*
Plant Production	195	51	–	245
Silviculture (South)	1484	12	89	1586
Silviculture (North)	1994	–127	36	1903
Site Studies (South)	697	79	45	821
Site Studies (North)	160	78	–	238
Tree Improvement	1180	282	6	1469
Physiology	283	94	20	398
Pathology	568	102	52	723
Entomology	727	113	45	886
Wildlife and Conservation	451	142	113	706
Mensuration	380	59	–	439
Forest Products	69	31	183	284
Statistics and Computing (South)	658	–379	–	279
Statistics and Computing (North)	223	–223	–	–
Communications	465	–142	–	322
Workshops (North and South)	169	–169	–	–
Total	**9703**	–	**589**	**10299**

Notes

a. Ordered as in 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 £1626(000) plus Forestry Commission headquarters overheads for common services of £728(000) net of income of £568(000) 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.

APPENDIX V

CONTRACTS FOR WORK UNDERTAKEN BY RESEARCH DIVISION

Department of the Environment	Arboriculture Pathology Arboriculture Advisory and Information Service Potential for woodland establishment on landfill sites
Energy Technology Support Unit	Biomass energy
British Coal	Opencast coal spoil
Kemforschungszentrum (Germany)	Spruce root stock
Department of Transport	Alternatives to peat
Scottish Forestry Trust, via TGUK	Private woodlands squirrel questionnaire 1991
Ministry of Agriculture, Fisheries and Food	Vegetative propagation Progeny testing Yield assessments
London Boroughs	Survey of salt damaged trees in London
Pilkington Trust	Dutch elm disease
EEC/Oxford University	Transgenetic poplar
Interox	Restocking with calcium peroxide
Lothian Regional Council	Transplant performance
Irish Forestry Service	Wind stability
Department of Transport	Backfill studies
Strathclyde Greenbelt Co.	Species choice on reclamation sites Use of sewage sludge
MacFarlane Smith	Animal repellent studies
Niko Chemical Co. Ltd.	Chemical repellents

APPENDIX VI

CONTRACTS FOR RESEARCH DIVISION UNDERTAKEN BY OTHER AGENCIES

Avon Vegetation Research	Nursery herbicide evaluation
Macaulay Land Use Research Institute	Nutrition of trees on restock sites Nutrition of nursery stock
University of East Anglia	Windspeed prediction in complex terrain
National Rivers Authority (Welsh Region)	Effects of forestry on surface water acidification
Institute of Hydrology	Effects of afforestation on water resources
University of Lancaster	Long-term effects of elevated carbon dioxide concentrations on trees
University of Aberdeen	Biocontrol of *Heterobasidion annosum* in Sitka spruce stumps
University College of Wales, Aberystwyth	Biology of Ramichloridium dieback of lodgepole pine
Royal Society for the Protection of Birds	Nightjar ecology Merlin ecology Golden eagle ecology
Institute of Terrestrial Ecology	Capercaillie ecology
University of Aberdeen	Songbird ecology in spruce forests
University College of North Wales, Bangor	Vegetation succession on clear-fell sites
University of Wales, Cardiff	Conifer seed as a food for vertebrates
Tweed Foundation	Fauna of a small burn

APPENDIX VII

STAFF ENGAGED IN RESEARCH AS AT 31 MARCH 1992

RESEARCH DIVISION

Director	D.A. Burdekin, B.A. Dip.Ag.Sci. M.I.C.For. *(Alice Holt)*
Administration and Finance Officer	J. Lumley *(Alice Holt)*
Chief Research Officer (South)	J. Evans, B.Sc., Ph.D., D.Sc., F.I.C.For. *(Alice Holt)*

(With general responsibilities for research south of the Mersey/Humber line, and with specific responsibilities for silviculture and site studies in the lowlands, and throughout Britain for research in pathology, entomology, wildlife and conservation, seed, arboriculture, instrumentation and technical aspects of legislation relating to plant health.)

Chief Research Officer (North)	T.C. Booth, B.Sc., M.I.C.For. *(Northern Research Station)*

(Head of the Northern Research Station with general responsibilities for research north of the Mersey/Humber line and in Wales, with specific responsibilities throughout Britain for research in tree physiology and tree improvement, and for silviculture and site studies in the uplands.)

STAFF AT ALICE HOLT LODGE

Plant Production

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

Silviculture Branch (South)

P.M. Tabbush, B.Sc., M.I.C.For., Head of Branch
A. Beaton, B.Sc., M.I.C. For.
D. Elgy
S.J. Hodge, B.Sc., M.Sc., M.I.C.For.
G. Kerr, B.Sc., M.I.C.For.
J.E.J. White *(Westonbirt)*
D.R. Williamson, B.Sc., M.I.C.For.

Outstation staff	*Centre*
J.L. Budd	Alice Holt
A.R. Hall	
K.R. Knott	
R.A. Nickerson	
R.B. Collins	Thetford
D.A. Hendrie	
D.G. Rogers	Exeter
N.A. Smith	
M.W. Allen	Midlands
I. Collier	

Arboricultural Advisory and Information Service (Department of the Environment)

D. Patch, B.Sc., M.Sc., M.I.C.For., N.D.Arb.(RFS), F.Arbor.A.
M. A. Lipscombe

Site Studies Branch (South)

P.H. Freer-Smith, B.Sc., Ph.D., Head of Branch
A. Armstrong
N.A.D. Bending, B.Sc., M.Sc.
Mrs S.E. Benham
P.G. Crow
M.C. Dobson, B.Sc., Ph.D.
D.W.H. Durrant, B.A.
J.L. Innes, M.A., Ph.D.
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.

Instrumentation Section (South)

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

Tree Improvement Section (of Branch at Northern Research Station)

R. Harmer, B.Sc., Ph.D., Head of Section
Mrs C.A. Baker
C.M. Cahalan, B.Sc., M.Sc., Ph.D.
M.R. Plowman, B.Sc., M.Sc.

Pathology Branch (with Section at Northern Research Station)

J.N. Gibbs, M.A., Ph.D., Sc.D., Head of Branch
C.M. Brasier, B.Sc., Ph.D., D.Sc.
Mrs S.E. Brown, B.Sc.
B.J.W. Greig, M.I.C.For.
Mrs S.A. Kirk
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.

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*)
M.R. Jukes, C.Biol., M.I.Biol.
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.

Wildlife and Conservation Research Branch

P.R. Ratcliffe, B.Sc., Ph.D., C.Biol., M.I. Biol., F.I.C.For., Head of Branch (*Northern Research Station*)
A. Chadwick (*Cowal, Strathclyde*)
R. Ferris-Kaan, B.Sc., Ph.D.
R.M.A. Gill, B.Sc.
Mrs B.A. Mayle, M.Sc.
H.W. Pepper
S.J. Petty (*Cowal, Strathclyde*)
G.S. Patterson, B.Sc., M.I.C.For. (*Northern Research Station*)

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

Forest Products

J.F. Webber, B.Sc., Ph.D., Head of Branch

Statistics and Computing Branch (South)

I.D. Mobbs, M.I.S., Head of Branch
R.C. Boswell, B.Sc., M.I.S.
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.
A.J. Peace, B.Sc.
T. Porter, B.Sc.
T.J. Randle, B.Sc.
Miss B.J. Smyth, B.Sc.

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)

Photography Section

G.L. Gate, Head of Section
J. Williams (Graphics Officer)

Publications Section

Vacant

Administration

HEOs: R. Murray (*Finance*)
M.G. Wheeler (*Personnel*)
EOs: Mrs J.C. Gates (*Office Services*)
Miss J.R. Lacey (*Personnel*)
Mrs S.J. Osborne (*Finance*)

STAFF AT NORTHERN RESEARCH STATION

Silviculture Branch (North)

W.L. Mason, B.A., B.Sc., M.I.C.For., Head of Branch
J.C. Dutch, B.Sc., Ph.D.
B.A. Gardiner, B.Sc., Ph.D., F.R.Met.S.
J.L. Morgan, B.Sc., Ph.D.
D.G. Nelson, B.Sc., M.I.C.For.
C.J. Nixon, B.Sc., M.I.C.For.
C.P. Quine, M.A., M.Sc., M.I.C.For.

Outstation staff:	*Centre*
Stability Project	
A.L. Mackie, M.I.C.For.	Northern Research Station
North and Mid Scotland Region	
A.L. Sharpe	Newton, Grampian
North Scotland Area	
W.G. Paterson	Lairg, Highland
J. Boluski	
North-east Scotland Area (including Central Highlands and Islands)	
J. Davidson, B.A., M.I.C.For.	Newton, Grampian
C. Edwards	
A.W. MacLeod	
West Scotland Area (including Mull)	
D.R. Tracy	Cairnbaan, by Lochgilphead Strathclyde
P. Cairns	

East Scotland Area
F.S. Smith — Perth, Tayside
D. Anderson

South Scotland and North England Region
J.D. McNeill — Northern Research Station
South-east Scotland Area
M.K. Hollingsworth — Northern Research Station
A.J. Harrison, B.Sc.
South-west Scotland Area (including Arran)
M . Riley — Mabie, Dumfries
D.M. Watterson
Borders Area
P.W. Gough — Kielder, by Hexham,
M.J. Ridley — Northumberland

North-east England Area
R.E.J. Howes — Wykeham, Scarborough,
J. Dick — North Yorkshire

Wales Region
N.P. Danby — Talybont-on-Usk
Wales Area
C.D. Jones, B.Sc. — Talybont-on-Usk
N.P. Hayward, B.Sc.

Site Studies Branch (North)
D.G. Pyatt, B.A., B.Sc., Ph.D., Head of Branch
A.R. Anderson
D. Ray, B.Sc.

Tree Improvement Branch (with Section at Alice Holt)
D.A. Rook, B.Sc., M.Sc. Ph.D., Head of Branch
Miss C.M.M. Baldwin
J. Cottrell, B.Sc., Ph.D.
A.M. Fletcher, B.Sc., Ph.D., A.I.W.Sc., M.I.C.For.
G.I. Forrest, B.Sc., M.Sc., Ph.D.
S.J. Lee, B.Sc., M.I.C.For.
A. John, B.Sc., Ph.D.
Mrs M. O'Donnell
J.J. Philipson, B.A., Ph.D.
C.J.A. Samuel, B.Sc., Ph.D.

Outstation staff: — *Centre*
Northern Scotland
C.E.S. Fleming — Newton, Grampian
R.J. Sykes
Mid Scotland to northern England
W. Brown — Northern Research Station
J.S. McIntyre
Wales and southern England
G.C. Webb — Shobdon, Hereford
A.S. Medhurst, M.I.C.For.

Physiology Branch
M.P. Coutts, B.Sc., Ph.D., D.Sc., M.I.C.For., Head of Branch
C. Walker, B.A., Ph.D., Assistant Head of Branch
D.C. Clark
K.A. Clifford, B.A.
Mrs. J. Harrower
C. McEvoy
H.M. McKay, B.Sc., Ph.D.
B.C. Nicoll, 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

Entomology Section (of Branch at Alice Holt)
S.G. Heritage, C.Biol., M.I. Biol., Head of Section
A.C. Hendry, B.Sc.
T. Jennings
D. Johnson, B.Sc.
S.R. Leather, B.Sc., Ph.D., C.Biol., M.I.Biol., F.R.E.S.

Statistics and Computing Branch (North)
I.W. Martin, B.Sc., M.Sc., Head of Branch
R.W. Blackburn, B.Sc.
I.M.S. White, B.Sc., M.Sc.

Administration
HEO: C.K. Smith
EO: Mrs M. Farm

Instrumentation Section (North)
C. Walker, B.A., Ph.D., Head of Section

INDUSTRIAL STAFF

The total number of industrial employees in Research Division at 31 March 1992 was 95.5.

STAFF CHANGES

Transfers in:

G.R. Brearley (Senior Photographer) from Ministry of Defence to Communications, Northern Research Station.

J. Dick (Forest Officer IV) from East England Conservancy to Silviculture North, Wykeham.

N.P. Hayward (Forest Officer IV) from Site Studies South to Silviculture North, Talybont.

M.A. Lipscombe (Forest Officer IV) from West England Conservancy to Silviculture South, Alice Holt.

J.C. Proudfoot (Forest Officer III) from Forest Surveys to Mensuration, Alice Holt.

M.J. Ridley (Forest Officer IV) from Wales Conservancy to Silviculture North, Kielder.

M.G. Wheeler (Higher Executive Officer) from Wales Conservancy to Administration, Alice Holt.

New appointments:

A. Armstrong (Forest Officer III) Site Studies South, Alice Holt (reinstatement).

R. Ashburner (Assistant Scientific Officer) Entomology, Alice Holt (2 year period appointment; contract).

J.E. Cottrell (part-time Assistant Scientific Officer) Tree Improvement Branch, Northern Research Station.

B.A. Gardiner (Senior Scientific Officer) Silviculture North, Northern Research Station (permanent following 5 year period appointment).

I.W. Martin (Grade 7) Statistics and Computing North, Northern Research Station.

M.L. Sutherland (Higher Scientific Officer) Pathology, Alice Holt (3 year period appointment; contract).

Transfers out:

H.C. Angus (Forest Officer III) from Silviculture South, Westonbirt to West England Conservancy.

Mrs B.K. Bartlett (Higher Executive Officer) from Administration, Alice Holt to Countryside Council for Wales.

A.D. Edwards (Forest Officer IV) from Silviculture North, Wykeham to Ministry of Defence.

B.G. Hibberd (Grade 7) from Communications, Alice Holt to the Forestry Authority, Cambridge (on promotion to Grade 6).

S.A. Mead (Forest Officer III) from Silviculture North, Talybont to Wales Conservancy.

C. Morgan (Forest Officer III) from Silviculture South, Bedgebury to East England Conservancy.

C.A. Palmer (Forest Officer III) from Pathology, Alice Holt to West England Conservancy.

P.R. Ratcliffe (Grade 7; Head of Wildlife and Conservation Research Branch) from Alice Holt to Northern Research Station.

T.D. Russell (Forest Officer IV) from Silviculture South, Westonbirt to West England Conservancy.

Promotions:

A.H. Chadwick (Wildlife and Conservation Research, Ardentinny) to Forest Officer III.

P.G. Crow (Site Studies South, Alice Holt) to Scientific Officer.

C.E.S. Fleming (Tree Improvement, Newton) to Forest Officer II.

R. Harmer (Tree Improvement, Alice Holt) to Grade 7.

Miss T.J. Houston (Statistics and Computing South, Alice Holt) to Higher Scientific Officer.

C. McEvoy (Physiology, Northern Research Station) to Scientific Officer.

C.J. Nixon (Silviculture North, Northern Research Station) to Forest Officer I.

C.A. Palmer (Pathology, Alice Holt) to Forest Officer III.

E.J. Parker (Communications, Alice Holt) to Grade 7.

S.J. Petty (Wildlife and Conservation Research, Ardentinny) to Forest Officer I.

T.J. Porter (Statistics and Computing South, Alice Holt) to Scientific Officer.

Resignations:

Miss A.C. Burnand (Higher Scientific Officer) Statistics and Computing North, Northern Research Station.

K.P. Donnelly (Senior Scientific Officer) Statistics and Computing North, Northern Research Station.

Retirements:

R.S. Howell (Grade 7) Statistics and Computing South, Alice Holt.

D.B. Paterson (Grade 7) Silviculture North, Northern Research Station.

F.R.W. Stevens (Forest Officer III) Silviculture South, Alice Holt.

D.H. Stewart (Grade 7) Statistics and Computing North, Northern Research Station.

APPENDIX VIII

ADDRESSES OF RESEARCH LOCATIONS

Main Centres

Forestry Commission
Forest Research Station
Alice Holt Lodge
Wrecclesham
Farnham, Surrey
GU10 4LH
Tel: 0420 22255
Fax: 0420 23653

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

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

Research Outstations

Ardentinny Wildlife
Forestry Commission
Wildlife & Conservation
Research Branch
Ardentinny
Dunoon
Argyll
PA23 8TS
Tel: 036 981 253

Bush Silv(N)
Forestry Commission
Northern Research Station
Roslin
Midlothian
EH25 9SY
Tel: 031 445 2176

Cairnbaan Silv(N)
Forestry Commission
Research Office
Cairnbaan
Lochgilphead
Argyll
PA31 8SQ
Tel: 0546 2304

Exeter Silv(S)
Forestry Commission
Research Office
Bullers Hill
Kennford
Exeter
Devon EX6 7XR
Tel: 0392 832262

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

Kielder Silv(N) & Entomology
Forestry Commission
Research Office
Kielder
by Hexham
Northumberland
NE48 1ER
Tel: 0434 250235

Lairg Silv(N)
Forestry Commission
Research Office
Ord Croft
Lairg
Sutherland
IV27 4AZ
Tel: 0549 2150

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

Mabie Silv(N) & Entomology
Forestry Commission
Research Office
Mabie
Troqueer
Dumfries
DG2 8HB
Tel: 0387 52267

Midlands Silv(S)
Forestry Commission
Research Office
Woodside
Arley
Coventry
Warwickshire
CV7 8GH
Tel: 0676 41668

Newton Silv(N) &
Tree Improvement
Forestry Commission
Research Office
Newton Nursery
Elgin
Morayshire
IV30 3XR
Tel: 0343 543165

Perth Silv(N)
Forestry Commission
Research Office
10 York Place
Perth PH2 8EJ
Tel: 0738 25344

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

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

Thetford Silv(S)
Forestry Commission
Research Office
Santon Downham
Brandon
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INDEX

This index was prepared by Dr John Chandler.

GLOSSARY

Latin names of trees cited by common name in this Report

BROADLEAVES

acacia, false	*Robinia pseudoacacia*
alder, common	*Alnus glutinosa*
red	*A. rubra*
ash	*Fraxinus excelsior*
beech (European)	*Fagus sylvatica*
birch, downy	*Betula pubescens*
silver	*B. pendula*
chestnut, sweet	*Castanea sativa*
elm	*Ulmus procera*
maple, Norway	*Acer platanoides*
oak, pedunculate	*Quercus robur*
sessile	*Q. petraea*
poplar	*Populus* spp.
sycamore	*Acer pseudoplatanus*
willow	*Salix* spp.
goat	*S. caprea*

CONIFERS

fir, Douglas	*Pseudotsuga menziesii*
noble	*Abies procera*
larch, European	*Larix decidua*
hybrid	*L.* x *eurolepis*
Japanese	*L. kaempferi*
pine, Bishop	*Pinus muricata*
Corsican	*P. nigra* var. *maritima*
lodgepole	*P. contorta*
Scots	*P. sylvestris*
spruce, Norway	*Picea abies*
Sitka	*P. sitchensis*

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