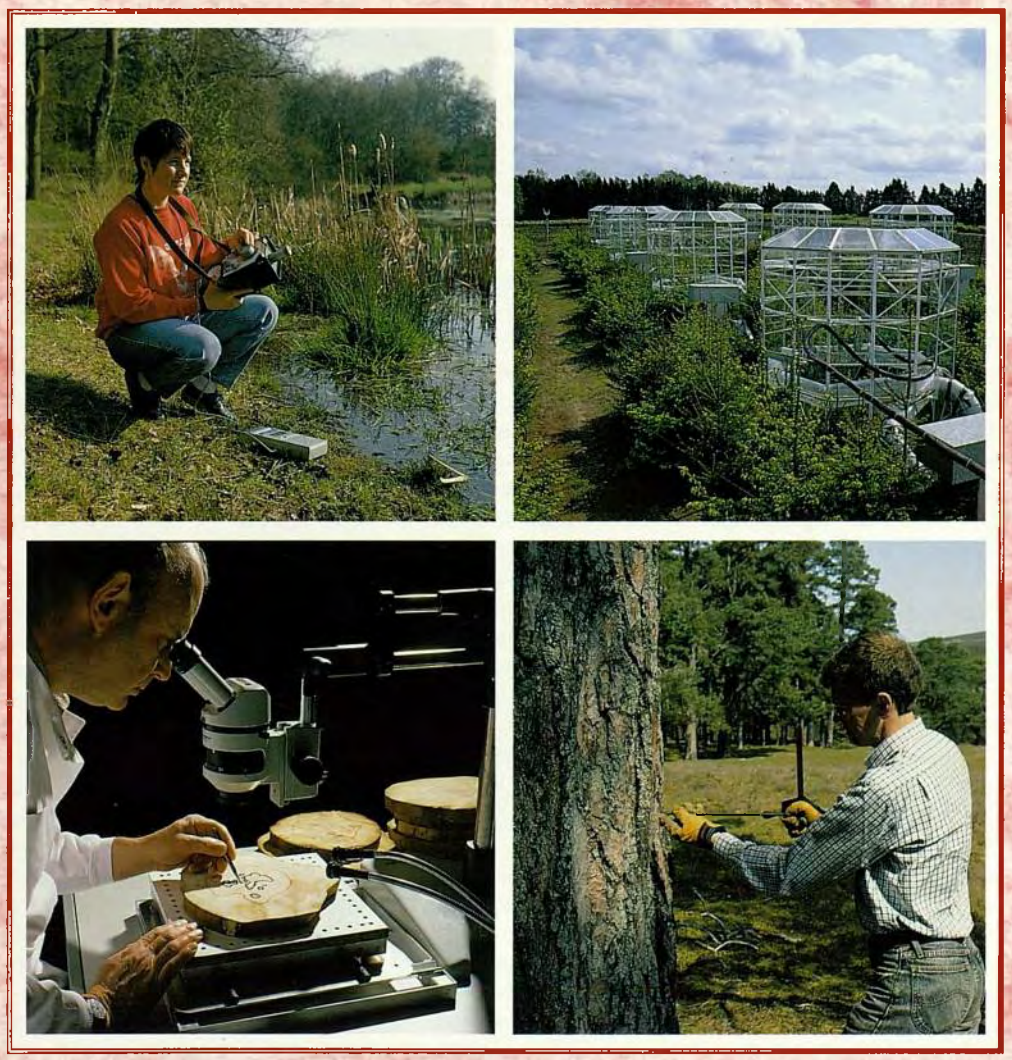
Forestry Commission

REPORT ON FOREST RESEARCH

1995



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REPORT ON FOREST RESEARCH

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INTRODUCTION

The Annual Report on Forest Research is a means of informing forest managers, policy makers, other client groups and other scientists of the research being undertaken within the Forestry Commission's Research Division and of research commissioned by the Forestry Commission but carried out by other organisations. The report describes the main scientific achievements and records the main developments affecting the FC's research activities.

Multi-Departmental Scrutiny of Public Sector Research Establishments

The report of the Multi-Departmental Scrutiny of Public Sector Research Establishments was published in July 1994. The recommendations included proposals for rationalising public sector research establishments by creating sectoral groupings which, if implemented, would sever the close links that currently exist between the FC's Research Division and other parts of the parent organisation. These links have served the industry well in the past by ensuring the relevance of the research undertaken and by promoting technology transfer. The report was subject to a period of public consultation and, at time of writing, the Government's response was still awaited.

Advisory Committee on Forest Research

The Advisory Committee on Forest Research provides advice on the quality of the FC's research activities through a cycle of Visiting Groups of scientists who examine particular aspects of the Division's work.

Visiting Groups were established and reported during the year on the work of Tree Improvement Branch and Mensuration Branch.

The Group which visited Tree Improvement Branch was led by Professor E. Cocking of Nottingham University assisted by Mr Martin Werner of the Forest Research Institute of Sweden and Dr Rod Griffin of Shell Forestry. While endorsing the strategy for improving the genetic quality of planting stock and commenting favourably on the quality of the research, the Group recommended a multi-disciplinary approach to improving wood quality through tree breeding, a reassessment of the prospect of success in achieving early flowering of Sitka spruce and exploitation of experience and apparent success of other laboratories with tissue culture. These recommendations are being acted upon.

The Visiting Group to Mensuration Branch was led by Professor Hugh Miller, Aberdeen University assisted by Mr Roy Lorrain-Smith, an independent forestry consultant. While complimentary about the management and achievements of the Branch the Group expressed concern that the Branch's role, often pivotal, in supporting external contracts was leading to unacceptable delays in producing a new generation of yield models incorporating the latest sample plot data. Although the Branch has suffered further staff losses since the Group reported, steps have now been taken to speed up the production of yield models while ensuring that commitments to existing contracts are met.

We are most grateful to the members of the Visiting Groups for their work and to the members of the Advisory Committee who give so freely of their time.

Forestry Research Co-ordination Committee

The Forestry Research Co-ordination Committee brings together public sector organisations sponsoring forestry research in order to co-ordinate their activities and avoid overlap and duplication in commissioning research. The Committee met on three occasions.

The Committee sponsored a two-day seminar on *Greenhouse gas balances in forestry* held at the Royal Geographical Society in London in November 1994.

The outcome of the FRCC Users Forum Review of Research Priorities was published in the course of the year and summarised in FRCC Information Note No. 44. It is planned to take forward the ideas of the theme *Low intensity silviculture* and convene a one-day workshop to focus in detail on what research should be funded.

STAFF

Mr D.A. Burdekin retired as Director Research in August 1994. He joined the Forestry Commission in 1964 as a forest pathologist and was variously head of the Pathology Branch, Chief Research Officer South and, for the last five years, Director Research. He also spent two years on secondment to the Department of the Environment as an administrator, a link which bore fruit in later years when the DoE began funding research by the Division into amenity trees. As Director Research his careful husbanding of the Division's resources and promotion of external contracts served the organisation well in a period of declining funding from the Forestry Commission. We wish him well in his retirement. He is replaced by Mr J. Dewar with the post being located at the Forestry Commission's Headquarters in Edinburgh.

The total number of non-industrial staff at 31 March 1995 was 201, a reduction of 6 on the previous year. Full-time equivalent industrial posts averaged 92 throughout the year, a reduction of 5 on the previous year. In addition we were pleased to provide training and experience to over 30 students during the year. At a time when it is difficult to offer young people permanent jobs their contribution to the work of the Division is much appreciated.

ENTOMOLOGY

Overview

In addition to the four main research programmes of Biodiversity, Impact, Restocking and Stress, the Branch has been active in a number of plant health and externally funded initiatives.

The completion of the European Union single market in June 1993 required major changes in the ways of dealing with external threats from insects and diseases. Responsibility for implementing these new rules lies with Plant Health Branch in Forestry Commission headquarters in Edinburgh, but Entomology Branch is responsible for many of the technical aspects of design and implementation. In particular, establishing protocols for protected zones (PZ) against several bark beetle species – notably *Dendroctonus micans* which is restricted to Wales and the bordering counties of England, and *Ips typographus* which is not resident in Britain – has resulted in a system of surveys to confirm absence of these pests from the PZ areas. Visual surveys are used and, for *Ips* spp., bait logs are placed in the field to act as an attractive breeding resource for the beetles. Results from the first year (1994) were negative, thus ensuring continuation of our PZ status for these important bark beetle pests.

Advisory highlights

Plant health featured prominently in advisory work, constituting 194 out of a total of 488 enquiries handled during the year. Interceptions of *I. typographus* by plant health inspectors during port inspections and from pheromone traps were the largest ever recorded. The total of 45 adults in the traps compares with the previous maximum record of three adults.

The discovery of the aggressive Asian strain of gypsy moth, *Lymantria dispar,* during large outbreaks in Germany led to an appraisal of the risks to Britain. An awareness campaign included publication of an arboriculture research note and deployment of pheromone traps. The latter captured nine male specimens in Hampshire, West Sussex and Kent, that had probably blown over from the Continent rather than come from a resident population.

An unusual example of defoliation by the pale tussock moth, *Calliteara pudibunda* was recorded in a 2.2 ha woodland of 44-year-old beech in Charlton Forest, West Sussex in October 1994.

Following a review of parameters for surveys of the pine looper moth, *Bupalus piniaria,* the number of sites in the 1994/95 survey was reduced from 36 to 16. Among these, several showed increases over the 1993/94 results, particularly in Moray Forest District where the highest compartment counts had risen at Culbin from 2.4 per m^2 to 10.8 per m^2 and at Lossie from 6.8 per m^2 to 21.6 per m^2. Counts at Tentsmuir also increased from 1.6 per m^2 to 6.0 per m^2.

In early October 1994, Entomology Branch staff at Alice Holt ran a very successful three-day course entitled *The recognition, impact and management of forest insects.* The course, attended by 19 people from Britain, Ireland and Denmark, covered identification of the main insect groups, their impacts on tree growth and their ecological role in forests and woodlands. These facets were brought together by considering methods of managing both population reduction and enhancement of biodiversity. Further courses are planned on similar and more specific themes.

Hugh Evans

Genetic and environmental factors in the resistance of trees to insect and fungal attack

Sitka spruce has an extensive geographical range within which there is considerable intraspecific variation. Although natural variation in silvicul-

tural traits is of particular interest to foresters, differences in susceptibility to insects and other herbivores is equally important. Variation in the extent to which spruce trees are defended against insects can be shown by bioassays or by measurements of secondary chemicals that may poison or deter insects. In trees, secondary chemicals such as resin, lignin and polyphenols are often present at relatively high concentrations and so provide a quantitative defence against herbivore attack. Many of these secondary chemicals are carbon-based and it has been suggested that they can be a significant drain on the tree's carbon budget so that there is a trade-off between growth and defence. If this is the case, then fast growing trees may be more vulnerable to insect attack because they are less defended. We looked for evidence of this effect in mature Sitka spruce trees in plantations and in very young plants grown in experimental conditions in a polyhouse.

Field observations

Lignified stone cell masses in bark provide a defence against the spruce bark beetle *Dendroctonus micans* (Wainhouse *et al.,* 1990). We examined the distribution of lignin among trees from a series of provenance trials in England and Wales and found that the density of bark lignin increased progressively with latitude of origin and was highly heritable (Wainhouse *et al.,* 1993; Wainhouse and Ashburner, in press). There were also large differences in bark lignin content between trees grown on different sites suggesting important environmental effects on lignin formation. Although there were differences in growth between provenances and between sites, detailed analysis of the data provided no convincing evidence of a trade-off between defence and growth, either between or within provenances or between sites. Further work should clarify these site-induced effects on spruce resistance.

Polyhouse experiments

The aim of experiments with young potted Sitka spruce trees was to obtain precise estimates of root and shoot growth and to measure associated biochemical changes in the plants. Two-year-old trees of Alaskan or Oregon provenance, i.e. from extremes of latitudinal range, were subjected to two levels of light and two levels of nitrogen. High (h) or low (l) levels of light (L) were equivalent to ambient or to ambient reduced to approximately 25% by shading; high or low levels of nitrogen (N) were equivalent to 100 or 10 ppm. A split-plot experimental design was used, with light as the main factor. After a single season exposed to the treatments (hLhN, hLlN, lLhN, lLlN) some trees were harvested and representative samples dried to estimate growth. Dried samples were used for chemical analysis to estimate nitrogen and other major nutrients as well as non-structural carbohydrates. The concentrations of resin and polyphenols were determined from fresh material. The relative susceptibilities to attack of remaining plants were tested by bioassays using insects and fungi, results of which will be presented in a later report.

A detailed study was made of the leaves of treated trees and, in particular, the effects of treatments on the resin content of needles. Resin was estimated gravimetrically following solvent extraction of needles.

Similar results were obtained for the two provenances and mean values for current needles formed during treatments and for old needles formed in the previous two years are shown in Table 1. The dry weight of current needles was highly correlated with the overall growth of the tree indicating that growth was highest in the high light treatment, but was reduced when nitrogen was limited. Where growth was limited by low nitrogen levels, both in high and low light, total carbohydrates and percentage resin were also high. Thus, in contrast to results from mature trees, the data on young trees provide some evidence for a trade-off between growth and defence. If substantiated, results suggest that there may be an initial period during which young fast growing plantations may be particularly vulnerable to attack by pests and diseases.

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DAVID WAINHOUSE, ROBERT ASHBURNER, ERNEST WARD*

*ENVIRONMENTAL RESEARCH BRANCH

Table 1. Weight and chemical composition of needles from young Sitka spruce trees exposed to different light and nutrient treatments

	Current needles				*Old needles*			
	hLhN	hLlN	lLhN	lLlN	hLhN	hLlN	lLhN	lLlN
% Resin	2.55	2.73	1.76	2.08	2.64	3.01	2.28	2.37
% Total carbohydrate	11.39	13.87	9.96	10.73	10.06	12.79	8.35	9.39
% Nitrogen	2.22	0.73	2.27	1.58	1.74	0.74	1.49	0.97
Needle dry weight per tree (g)	15.05	7.07	4.24	4.01	3.14	3.28	2.46	2.47

Notes:
h = high
l = low
L = light
N = nitrogen

Possibilities for the use of biological agents against *Hylobius abietis*

Introduction

The area of restocking after felling of conifer crops is increasing rapidly as forests planted after the second world war reach maturity. By the year 2000, the area of restocking of sites previously carrying conifers will be over 15 000 ha a year and may then exceed the area of new planting with conifers. In restock areas, feeding activity by the large pine weevil, *Hylobius abietis,* is regarded as the main cause of plant losses during the early years of establishment.

Currently, insecticides provide the only method of protecting transplants from adult *H. abietis* feeding. As legislation becomes more restrictive and public concern over the use of insecticides increases, there is need to find alternatives. The trend for modern insect control is shifting away from the prophylactic use of synthetic insecticides and towards a more integrated pest management (IPM) approach, to make plant protection safer for the environment and operators and more cost effective.

H. abietis *biology*

There are several features of *H. abietis* biology that make this pest difficult to manage. Each year, there are two peaks of feeding activity. The first occurs in the spring and is caused mainly by adults emerging from over-winter hibernation. The second occurs in late summer after newly developed adults have emerged and are preparing for over-wintering. The time and magnitude of these peaks varies considerably between forests and from year to year. This makes the need for protective measures and their timing difficult to predict and, for these reasons, prophylactic treatments of plants are usually the most effective. On these young trees, removing a small amount of bark can cause serious damage so a single adult is capable of killing several plants. The eggs, larvae and pupae develop under the bark of roots and stumps, making them difficult either to monitor or to control using chemicals.

Possible approaches to H. abietis *damage reduction*

The most attractive and promising alternative to using insecticides would be to use biological control agents. There are a number of organisms that might be employed, either to provide direct protection or to give a general reduction in the populations of *H. abietis* in a restocking area.

Plant protection. In this approach, the biological agent would be substituted directly for the insecticide and thus would minimise environmental contamination. The treatment could be applied as part of an established procedure, would require minimal worker training and would be low cost. However, to be effective, the agent would have to provide immediate and lasting protection. Both entomopathogenic nematodes and fungi have been shown to attack adult weevils and may offer some plant protection but they may not work fast enough to protect the plant.

Population suppression. Biological agents might also be used either to reduce the population within the treated area or to suppress it gradually in a forest unit over a number of years. This approach would target the *H. abietis* populations in the stumps, and have the advantage that

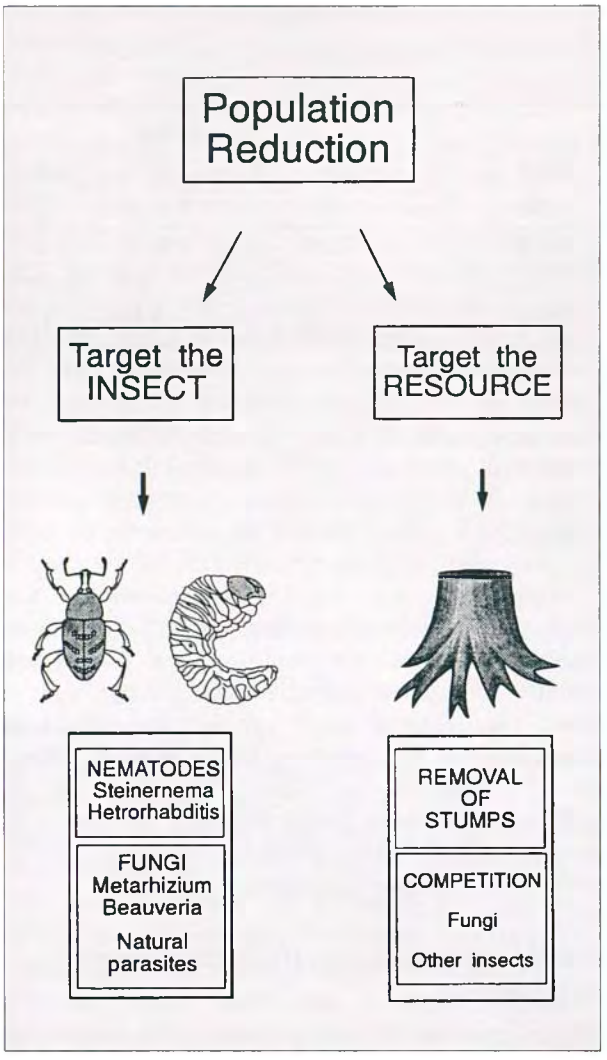

Figure 1. Population reduction.

reduction of larval populations could take place over a number of months. However, unless it were part of a long-term population management strategy, the treatment might provide no protection from migratory weevils, which may form a significant proportion of the damaging population. Such an approach would concentrate on reducing the population emerging from stumps over a wide area so that the number of adults available to invade new restock sites would be reduced. With sustained pressure on the populations during each successive season, populations of *H. abietis* in a forest area might be reduced over a period of years.

There are two ways that biological agents might reduce *H. abietis* populations (Figure 1).

1. The quantity and quality of stumps and roots available for larval development could be reduced by the introduction of competing organisms. A number of wood rotting fungi (*Basidiomycetes*) grow rapidly under the bark of stumps and root systems, competing with larvae of *H. abietis* and thus offer the potential for development as biological agents. The use of *Phlebia gigantea* to reduce *H. abietis* populations in this way is being investigated at a number of institutes.
2. The adults and larvae could be attacked directly using pathogens; most work so far has been in this area. Although this has concentrated on the use of nematodes because they are available in commercial quantities, many of the principles and techniques for their use are the same for all biological agents.

Biological agents as alternatives to insecticides

Both adults and immature stages of *H. abietis* are vulnerable to attack. The adults spend most daylight hours below ground and are therefore vulnerable to soil-borne biological agents for a considerable part of each day. The larvae feed under bark in temperature and moisture conditions that are ideal for biological agents providing they can reach their target.

Entomopathogenic nematodes

The characteristics of entomopathogenic nematodes make them suitable for use in the long term suppression of *H. abietis* populations. Several strains and species are able to kill both adults and larvae of *H. abietis* as well as inducing behavioural changes in the adults. Nematodes survive for many months in a variety of soil types and pH ranges and they do not move significantly from the point of application.

In Britain, the entomopathogenic nematodes *Steinernema feltiae, Steinernema carpocapsae* and *Heterorhabditis megilithes* are indigenous and commercially available. The life cycles of

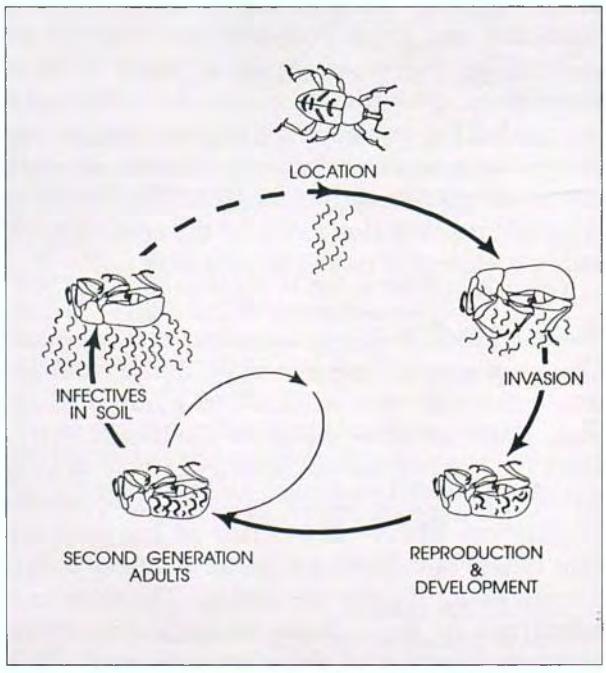

Figure 2. Life cycle of entomopathogenic nematodes.

the families are similar (Figure 2). Infective juveniles present in the soil locate and infect their host via natural body openings. Once in the insect haemocoel they inject a pellet of symbiotic bacteria (*Xenorhabdus* spp.) into the body cavity. The bacteria replicate, producing toxins that kill the insect by septicaemia. The nematodes feed upon the bacteria and degraded host tissue, developing into first generation males and females. After mating, eggs hatch within the females and these develop into second generation adults which may continue to cycle to form third generation adults. If the insect resource is exhausted, the second generation of juveniles moult, retaining their old cuticle, to become the survival form. Finally, the insect cuticle ruptures releasing third stage unsheathed infective juveniles into the soil.

Preliminary field trials in 1988 and 1993 in which nematodes were applied to artificial stumps (buried conifer billets) reduced the numbers of larvae, the cause of death being confirmed by extraction of nematodes from the dead larvae. The trials demonstrated that nematodes are able to locate and infect their target hosts under the bark of stumps. These, and other, experiments showed that nematodes can persist without a host, are resistant to most chemicals and are easy to store and apply; but their successful use as biocontrol agents depends on their application under conditions which optimise host infection in the field.

In 1994, field trials were undertaken to determine whether adequate population suppression of *H. abietis* could be achieved using entomopathogenic nematodes directed at natural stumps in the field. Several clearfell sites across Scotland and northern England with high larval populations of *H. abietis* were selected. Stumps were treated individually with nematode suspensions at optimal soil moisture and temperature conditions. On a lodgepole pine site the results were dramatic. Within five weeks *H. abietis* survival on treated stumps was reduced by 70%, with all stages of the beetle being infected by nematodes. Significantly, 98–99% of all pupae and callow adults (which make up the greatest proportion of the population) in treated stumps were infected with nematodes (Figure 3). It seems likely that surviving larvae would become infected as they continued their development. Similar trends of nematode infection were recorded on spruce sites in Loch Awe District and Kielder.

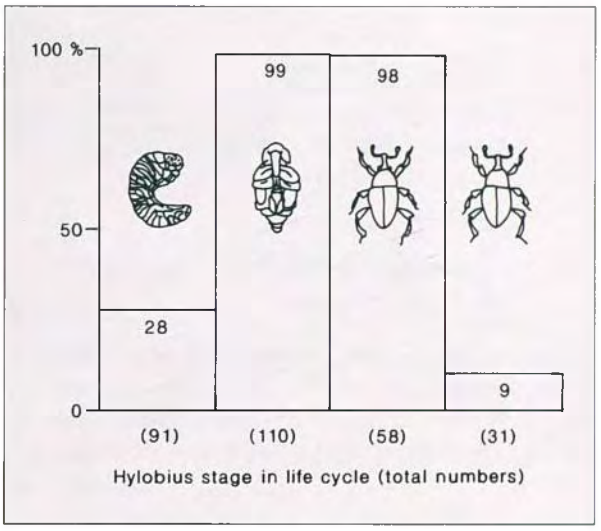

Figure 3. Hylobius *killed by nematodes.*

Parasitoids

A number of parasitoids of *H. abietis* have been reported, but perhaps the wasp *Bracon hylobii* (Hymenoptera: Braconidae) offers the greatest potential as a biological agent. The female wasp lays her eggs through the bark onto the *H. abietis* larva, after which the parasite larvae feed on the surface of the host and develop to adults within a few days. In previous studies, a 90% mortality rate of *H. abietis* larvae in pine stumps due to *B. hylobii* was recorded by Hanson (Munro, 1914) while, in small studies of pine restocking areas, Crooke and Kirkland (1956) found up to 30% parasitism by this wasp. In the UK it appears to occur wherever larvae of its host *H. abietis* are found. However, until recently, no large scale surveys of the effect of the insect had been undertaken. A large field survey of felled Sitka spruce stumps in 1993 showed that *B. hylobii* was the most significant cause of *H. abietis* mortality in stumps, destroying 50% of larvae by the end of the third season after felling. Although peak populations of the parasitoid lagged behind the period of peak host availability, artificially increasing naturally occurring parasitic wasp populations might bypass this lag effect and lead to a higher rate of parasitism. This method has been shown to be effective against many greenhouse and agricultural pests (Jones *et al.*, 1986). More recently, augmentative releases of a braconid parasitoid, *Cotesia melanoscelus,* had a significant effect in increasing the rate of parasitism of the gypsy moth (Blumenthal *et al.*, 1979). Methods for mass rearing of *B. hylobii* have been developed and could form part of a release programme to reduce host populations.

Fungi

Three strains of *Beauveria bassiana* have been isolated from *H. abietis* collected in Scotland and are presently being cultured at the Northern Research Station for use in preliminary laboratory trials. Although fungal and bacterial agents

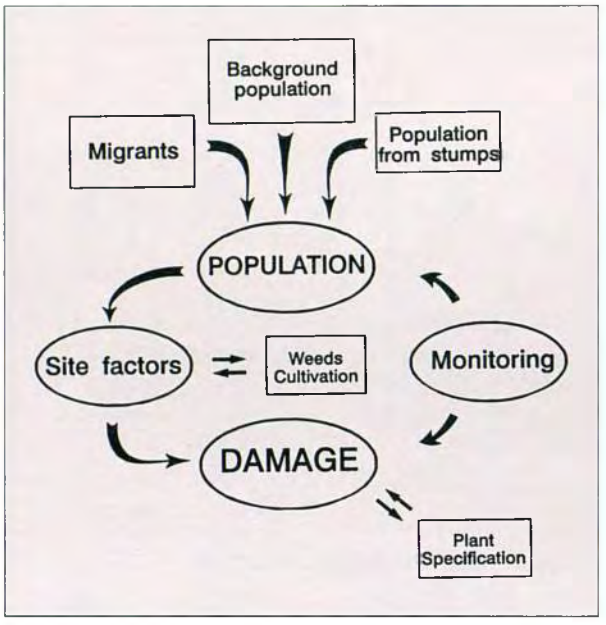

Figure 4. Assessing the level of plant protection required.

are being tested, these are not yet available in large quantities and have to be approved for use by the Pesticide Safety Directorate under the same procedure as chemicals.

Conclusions

Successful use of any of these biological agents is likely to depend on a knowledge of *H. abietis* population changes and migration because the greatest potential for biological agents is likely to be as part of a long-term population management strategy.

Initially, the required plant protection would be provided by insecticides. However, during successive growing seasons, the *H. abietis* populations in each area would be monitored and assessed for the level of plant protection required (Figure 4).

In areas with a high risk of damage, insecticides could still provide protection, but in areas considered to be of low risk, other techniques such as cultivation may reduce damage levels to an acceptable level. Success of this strategy will depend on the validity of the following assumptions:

a. Damage levels are related to the population of *H. abietis* present.
b. The initial size of the population in the area is determined mainly by the number of migrants from adjacent older felling sites.
c. The number of adults leaving a site to become migrant seeds in a new felling site is proportional to the density of the population where they developed.

Testing the assumptions inherent in the population management strategy, particularly the role of migrants in the determination of damage and the developing populations, is a central part of the current research programme for development of integrated pest management of *H. abietis*.

STUART HERITAGE, ROGER MOORE, JULIA BRIXEY AND CLIFF HENRY

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ENVIRONMENTAL RESEARCH

Significant progress has been made on the monitoring of forest condition and on research into soil sustainability over the year. Annual surveys of forest condition have been undertaken since 1984. The existing network of monitoring plots (the Level I network) has now been strengthened by the establishment of more detailed research plots as part of the UK Environmental Change Network and of a European programme of intensive monitoring of forest ecosystems (the Level II network).

The effects of elevated concentrations of carbon dioxide and gaseous air pollutants on trees, forest hydrology (water quality, particularly acidification, and quantity), reclamation of degraded land to woodland, and climate change have remained key areas of work. The initial phase of intensive research and advice on the upper Halladale catchments has been completed and equipment for long-term monitoring has been installed.

The advisory work undertaken by the branch has reflected the continuing strong public and Government interest in the environmental issues listed above. The management of climate data and of the meteorological stations has remained an important role. The chemical analysis service has been operating at full capacity after its recent upgrading (see *Report on forest research 1994*). There has been a major increase in the demand for chemical analysis of water samples (866 samples have been analysed for determination of pH, turbidity, cations, anions and other indices) and soil samples (1382 samples analysed for pH, conductivity, total nitrogen, etc). The requirements for foliar analysis have remained steady with 4703 samples analysed for macro and micro nutrients, carbohydrates and chloride. There is a steady demand for advice on the catchment-based assessments which are now required when applications for support under the Woodland Grant Scheme arise in areas where the deposition of acidic pollutants causes concern to water interests.

Jobs completed by the Instrumentation section include throughfall collectors for Level II forest monitoring plots, soil piezometers, a rotating drum device for pretreating seeds, a specialised sampling quadrat, calibration pots for humidity sensors, girth bands, electrical testing and modifications to leaf cuvettes and squirrel hoppers.

PETER FREER-SMITH

THE ESTABLISHMENT OF AN ENVIRONMENTAL CHANGE NETWORK SITE IN ALICE HOLT FOREST

The Environmental Change Network (ECN) of terrestrial sites is a multi-agency, long-term research programme established to measure, analyse and predict environmental change in the United Kingdom. The sites follow strict protocols to monitor physical, chemical and biological variables that are likely to respond to environmental change (climate change and pollutant inputs). A good research background with reliable existing long-term records are the essential requirements of all ECN sites. The network is sponsored by government departments and agencies with each sponsor responsible for funding at least one site. Alice Holt Forest is the Forestry Commission site (see Figure 5).

Management of the network is co-ordinated by the Natural Environment Research Council (NERC) on behalf of the sponsoring organisations. The ECN Steering Committee includes a representative from each sponsoring organisation and is responsible for policy. The daily running of the network is managed by the ECN Central Co-ordination Unit (CCU) at NERC's Institute of Terrestrial Ecology, Merlewood Research Station, Cumbria.

Alice Holt Forest became an ECN site in 1994 and the Research Division is running the site on behalf of the Forestry Commission. It is an inter-branch project involving Environmental Research, Woodland Ecology, Silviculture South, Statistics, Mensuration and Entomology Branches. Forest Enterprise South Downs District, which manages Alice Holt Forest, also provides support.

Figure 5. The location of the ten terrestrial sites of the Environmental Change Network. The sponsoring organisations are the Department of Agriculture for Northern Ireland (DANI); the Ministry of Agriculture, Fisheries and Food (MAFF); the Scottish Office, Agriculture and Fisheries Department (SOAFD); the Department of the Environment (DoE); English Nature (EN); the Agricultural and Food Research Council (AFRC); the Natural Environment Research Council (NERC); the Forestry Commission (FC); the Ministry of Defence (MoD); Oxford University.

A sampling site of nine hectares and a target sampling site of one hectare within the sampling site have been established in a stand of sixty-year-old oak. Some core measurements are carried out in this area; others take place in the surrounding forest and in the grounds of Alice Holt Research Station.

The following core measurements have been established:

- meteorology
- precipitation chemistry
- atmospheric chemistry
- soil solution chemistry
- managed and semi-natural vegetation
- invertebrates
- vertebrates
- soil biology
- site management
- soils.

Data sets of core measurements are e-mailed to the CCU database, which is linked with a geographical information system (GIS). Field maps, transects, plots and instrument locations for all the core measurements at each site are digitalized and stored within the GIS. National surveys are sent to the organising bodies and copied to the CCU.

The data produced from core measurements belong to the Forestry Commission and can be published by project leaders. Amalgamation of data from other sites is possible with agreement from all parties. All ECN data are analysed by the ECN statistician at the CCU and will be published in due course.

DEIRDRE WADDELL

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SOIL SUSTAINABILITY

Resolution 1 of the Ministerial Conference on the Protection of Forests at Helsinki in June 1993 declared that 'human actions must be avoided which lead, directly or indirectly, to irreversible degradation of forest soils...' The Government publication *Sustainable forestry: the UK programme*, published in 1994, sets out the policies and actions that the Government is pursuing to meet the aim of sustainable forest management. It acknowledges that 'forest operations can affect the physical and chemical properties of soils', and that 'poorly designed or inappropriately used heavy machinery may damage soils'. It underlines the need to appreciate that the soil is an important part of the forest ecosystem, and must be used sustainably.

Foresters have long known that productivity ultimately depends on the soil in which trees are grown. They have appreciated that it has been important to manage forests to conserve the soil resource. However, with increasing mechanization, external threats from atmospheric pollution and climate change and the need to co-exist with other users of the land, it is important to take stock of the way that we treat the soil. The following describes research activities in the Environmental Research Branch that underpin our need to understand and advise on this subject.

The effect of harvesting on soil physical properties

Harvesting operations have undergone considerable change in recent years, such as the increasing use of mechanical harvesters and

renewed interest in removal of harvesting residues in whole-tree harvesting. These changes of practice could pose problems for soil protection, especially its physical condition which can be damaged if run over while wet and of low strength. Visual signs of damage include rutting, mixing of soil horizons, erosion and deposition, but the soil may also suffer compaction, with consequent effects on its water-holding capacity, aeration status and rootability. In conventional harvesting, there is a strong reliance on the use of brash mats, but the degree of protection which these provide, and thus whether or nor they afford sufficient protection, remains unclear.

In 1993 a project to investigate soil damage from the range of harvesting operations in use within Forest Enterprise was begun. To date, detailed assessments of the effects on soil and watercourses have been made for 23 sites in England and Wales following clearfelling. A database has been built to establish trends and patterns in the data. It is clear that whilst most of the soil on a majority of sites surveyed suffers little or no damage, a significant proportion of some sites does suffer damage. The use of brash mats was pivotal for soil protection: damage occurred where they were too narrow or too thin. Large amounts of soil rutting occurred where minor tracks joined the principal track at 90°, or where grass rides were used for extraction; further investigations will examine soil compaction as well as rutting and displacement. However, the research to date confirms that conventional harvesting can cause damage which is not compatible with sustainable soil use; it also suggests that the lack of brash on whole-tree harvested sites must be addressed. Nevertheless, it is apparent that in conventional harvesting existing protection measures should be adequate for most sites, though some modifications and more supervision to ensure compliance may be necessary.

Soils and forest condition

The UK began systematic surveys to monitor forest condition in 1984. Such information has been valuable in indicating aspects of forest health and growth from year to year, and has allowed comparison with other European countries. However, it has not been possible to ascribe cause to the observations made on forest condition: the role of the soil quality in determining crown density and forest conditions remains unknown.

In 1993–94, 74 plots used to provide data for the UN/ECE international co-operative programme (ICP Forests) Level I survey of forest condition were visited (Figure 6), and representative soil samples were taken for detailed chemical analysis. This project represents the first systematic survey of UK forest soil chemistry and should enable us to assess its condition. The relationship between forest condition and soil condition will also be examined; the role of soil acidity and base status in determining forest condition is especially interesting. The chemical dataset will also form the baseline from which to monitor soil change over future years. As well as evaluation at the national (UK) level, the soil dataset will be combined with those from other participating countries in Europe; a Forest Soil Co-ordinating Centre has been set up in Gent, Belgium, to evaluate data on a European scale.

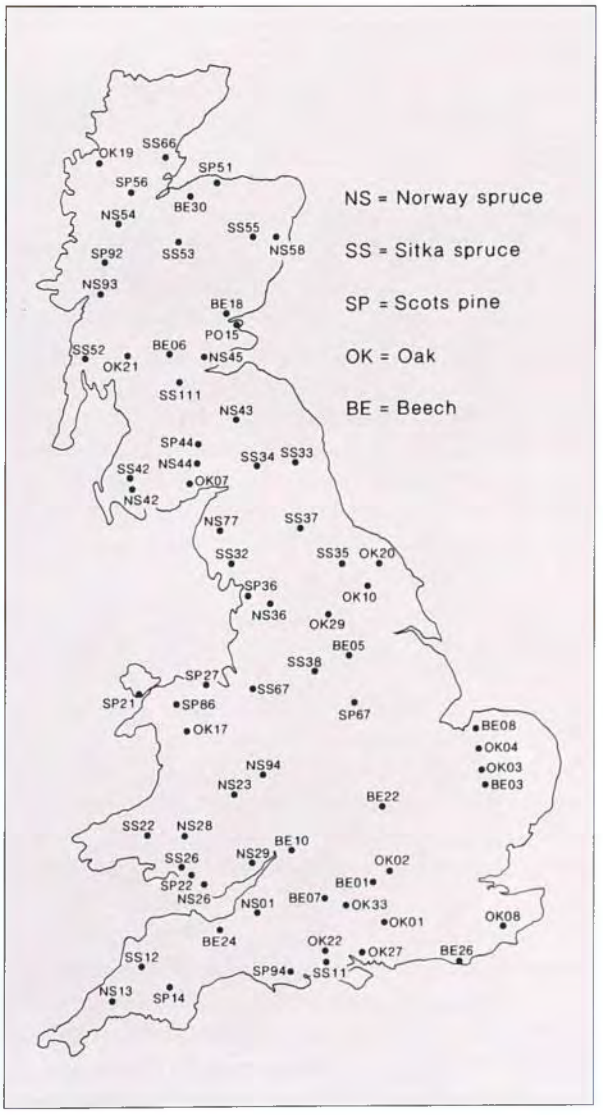

Figure 6. The location of the Level I monitoring plots at which soil analysis has been undertaken during 1994/95. Each plot consists of 24 trees of oak (OK), beech (BE), Sitka spruce (SS), Norway spruce (NS) or Scots pine (SP); soil samples were taken from the humus and organic horizons, and at three depths in the mineral soil from 28 pits in each plot.

Soil condition is being evaluated in greater detail at ten Level II sites in the UK (Figure 7). These have been chosen to represent important tree species (Sitka spruce, Scots pine, oak) and are situated across a range of soil types and air pollution climates. Extensive soil sampling and analysis will be undertaken in 1995 (Table 2). The soil research forms part of an intensive monitoring programme of forest condition aimed at the recognition of factors and processes with special regard to the impact of atmospheric pollution.

Soil acidification

The acidification of forest soils has been a contentious issue for many years, in the UK as elsewhere, but to date there has been little systematic research. An initial survey of the soil solution chemistry of six oak and six Sitka spruce Level I plots showed that base cation (Mg + Ca) to aluminium ratios are at the upper end of the range of values reported in Europe (Freer-Smith and Read, in press). Low values of this ratio are considered indicative of where the acidification of forest soils may be detrimental to tree condition and growth. A NERC CASE studentship, jointly supervised by Environmental Research Branch and the Department of Soil Science, University of Reading, has been established to examine soil acidification at the Level II sites. At each site, soil samples have been taken for detailed mineralogical and chemical analysis so that the sites can be evaluated for their sensitivity to acidic atmospheric inputs and critical load class. The PROFILE and SAFE process-based models will be used to evaluate current guidance on critical loads for acidity. In addition, the importance of soil acidity and buffering capacity in influencing the indices of forest condition and growth will be evaluated.

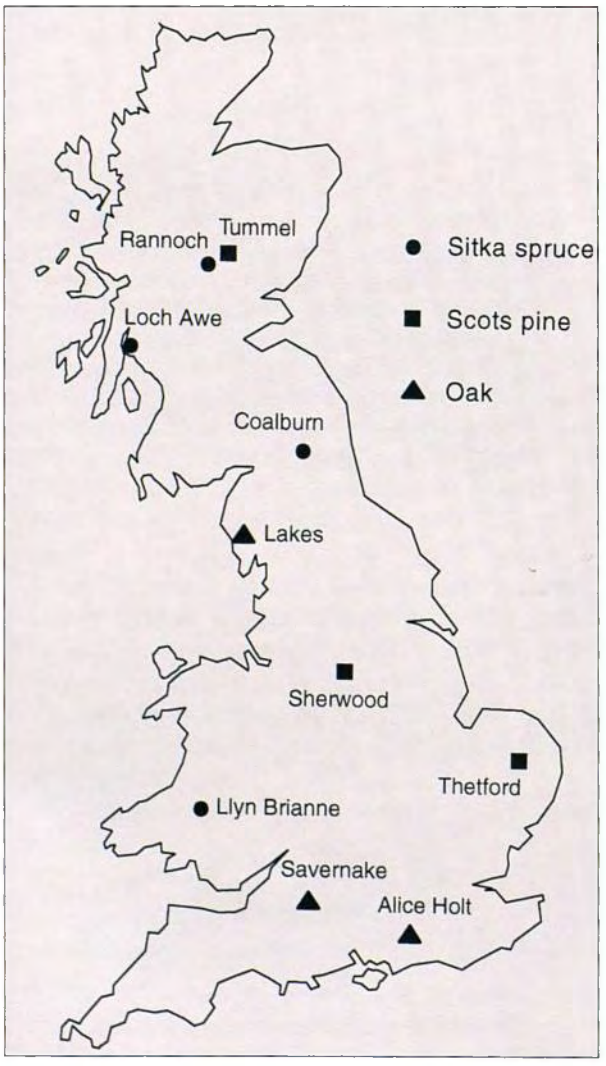

Figure 7. The location of the ten Level II plots established for the intensive monitoring of forest ecosystems. The plots are a minimum size of 0.25 ha and are oak (△ Alice Holt, Savernake and the Lake District), Scots pine (□ Thetford, Sherwood and Rannoch) or Sitka spruce (○ Llyn Brianne, Coalburn, Loch Awe and Tummel). Tree increment, foliar nutrient status, soil condition, meteorological data and pollutant depositions are measured at each plot.

Table 2. The soil parameters and elements analysed at the ten EU intensive forest monitoring plots (Level II). Sampling protocols are set out in regulation (EEC) 2157/92. An inspection pit is dug at each site in order to provide a soil description (based on the FAO system). Then soil samples are taken from 30 points using a systematic grid over the entire plot.

pH ($CaCl_2$)	Sodium
pH(H_2O)	Aluminium
Electrical conductivity	Iron
Total organic carbon	Chromium
Exchangeable base cations	Nickel
Exchangeable acidity	Manganese
Cation Exchange Capacity	Zinc
Base Saturation	Copper
Calcium carbonate	Lead
Nitrogen	Cadmium
Phosphorus	Calcium
Potassium	Magnesium

Soil conservation guidelines

The *Forests and water guidelines* were first published in 1988 as a response to the increasing need to undertake forest operations in ways that minimised or prevented adverse effects on the aquatic environment and on water supplies. The guidelines have been important in helping forest managers to plan and carry out forest operations so that water pollution, for example through soil erosion or fertiliser run-off, is avoided. They have also had a useful role in soil protection – many of the operations that

have potential to cause water pollution also pose risk to the soil. *Soil conservation guidelines* have now been drafted to advise managers on all aspects of forestry which impinge on soil sustainability. The guidelines are in three main sections: Section 1 examines forestry activities that affect soil fertility; Section 2 looks at operations that pose a risk to soil physical quality; and Section 3 discusses soil contamination. It is intended to publish the guidelines in 1996.

ANDY MOFFAT

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IMPROVING THE ESTABLISHMENT OF TREES ON METALLIFEROUS MINE WASTES

Metalliferous mines cover over 3000 ha of the Cornish countryside. A common method of reclaiming land containing their wastes in west Cornwall is by planting trees. However, many tree planting schemes have been only partially successful. A four-year investigation (partly funded by the Forestry Commission) was undertaken at Cambourne School of Mines into the causes of poor tree establishment; methods for improvement are suggested.

A two-pronged approach was used: fieldwork identified the causes of poor tree performance, and pot experiments investigated in detail two common reclamation methods. There were three main parts to the fieldwork investigations: a study of the success of covering mine wastes with soil at Tresavean Mine; growth of trees planted in *in situ* mine waste and natural colonization at United Downs; and preliminary investigations into the effects on soil moisture of different reclamation regimes and vegetation cover types. The first two studies showed that there are several problems to be overcome before tree establishment can be improved, namely poor site preparation, poor species choice and a lack of aftercare. If these are addressed adequately, then the inherent hostile mine waste properties are usually not too serious or can be suitably ameliorated. In general, heavy metal and nutrient (mainly nitrogen and phosphorus) availability was low, and pH was low to moderate. The most widespread problem affecting the establishment of trees appears to be the lack of organic matter and the accompanying effects on substrate structure and nutrient and water availability.

The most promising planted tree species of those observed were *Alnus* spp., *Pinus contorta* and *Pinus sylvestris*. *Fraxinus excelsior* was observed to be doing well on a deep, fertile soil cover over waste but, in less well reclaimed areas, it performed poorly. *Quercus* spp., *Acer platanoides, Fagus sylvatica* and *Castanea sativa* did poorly on all the sites observed. Invasion by natural woody colonizers (mainly *Buddleia davidii, Salix cinerea* and *Ulex europaeus*) was noted as being of major importance in the development of a woody vegetation community.

Multivariate statistical techniques were used to investigate site colonization by invasive species in relation to nineteen substrate variables. Mine waste properties vary widely over short distances even after reclamation, and this is reflected in the colonizing vegetation. The species shown to be most tolerant of adverse substrate conditions were *Calluna vulgaris* and *Erica cinerea*, hence their widespread occurrence on mine sites.

The use of soil amendments and soil cover over waste was investigated in two pot experiments. It was found that with a shallow soil cover, sycamore root growth was restricted to the soil layer and did not penetrate the underlying waste; upward diffusion of copper from the waste into the soil occurred, and leaching of nutrients was also a problem. These findings have important implications for the use of a shallow soil cover as a means of reclaiming mine wastes.

Cake sewage sludge is the most promising amendment despite its effect of increasing zinc availability. Its growth enhancing properties are thought to be caused by improvements to the substrate structure and moisture regime, and by increasing the microbial activity of the substrate. However, this amendment has not been widely used in Cornish mine waste reclamation schemes to date.

In conclusion, research work has shown that the cheapest way to improve tree establishment on Cornish metalliferous mine wastes is to:

- improve species choice; initially, only one or two nurse species need be planted, followed by more sensitive species a few years later;
- improve the site preparation, planting and aftercare regimes by better supervision/training of workers and by referring to ecologists/foresters; the most important aftercare problem is weed control; and
- make more use of sewage sludge amendments.

Acknowledgement

P.H.W-A would like to express his thanks to the Forestry Commission for funding which enabled the completion of this research.

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ABRUTAT, P.H. (1995). *The improvement of tree establishment on metalliferous mine wastes.* PhD thesis, Camborne School of Mines, University of Exeter.

FOREST PRODUCTS

The annual production of British-grown softwood, much of it Sitka spruce, is expected to reach more than seven million cubic metres by the year 2000. Much of this increased ouput must penetrate the construction sector, competing against imported timber in long established markets. A major part of the Branch programme, therefore, is dedicated to research on the timber properties of home grown species with the aim of predicting and enhancing timber quality.

The majority of the Branch's resources is directed towards commissioned research and recently this has included testing the major British grown softwood timbers to provide the characteristic values for strength and density required in Eurocode 5. The Code will supersede many timber related British Standards and contains grading rules for sawn and processed softwood timber. Similar testing of hardwoods has resulted in grading rules applicable to all temperate hardwoods, outlined in a draft British Standard. Once this Standard is accepted, for the first time it will be easy to specify design properties for British grown oak, encouraging its use in construction and restoration projects. Research also continues on modelling the relationship between wood characteristics and yields of construction grade timber in spruce. This work is particularly relevent to the Sitka spruce breeding programme, providing a tool to evaluate the extent to which increased growth and vigour, which is associated with reduced wood density, could compromise timber strength. In-house, Forest Products' research has focussed on factors influencing the deterioration of timber, in both the round and sawn form, as colonisation by sapstain fungi during harvesting and after processing remains a recurring problem for the forest industry. The extent to which mechanised harvesting may encourage increased attack by sapstainers is reported in some detail below. In addition, the Branch was commissioned to undertake trials of various chemical treatments for their effectiveness in preventing stain and decay of timber. This project forms part of a European programme of work to evaluate the methods required to standardise the testing of new protective treatments for timber.

Advisory work has included processing almost 200 enquiries from the public, educational establishments and commercial interests. These covered a diverse range of subjects including wood properties, kiln drying, residues, fuel and preservation. A small amount of consultancy work was also undertaken. Forest Products staff continued to represent the Forestry Commission on British Standards committees and most recently attended a series of meetings to review the environmental impact of building and construction materials hosted by the Construction Industry Research and Information Association. The Branch also played a central role in organising and contributing to the Technical Sub-Committee of the Home Grown Timber Advisory Committee.

IMPROVING TIMBER QUALITY

Two new projects were initiated to explore ways of improving the quality of British grown spruce. One of these, jointly funded by the Forestry Commission, the Department of the Environment and timber processing industries, is assessing the potential of the GREENWELD™ system which was first developed by the New Zealand Forest Research Institute. This system enables wood of any moisture content to be joined together without applying heat and can be used for end-jointing, edge-jointing and laminating. GREENWELD could greatly enhance the utilisation of the available British timber resource by extending timber lengths cut from short logs, counteracting the distortion which occurs during drying, and up-grading the strength of jointed timber. It thus has the potential to minimise waste and to enable British wood to compete more effectively with imports in some of the more specialised structural areas. However, for this to be realised, research and development is needed to evaluate the practical, technical and economic aspects of applying the system to British grown timbers. The first phase

of the work has concentrated on Sitka spruce, and in particular the production of longer lengths of structural material that can be successfully machine graded and are distortionally stable. Initial results have been promising and pilot trials suggest the process could also be usefully applied to small-section hardwoods.

A second project is underway to explore how harvesting practice and storage time can affect the brightness of paper pulp. More than one million cubic metres of British-grown small roundwood are used each year in the manufacture of paper. Sitka spruce is the species of choice for pulping because of its whiteness and ease of handling. However, during the summer months pulping companies experience increased bleach demands associated with reduced moisture content of the logs awaiting pulping. It is not clear whether reduced moisture content in itself causes loss of brightness, or whether it encourages increased bacterial and fungal invasion which in turn leads to reduced brightness. The aim of the project, which is jointly funded by three major British pulping companies and the Forestry Commission, is to establish what causes changes in the brightness of roundwood and woodchips of spruce and explore the extent to which this occurs during harvesting, extraction and storage prior to pulping and paper manufacture.

JOAN WEBBER

MECHANISED HARVESTING OF PINE

Changes in forestry practice have meant a move from motor manual methods of harvesting to mechanised harvesting. In Thetford Forest District, which is one of the main pine growing areas of Britain, more than 50% of the annual cut is now harvested by machine. Compared to motor manual systems, mechanised harvesting gives reduced unit costs and allows safer working. However, harvesters can debark excessively, though this varies with different models and is most marked when the harvesting head is fitted with spiked metal rollers rather than rubber rollers. With bark damage, pine is more liable to suffer attack from sapstain or blue stain fungi that can cause serious degrade and economic losses in roundwood and processed timber. To meet a concern about the connection between blue stain and harvesting damage, trials were set up to look more closely at the type of bark damage caused by harvesters, and the relationship between the incidence of stain and the nature and size of wounds.

Logs were selected during commercial harvesting using an Åkerman harvester fitted with rubber feed rollers and grouped into two sets of twenty logs consisting of those with severe bark damage and those with minimal bark damage. The same number of logs was processed by chainsaw avoiding bark damage, to act as a control. All logs were then left in the forest, and batches removed for destructive sampling 3, 6, 9 and 12 weeks after harvesting. One such trial was started in June, to coincide with summer temperatures which encourage the development of blue stain fungi; another started in August when blue stain attack is not generally considered to be such a problem. Logs were sampled by removing a series of discs from each one. The extent of bark loosened and removed from the discs was then assessed and also the extent of blue stain colonisation expressed as area, circumferential spread and radial penetration into the disc.

The results demonstrated that as whole trees were processed by mechanised harvester, different types of damage were caused by the chains, delimbing knives and measuring wheel which were readily visible on the log surfaces. On average about a third of the bark was lost from logs severely damaged by mechanised harvesting compared with 2% or less for motor manually harvested logs; damage also included loosened but still attached bark and splintered wood following bark removal (Table 3). The most accurate measurements of bark damage came from the three- and six-week samplings; beyond this the bark suffered additional damage as a result of casual insect and fungal activity. Combining the values for nine- and twelve-week samplings indicated that blue stain damage tended to be worse in both sets of harvester processed logs compared with motor manually felled logs (Table 3a). Indeed, large amounts of bark loss were strongly correlated with a high degree of blue stain around the circumference of the log and, to a lesser extent, the total area of blue stain visible on the disc cross section. The increase in stain over time in the June to September experiment was also obvious in the June–September trial but less marked in the August–November period (Figure 8). None of the stain originated from bark beetle attack but was apparently introduced onto the exposed wood surfaces by casual arthropod vectors such as mites and flies.

Clearly, mechanically harvested logs are more susceptible to attack by staining fungi than those cut and processed manually by chainsaw. Even the recommended usage of rubber feed rollers with basket chains for harvesting pine in

Table 3. Mean values for various types of damage on logs harvested motor manually and by mechanised harvester

Felling date	*Treatment*	*Circumference without bark (%)*		*Circumference with loose bark (%)*		*Circumference with wood ripped (%)*		*Circumference with outer bark removed (%)*	
June	Motor manual	0.2	(0–1.4)	0.5	(0–2.8)	0.0		0.1	(0–0.8)
	Harvester, min	12.7	(0–23.9)	6.1	(0–14.7)	0.5	(0–2.5)	6.0	(0–13.9)
	Harvester, max	34.8	(19.4–52.2)	10.6	(6.7–17.2)	4.8	(0–17.8)	5.9	(0–17.5)
August	Motor manual	2.1	(0–8.3)	1.0	(0–3.9)	0.2	(0–2.2)	0.2	(0–0.8)
	Harvester, min	6.9	(2.5–14.6)	3.7	(0–8.1)	1.3	(0–4.1)	1.3	(0–2.8)
	Harvester, max	29.0	(13.3–37.2)	7.8	(4.4–11.7)	3.4	(1.1–17.2)	3.4	(0.3–6.4)

Brackets indicate range of values.

southern Britain apparently does not prevent blue stain. There was also some evidence to suggest that even with minimal harvester damage to bark, stain often occurred unexpectedly, possibly because small punctures or areas of crushed bark provided suitable entry points for blue stain fungi. Morever, there were no grounds for considering that logs from August fellings might be more vulnerable to stain compared with those felled in mid-summer. To minimise degrade from staining fungi at any time therefore, harvesters should always be fitted with rubber feed rollers, be well maintained and operated with care. As this will not eliminate all bark damage, the time between felling and processing at the sawmill should be minimised, and preferably not exceed more than four weeks. There may also be scope for improving the design of harvesting heads to ensure that bark damage is reduced as much as possible.

ADNAN UZUNOVIĆ * AND JOAN WEBBER

*DEPARTMENT OF BIOLOGY, IMPERIAL COLLEGE, LONDON

Table 3a. Extent of blue stain damage (combined values for nine and twelve weeks)

Felling date	*Treatment*	*Mean radial penetration of blue stain (%)*		*Mean area of blue stain (%)*		*Mean circumferential spread of blue stain (%)*	
June	Motor manual	2.5	(0.0–10.0)	0.2	(0.0–0.7)	1.4	(0.0–3.8)
	Harvester, min	16.4	(10.1–30.9)	3.0	(0.8–6.6)	17.1	(6.9–32.8)
	Harvester, max	16.6	(7.7–28.9)	5.3	(1.3–13.1)	35.4	(14.7–60.0)
August	Motor manual	2.6	(0.0–11.3)	0.4	(0.0–2.5)	1.6	(0.0–6.1)
	Harvester, min	6.2	(1.2–12.7)	0.6	(0.1–1.2)	5.9	(1.9–8.8)
	Harvester, max	13.0	(8.7–15.4)	2.0	(1.0–4.1)	19.9	(8.1–31.1)

Brackets indicate the range of values
Means expressed as % of total disc area, % of disc radius and % of disc circumference.

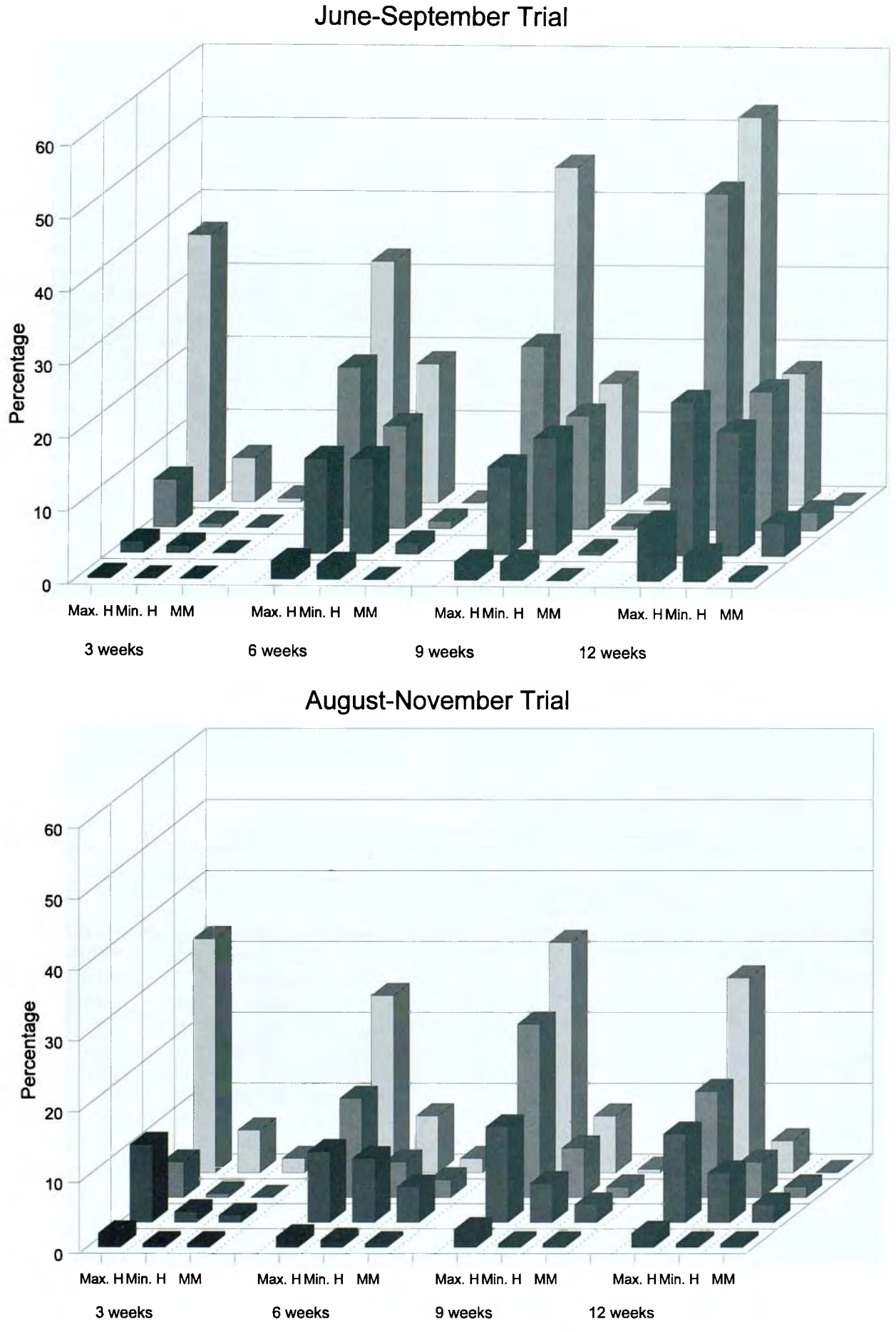

Figure 8. Bark loss and associated stain. Logs were processed motor manually (MM) and by harvester and selected for minimal damage (Min H) or maximum damage (Max H). indicates percentage loss of bark around disc circumference; percentage of disc circumference with blue stain; radial penetration of blue stain as a percentage of disc radius; percentage of blue stained area on disc face.

MENSURATION

Overview

In June 1994 the work and priorities of Mensuration Branch were scrutinised by a Visiting Group, advising on strategy for mensuration research for the next five years. Highest priority was given to the development of new computerised yield models in a range of formats and with wide applicability. The importance of collecting periodic growth measurements from permanent sample plots was also highlighted. These periodic growth data are essential for the development of all types of yield models and the Branch will continue to give the management of the sample plot programme a high priority. The Visiting Group emphasised the centrality of mensuration to effective forest management and the importance of this research discipline to the forest industry.

During the year a total of 48 permanent sample plots were given a full measurement. Eight plots had to be abandoned due to a combination of wind damage and local management needs. Plate 5 shows the final measurement in progress in Glenbranter Forest of a Norway spruce sample plot, yield class 16, which had to be felled because of wind damage to the plot surrounds. A further 88 sample plots in replicated thinning and spacing experiments were measured for girth only. Eight new permanent sample plots were established, five of which were set up as part of the European Union/United Nations Economic Commission for Europe (EU/UNECE) Level II programme for intensive monitoring of forest condition. Plate 6 shows an existing Mensuration Branch Sitka spruce sample plot within a newly established Level II plot in Inverliever forest. The other three new plots were established on Finn planted sites in Thetford Forest at the request of Forest Enterprise, to develop provisional yield models for these stands established at strongly rectangular spacing. Over 60 temporary sample plots in Sitka spruce and lodgepole pine mixture crops were established to provide additional data on such crops for input to the production forecast.

A number of contracts were progressed through the year. Work on the site yield project, jointly funded by the Forestry Commission and the Ministry of Agriculture, Fisheries and Food, is now in its final stages although progress has been hindered by the need to verify site factor datasets. A new inter-branch site yield contract was funded by the Energy Technology Support Unit (ETSU) of the Department of Trade and Industry, to develop models for predicting yields of coppice crops from site factors and clonal characteristics. In support of this project the Branch has been developing non-destructive methods of biomass estimation in short rotation crops. Mensuration and Environmental Research Branches have been successful in securing EU funds for the second phase of the EU/UNECE Level II programme primarily concerned with collection and measurement of increment cores and validation of crown density measurements.

Three visiting scientists worked with members of the Branch during the year. Mr Gong Wencai from the South Central Forestry Inventory Planning Institute, Changsha Province, China spent eight months on a Food and Agriculture Organization fellowship learning yield modelling methods. Dr Karoly Redei from the Forest Research Institute, Kecskemet, Hungary and Miss Shanta Dhoubhadel from Nepal both completed short study tours with the Branch covering topics such as sample plot and yield modelling methods, and database management.

Branch members dealt with 133 measurement and yield enquiries for the Research Division Advisory Service. Three two-day seminars on the tariff procedure for Forest Enterprise staff and representatives of the private sector, were carried out at the request of South and West England and Wales Forest Enterprise Regions. A seminar on thinning control for North Scotland Forest Enterprise Region staff was developed and run collaboratively with Education Safety and Training Branch and Forest Enterprise staff. Data from the Ae thinning experiment, showing the effect of thinning treatment on cumulative volume production and sawlog out-turn, were presented

at the seminar and are shown in Table 4. The new provisional yield tables for poplar were published. These models were developed by J.M. Christie in collaboration with the Branch. The Branch again had major involvement in the Forest Condition Monitoring Survey, with John Proudfoot playing a key role in surveyor training and in the connectivity assessment. The Branch continues to represent the Forestry Commission and the UK on the European Standards Committee CEN TC175 Working Group 1: Methods of Measurement of Round Timber. The Branch now also represents the UK on the EU Level II Scientific Advisory Group.

JANET METHLEY

PROGRESS ON NEW METHODS OF YIELD MODEL CONSTRUCTION

New yield modelling methods, and newly constructed yield models for ash planted at wide, agroforestry spacings, were reported in the *Report on forest research 1989*. Progress has now led to a unified method for the construction of yield models for all planting spacings and thinning treatments. New yield models for ash are under construction to represent a continuous range of planting spacings from one metre to free growth, and a wide range of regular and irregular thinning types, intensities and cycles.

Figure 9b shows provisional general yield class (GYC) curves for ash planted at 1.5 m spacing, and compatible curves for free grown ash as generated by the new mathematical model. The enhanced height growth due to between-tree competition of ash trees planted at close spacings can be clearly seen. Figure 9a compares the new GYC curves with the published GYC curves for sycamore, ash and birch (SAB) at 1.5 m spacing. The new GYC curves for ash at 1.5 m spacing lie above the equivalent curves for SAB, suggesting that ash achieves a lower volume production for a given top height than do sycamore and birch. This result is consistent with the recommendation in the published SAB model that production class C should be assumed for ash. Figure 9c shows the old and new height/age curves for free grown ash. In contrast to the old curves for free grown ash, height growth terminates less abruptly in the new curves.

Although research has concentrated on ash, the newly developed techniques are applicable to any tree species, and will be invaluable as part of the present validation and revision of yield models for Sitka spruce.

ROBERT MATTHEWS AND GONG WENCAI

TIMBER QUALITY ASSESSMENT

The timber quality pilot study, initiated by the Home Grown Timber Advisory Committee, Technical Subcommittee (HGTAC, TSC), and Director Research was completed. Detailed interim and final reports, Papers 852 and 858, were presented at the 1994 spring and autumn TSC meetings. A quality assessment method has been devised based on a straightness assessment of the first six metre portion of the stem of standing trees. The assessment data were analysed to produce a series of scores which can be used to classify the crop by quality classes that are meaningful in terms of product potential. Table 5 illustrates the log combination scoring system applied to individual tree data. The individual scores can be used to derive an overall quality score for the crop; for example a score may be based on the arithmetic mean, or the median value or the mode, or a combination of all three.

Table 4. Impact of thinning on cumulative volume production and green sawlog out-turn. Ae Sitka spruce replicated thinning experiment, yield class 20

Thinning intensity	*Cumulative volume (cv) production at 45 years* ($m^3\ ha^{-1}$)	*Green sawlog[1] production at clear fell (45 years)* ($m^3\ ha^{-1}$)	(% of cv)
Unthinned	815	146	18
Light[1] (MT–⅓)	777	249	32
Management table (MT)	717	305	43
Heavy (MT+⅓)	637	253	40

[1]MT Management table intensity which is 70% of yield class

Table 5. Scores assigned to different combinations of log lengths per tree for timber quality assessment

	Estimated number of green logs in butt 6m		
Score	*≥ 4m*	*≥ 3 m <4 m*	*≥ 2 m <3 m*
1	0	0	0
2	0	0	1
3	0	0	2
4	0	1	0
5	0	1	1
6	1	0	0

Alternatively the distribution of the individual scores can be used as an indicator of crop quality and product potential. Figure 10 illustrates distributions for five assessors, for the Sitka spruce and Norway spruce study sites at Ae forest. The overall crop scores for each assessor were in distinct bands which compared well with straightness assessments carried out on the felled timber in the sawmill, and with actual sawmill out-turn. The analysis also revealed patterns of differences between assessors and sites which, through training and calibration, could be reduced to achieve a consistent standard of assessment.

In addition to the two study sites at Ae reported in the *Report on forest research 1994*, three further studies were carried out at sites in Kielder, Castle Douglas and Gwydyr forests.The results of these studies confirm that the crop straightness assessment score can distinguish different crop qualities which are meaningful in terms of sawmill out-turn.

The original objective, to establish a system for classifying stand quality and to demonstrate its relevance to sawmill output, has been achieved although further work is required before the method can be used in crops for production forecasting purposes, or in crops due to be felled to optimise product potential.

JANET METHLEY AND JOHN PROUDFOOT

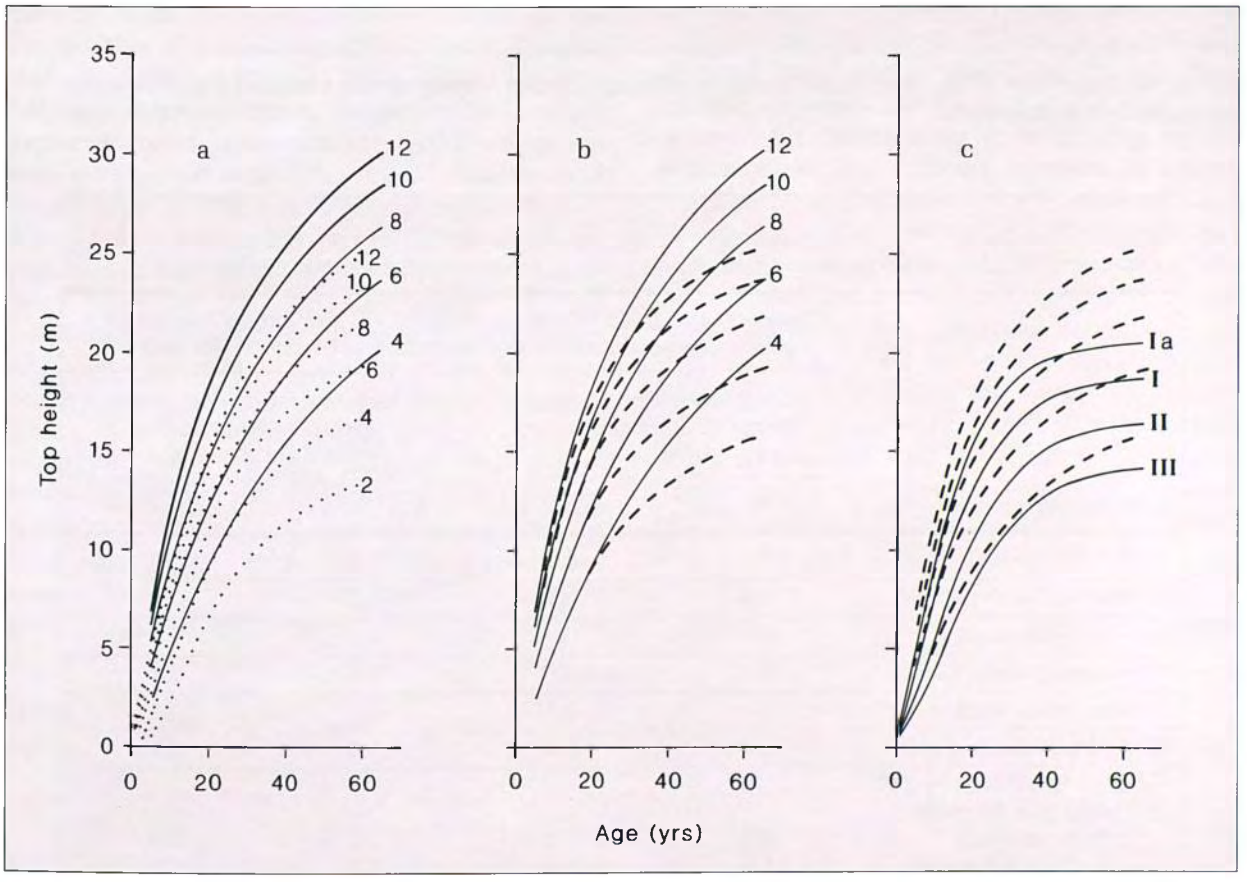

Figure 9. Comparison of height-age curves of existing and new yield models for ash. a) Comparison of general yield class curves of the new ash model (solid lines) with general yield class curves of the existing model for sycamore, ash and birch combined (SAB, dotted lines); both models assume a planting spacing of 1.5 m. b) Comparison of general yield class curve of the new ash model (solid lines) with equivalent curves for free-grown ash based on the new model (dashed lines). c) Comparison of new height-age curves for free-grown ash (dashed lines) with existing quality class curves for free-grown ash (solid lines).

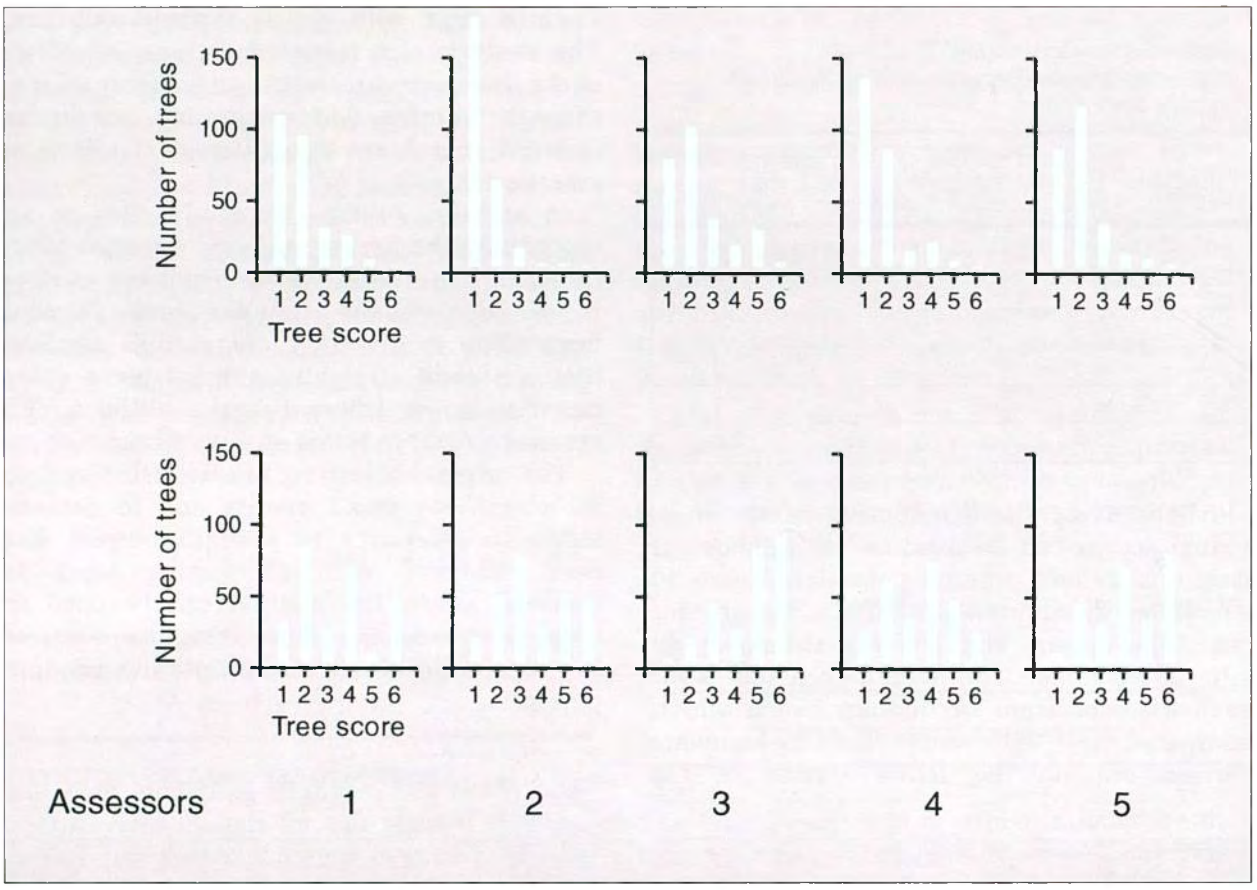

Figure 10. Distribution of log combination scores for Sitka spruce and Norway spruce trial plots in Ae Forest as assessed by five observers.

Table 6. Evaluation of forest policy/management options for enhancing carbon sequestration potential of British forests[1], including comparison of two alternative carbon budget methodologies

	Change in annual carbon sequestration by British forests relative to business-as-usual scenario in megatonnes of carbon per year			
	Ecosystem methodology (not including direct and indirect substitution)		*Forestry sector methodology (including direct and indirect substitution)*	
Example management option	*over 50 yrs*	*over 500 yrs*	*over 50 yrs*	*over 500 yrs*
Shorter rotations[2] (–20 yr)	–1.2	–0.2	–1.3	–0.8
Longer rotations[2] (+20 yr)	0.6	0.1	–0.6	–0.8
Harvest whole trees	0	0	0	0
Utilise unmanaged forests	–0.3	0	0.1	0.3
Improve timber quality	0	0.1	–0.1	0.1
Stop all harvesting and felling	5.4	0.7	–1.5	–6.4
Increase forest area by 20% (0.5 Mha) over 50 years				
(with conifers)	0.7	0.1	1.1	2.2
(with broadleaves)	0.5	0.1	0.8	2.0

1 'British forests' refers to high forest and coppice on rotations longer than 5 years but not short rotation wood fuel coppice crops.

2 Conifer plantation forests are typically grown on a rotation between 40 and 70 years. Broadleaf plantation forests are typically grown on rotations between 50 and 200 years.

MODELLING IMPACTS OF FORESTRY POLICY ON CARBON SEQUESTRATION

Carbon budgets of forest ecosystems are required for two main purposes. Firstly, they are an essential contribution to global statistics on carbon fluxes to and from the atmosphere, necessary for modelling and predicting climate change. Secondly, they form the factual basis for negotiations and policy formulation on the management of forests for offsetting or reducing global carbon emissions. In preparation for a NATO Advanced Research Workshop, *The role of global forest ecosystems and forest resource management in the global carbon cycle*, held at Banff, Alberta, Canada, September 1994, the influence of carbon budget methodology on assessments of the impacts of forest management on the carbon balance was investigated using model simulations.

In compilations of regional global statistics on carbon fluxes for national and international reports, forest ecosystems comprise just one of many land uses. Data on carbon in terrestrial plants are just one element in a complete carbon budget that also includes soils, aquatic systems and burning of fossil fuels. The linkages between these elements, in particular linkages between forest management, wood utilisation and energy consumption, are of fundamental importance to the evaluation of the impact of forest policy and management on the direction and rate of flow of carbon to or from the atmosphere. Sustainably harvested wood has the potential to substitute for fossil fuels as a source of energy by direct substitution, or for more energy-expensive materials by indirect substitution and it is important that this potential is accounted for in carbon budgets. Table 6 presents the results obtained when two different budgeting methods are applied at the national level in order to evaluate the carbon sequestration potential of a series of alternative forestry policy options for Britain. The first pair of results are for 50-year and 500-year simulation periods obtained using a carbon budget methodology, referred to here as the ecosystem methodology which accounts for exchanges of carbon between the atmosphere and forest biomass, dead matter, forest soils and harvested wood products. The second pair of results are for 50-year and 500-year simulation periods obtained using an alternative carbon budget methodology, referred to here as the forestry sector methodology, which is similar to the ecosystem methodology but also accounts for direct and indirect substitution by harvested wood. All results were produced using carbon sequestration models, developed by the Branch, used in conjunction with national forest inventory data for Britain. The results in Table 6 represent, for a series of possible changes in forest management, the resultant change in the rate of carbon sequestration by British forests, in megatonnes of carbon per year, relative to that achieved by continuing to manage forests according to current practice.

It is evident from comparing the ecosystem and forestry sector methodologies that exclusion or inclusion of direct or indirect substitution in the calculation of carbon budgets can produce results from which diametrically opposed conclusions would be drawn about optimal strategies for forestry policy and management for maintaining or enhancing carbon sequestration. It is difficult, however, to recommend a correct methodology, as the relevance of a given carbon budget methodology may depend on the specific objectives of the study, and possibly on any economic, social and environmental objectives, costs and benefits associated with the forests under consideration. It is clear, however, that ignoring direct and indirect substitution in carbon budgeting would result in a misrepresentation of the carbon sequestration potential of timber production from industrial plantation forests such as those currently forming the bulk of forested land in Britain.

ROBERT MATTHEWS

MYCORRHIZA RESEARCH

The role and importance of mycorrhiza in British forestry continues to be the major priority for research in this Unit. The establishment of trees on damaged sites such as mining spoils can be improved by using appropriate mycorrhizal fungi. New isolates of arbuscular mycorrhizal fungi were obtained from earlier work on a coal spoil heap in Scotland (*Report on forest research 1994*). Work continued on purification of these isolates so that their efficacy as symbionts can be tested.

Clonal cuttings of Sitka spruce were inoculated with the mycorrhizal fungus *Laccaria proxima* at different times during the rooting phase to investigate the effects of inoculation on rooting success and mycorrhiza formation. Preliminary results showed that mycorrhizas were established, but at low levels. Timing of inoculation had some effect. Inoculation was less successful at the time of cutting insertion (March) than at weaning (June). Introducing the fungus at the beginning of the second year was not very successful, probably because naturally occurring fungi had occupied the susceptible roots. Overall mycorrhiza establishment was poor, usually with less than 3% of the root tips colonised by *L. proxima*. None of the treatments affected rooting or total root dry weight when compared with untreated control cuttings. The cuttings came from spruce hedges that were approximately 10 years old. Such mature material does not usually root well, and a repeat experiment has been established with more juvenile material. This work is part of a European Union (EU) project (CT 93 – 1742) in cooperation with scientists in France, Germany, Spain and Portugal.

Final measurements were made in a long series of field experiments (*Report on forest research, 1980–1994*) in which Sitka spruce and Douglas fir seedlings were inoculated with different ectomycorrhizal fungi. No consistent long-term growth effects have been recorded, and it is concluded that, for Sitka spruce in particular, inoculation with mycorrhizal fungi is not necessary under normal British forestry conditions, probably because of the abundance of suitable natural inoculum from airborne or soilborne mycorrhizal fungi.

Much of the work carried out by the Unit this year has been funded by contracts undertaken for the EU, the Overseas Development Administration (ODA) and the Food and Agriculture Organization. This recognises the high international standing of the unit, particularly in taxonomy of the main group of mycorrhizal fungi. Work started on a cooperative project, Restoration of Environmental Diversity by Effective Ecosystem Monitoring (REDEEM), as part of the EU's Environment Programme. Populations of mycorrhizal fungi were examined from a desertified ecosystem in southern Spain. Samples were taken from the rhizosphere of the main remnant plants and mycorrhizal fungi in the soil identified. Some species that were isolated by baiting techniques were not found in the direct extractions from the soil, indicating greater biodiversity than shown by simple surveys. Some of these fungi may be useful for restoration projects, and work is now proceeding to establish them in pure culture for use in plant growth trials.

The database, produced in the Unit, for registration of mycorrhizal fungal cultures in the European initiative, La Banque Européenne des Glomales (BEG), was tested, and several improvements made at the suggestion of colleagues. Registration of fungi in the germ plasm collection was initiated, and the BEG was officially launched at the Fourth European Symposium on Mycorrhizas, Granada, Spain in August. Initially, ten cultures were registered. Subsequent registrations have brought this to 45. More than 20 are in the process of registration, and it is planned that the number will exceed 100 by the end of the first year. The project has attracted considerable interest among mycorrhiza workers world-wide. Cultures have been registered from North America, Latin America, and Australasia, as well as from within Europe, and registrations are pending from Japan, India, and several European countries from both within and outwith the European Union.

The Unit provided advice and training on identification of mycorrhizal fungi, and cooperated in mycorrhiza research projects at several

British institutions, including ODA, the Institute of Terrestrial Ecology, Edinburgh University, The University of York, The University of Sheffield, Kent University and Leeds University. Advice and assistance has also been provided to colleagues in Australia, Denmark, Finland, France, Italy, Kenya, Nigeria, Switzerland, Spain and the United States of America. Courses on mycorrhizal research and identification of mycorrhizal fungi were taught in Japan and Venezuela, made possible through grants from the Japanese Ministry of Agriculture and the British Council, respectively.

CHRIS WALKER AND ALICE BROOME

PATHOLOGY

Over 30 years ago, mandatory treatment of freshly cut conifer stumps was introduced throughout the Forestry Commission as a safeguard against Fomes root and butt rot caused by the fungus *Heterobasidion annosum*. Since that time, research within the Branch has been aimed at determining whether treatment can safely be discontinued on certain sites. During the year, Derek Redfern and Jim Pratt of Pathology Branch, together with Adrian Whiteman, Policy Studies Division, produced a Research Information Note based on data collected during this work. It showed that on strictly commercial grounds stump treatment could be justified on mineral soils but not on peat soils. However, a more general use of stump treatment might well be appropriate if treatment costs were to fall or if non-market benefits, such as the value attached to the maintenance of disease-free crops, were taken into consideration. It was also noted that an element of uncertainty exists about disease development on peat sites prepared by modern techniques, since the effect of site amelioration on the behaviour of *H. annosum* has not yet been fully explored (Redfern *et al.*, 1994). For the time being at least, Forest Enterprise intends to continue with stump treatment on all sites (addendum to Harvesting and Marketing Memorandum UM2, November 1994). Also during the year, Jim Pratt assembled data based on several years research to support an application to the Pesticide Safety Directorate for approval of the use of disodium octoborate (polybor) as a stump treatment chemical. On a more general note, work has begun on a European Union concerted action programme to produce a handbook on Fomes root and butt rot in Europe. Members of the Branch will be writing several of the chapters.

In the summer of 1993, a Phytophthora root disease of common alder, *Alnus glutinosa*, was investigated at several sites in southern Britain (*Report on forest research 1994*). During 1994, a research project, supported in part by the National Rivers Authority, was initiated. A sample survey was established on the status of disease on riversides in southern England and east Wales and this is described later in this Report. Most of the disease records come from trees on the banks of streams and rivers, but the disease also occurs in woodland and amenity plantings and in orchard shelterbelts. It has been found in grey alder, *A. incana*, and Italian alder, *A. cordata*, as well as in *A. glutinosa*. Research on the pathogenicity of the *Phytophthora* isolated from diseased trees and on its similarity to and differences from the well-known root pathogen, *P. cambivora*, is about to be published (Brasier *et al.*, in press; Gibbs, in press). A more general account of the disease and its known distribution was issued as a Research Information Note (Gibbs, 1994) and this was supplemented by the subsequent production of a coloured leaflet on disease identification.

Work done by the Branch on the Forest Condition Survey is described later in this Report. The amenity tree health monitoring programme for England set up under contract from the Department of the Environment is now in its second year and a network of rural observation plots has been established. These provided useful information for the 1994 annual report (Strouts, 1995). Work is well advanced on the selection of urban observation plots.

A major achievement during the year was the publication of *Diagnosis of ill-health in trees* by Robert Strouts and Tim Winter (Entomology Branch). With its wealth of information and abundant colour illustrations, it represented the culmination of work conducted over a three-year period on contract from the Department of the Environment (Strouts and Winter, 1994). HMSO has reported an excellent response to the book.

The Branch again had the pleasure of hosting visitors from abroad. Dr Esperanza Sanchez from the Instituto Nacional de Investigaciones Agrarias in Madrid completed her assignment with the Forestry Commission by conducting some research on *Phytophthora* from sites in Spain and Portugal as part of Clive Brasier's programme of work on the Iberian oak decline. Mr Kiril Sotirovski, from the University of Skopje in Macedonia, spent six months at Alice Holt working with Louise Sutherland on aspects of Dutch elm disease.

JOHN GIBBS

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DISEASE DIAGNOSTIC AND ADVISORY SERVICES

Scotland and northern England

The most frequently recorded causes of damage during the year were *Armillaria* root disease and misuse of herbicides, both of which were diagnosed in a range of hosts from amenity broadleaves to plantation conifers. Almost as frequently encountered was, more remarkably, needlecast of Scots pine caused by *Lophodermella sulcigena,* a pathogen best known on Corsican pine. The more usual Scots pine needle pathogen *Lophodermium seditiosum,* was nevertheless also a frequent cause of foliage browning in spring and early summer (see Plate 7). Notably severe cases of two other common needlecast fungi were seen during the year: *Meria laricis* on recently planted hybrid larch, and the rust *Chrysomyxa abietis* on pole-stage Norway spruce in the Tweed Valley. A large number of requests for general advice as distinct from diagnosis, were received. The majority of these involved either provision of advice on tree health nationally, or assessment of risks associated with one or other of the major tree pathogens: *Armillaria* spp., *Ophiostoma* spp. (Dutch elm disease), or *Heterobasidion annosum* (Fomes). *H. annosum,* which is probably our most important forest pathogen, was diagnosed as a cause of root- or butt-rot on many occasions. In one case, it was responsible for significant mortality in 25-year-old Scots pine on a former arable site with soil pH in the range 3.5–4.4; normally, killing of older Scots pine by *H. annosum* only takes place at much higher pH levels. Equally noteworthy was the occurrence of root killing by the same pathogen in sycamore interplanted with the pine.

Following publicity given to the occurrence of *Phytophthora* disease in alder, several reported cases of dieback in alder were investigated in northern England and Scotland. Only two of these (in West and South Yorkshire) proved to be attributable to *Phytophthora* sp., and it became apparent that other health problems of alder in the north warranted further attention in their own right. A dieback syndrome responsible for significant mortality in parts of the Highlands is currently under investigation. Public concern was also aroused over the poor condition of crack willow at several localities in north-west England. On investigation, much of the dieback could be accounted for by the outbreak of scab disease in 1993 (*see Report on forest research 1994*), though the severity of crown loss in trees over 10 m in height was unprecedented in our experience. A *Cryptodiaporthe* sp. was found on some branches and may have been involved secondarily in dieback.

Although *Phytophthora* appeared not to be widely associated with damage to alder in the north, members of this group of pathogens were involved in an unusually high number of other cases. *Phytophthora* spp. were isolated from dying roots of yew in northern England, from *Abies nobilis* nursery stock also in northern England, and from *A. nobilis* grown as Christmas trees in northern Scotland. In the last case, the species isolated was identified as *P. megasperma* by Dr J. Duncan, Scottish Crop Research Institute, Invergowrie, Dundee. Dying *Castanea sativa* in woodland in northern England were found to exhibit symptoms of the *Phytophthora* disease commonly known as ink disease, though the pathogen could not be isolated on this occasion. Although this disease is well known in chestnut plantations in southern England, it has not been commonly recorded in the north.

Among the most noteworthy of the many cases in which climatic injury was believed to have been involved were those in which 1993 shoots on young oaks died back before flushing. This damage, which was recorded from several places in northern England and southern Scotland, was attributed to low temperature injury in autumn or early winter of the previous year. It was strongly suspected that defoliation by mildew in the previous year (see *Report on forest research 1994*) had disturbed the normal hardening processes of some affected trees.

Autumn frost was more clearly responsible for a case of severe foliage browning of Norway spruce in the Scottish Borders. Affected trees exhibited symptoms which were identical to those often associated with autumn frosting on Sitka spruce, but which are rare on Norway spruce. Winter injury was recorded on several occasions as a cause of shoot dieback and foliage browning in pines and Douglas fir.

The most unusual records made during the year were graft union failure in *Sorbus aria* and infection of young (two years planted) Scots pine by *Peridermium pini*. The former, though not unique in our experience, was responsible for a number of deaths in an avenue of 14-year-old *S. aria* 'Lutescens' on an unidentified rootstock. *P. pini* is a well known stem-rust of older pine in north-eastern Scotland and East Anglia but it is uncommon outside those areas and rare anywhere in trees under 10 years old. In this case, two infected trees, planted in 1992, were found close to each other in Tentsmuir Forest, Fife. The circumstances were even more remarkable in that the position of the cankers on both plants suggested that infection probably occurred when they were in their second year, and therefore still in the nursery (in north Yorkshire). A germination test (Gibbs *et al.*, 1988) was carried out on aecidiospores from both plants but the results fitted neither of the previously known forms of the fungus in Britain – the 'Scottish race' and the 'Thetford race'.

STEVE GREGORY, GRACE MACASKILL,
DEREK REDFERN, JIM PRATT

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Wales and southern England

The cool and very wet spring was responsible for severe 'willow blight' (Scab, *Venturia saliciperda*, and black canker, *Glomerella miyabeama*) mainly in the area south of a line from Gloucestershire to Essex. These weather conditions were also responsible for the widespread recurrence of blossom wilt, caused by the fungus *Monilinia laxa*, on ornamental cherries, especially *Prunus subhirtella* 'Autumnalis'. Reports of poor flushing in oak were received from Cornwall to Cheshire. As in northern Britain, the cause was thought to be severe autumn frost or winter cold, and a link with oak mildew was suspected. Following an article in a national newspaper, in March 1994, on the bronzing of yew foliage, a large number of reports from throughout the area were received. The nature of the damage indicated an abiotic cause and its timing the involvement of a period of very low temperatures in October 1993. Waterlogging was suspected to be the cause of damage to Corsican and Scots pine on some heavy clay sites in east England. Examination of trees that had been winched over indicated that, during the drought years of 1989 to 1991, they had rooted more deeply than usual and that the roots formed at this time had died with the onset of wetter conditions. It would appear that the remaining live root system in the upper part of the soil was insufficient to sustain the trees. On one site 20% of the trees in a 10 ha plantation of 32-year-old Corsican pine had died.

Damage to young wild cherry caused by bacterial canker, *Pseudomonas syringae* pv *morsprunorum*, affected several plantations planted under the Farm Woodland Scheme. Losses were very high and often involved well established trees. In late July a severe outbreak of needle-cast disease caused by the fungus *Cyclaneusma minus* was found on a plantation of Scots pine grown for Christmas trees in Cheshire. Though no deaths or dieback occurred, the loss of most of the older needles rendered the trees virtually useless for sale. This pine disease can be a serious problem for Christmas tree growers in North America but as yet it has caused only isolated damage in this country. An unusually severe outbreak of beech canker, *Nectria ditissima*, affected over 20% of six- to twelve-year-old beech trees in a five ha plantation in East Sussex. Affected trees had multiple cankers that had caused severe distortion to their stems and rendered them useless for future timber production.

Other problems during the year involved a number of cases of high planting losses due to either poor plant quality or poor plant handling and storage. Such losses, which are relatively easy to avoid, far exceed those caused by diseases. There were a number of cases of herbicide injury to amenity trees, particularly those in pavements and paved areas. The reasons for the damage ranged from failure to follow the manufacturer's directions to the use of an inappropriate herbicide around trees. Progressive dieback of Scots pine in plantations in the Midlands was found to be due to lime-induced chlorosis. This condition seems to have become more prevalent in recent years, possibly due to the retention of Scots pine, originally intended as a nurse crop for lime-tolerant broadleaves, beyond the normal limit on such sites of 25 to 30 years. A report on the pests, diseases and

disorders of amenity trees, produced as part of the Department of Environment contract for monitoring the health of non-woodland trees in England, gives additional information on amenity tree problems occurring during the year (Strouts, 1995).

DAVID ROSE, ROBERT STROUTS AND JOAN ROSE

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SURVEYS TO MONITOR FOREST HEALTH

'Forest declines' have been reported in Europe for more than 100 years. Large-scale damage has occurred in several species, including Norway spruce, silver fir (*Abies alba*) and oak (Innes, 1993). In more recent times, an apparently new type of forest damage was observed in Germany in the early 1980s, affecting principally silver fir and Norway spruce at high elevation (above about 800 m). The primary symptoms were foliage loss and yellowing of older needles associated with magnesium deficiency (Binns and Redfern, 1983).

The local effects of air pollution on forests in the immediate vicinity of major sources have been recognised for many years, both in North America and Europe. In eastern Europe severe damage in Poland and the former Czechoslovakia has been associated with high levels of sulphur dioxide. The proximity of such damage to some of the areas affected by the so-called new forest damage in the former West Germany gave rise to fears that it might also be caused by atmospheric pollution. The effects were thought to be chronic rather than acute since sulphur dioxide levels were much lower than in Poland and the former Czechoslovakia, but nevertheless the problem was perceived to be potentially serious and widespread.

In order to assess the extent of damage, a survey was initiated in Germany which has since been extended to most other countries in Europe, including those of Scandinavia, under the international cooperative programme on the assessment and monitoring of air pollution effects on forests (ICP Forests). This programme was established in 1985 under the auspices of the Convention on Long-range Transboundary Air Pollution. Since 1987, EU member states have been obliged to carry out a forest health-monitoring programme under Regulation No 1696/87 on the protection of the Union's forests against atmospheric pollution.

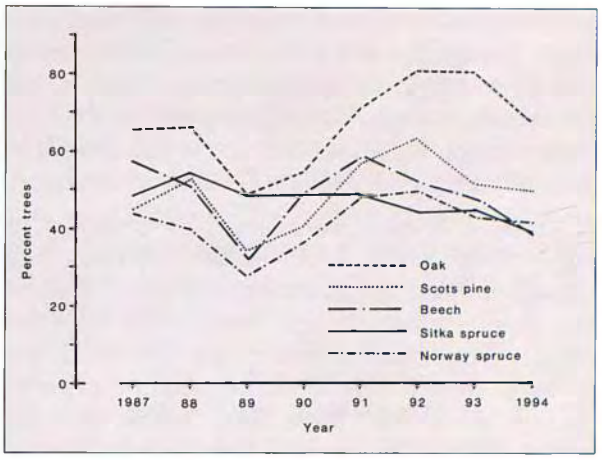

Figure 11. Changes in crown density since 1987 for five species surveyed annually. The proportion of trees in which crown density was reduced by more than 25% compared to an ideal tree is shown for each species.

In Britain, annual surveys of five of our major species – oak, beech, Scots pine, Norway spruce and Sitka spruce – have been conducted by the Forestry Commission since 1984. In the most recent survey, carried out in 1994 (Redfern *et al.*, 1995), a total of 8808 trees were assessed on 367 plots. Following the procedure established in Germany and adopted throughout Europe, the feature of greatest interest in the survey is an assessment of crown density, i.e. the degree of transparency of the crown, which is used to provide an index of tree condition. The method has value in establishing trends, but one should not infer that there is a general relationship between crown density and tree health, although this may be true for particular diseases or disorders.

Figure 11 shows changes in crown condition that have taken place since 1987 by recording the proportion of trees in which the **reduction** in crown density (compared to that of an ideal tree) has exceeded 25%. An upward gradient in the graph therefore indicates a **deterioration** in crown condition. Data for the period 1984–1986 have been excluded due to problems of standardisation. The figure of 25% was chosen arbitrarily by ICP Forests to represent the threshold level for damage. Crown densities have fluctuated from year to year, revealing little evidence of a long-term trend for most species. Sitka spruce in particular has shown only minor changes during this period. Since 1993 there has been an overall increase in the crown density of all species, which continues an improvement observed in three species the previous year. Improvement was most marked in oak, in which

a continuous decline since 1989 only ceased in 1993. Except for the peak year of 1989, beech was in better condition than at any time during the last eight years. The improvement since 1992 suggests that most species benefited from the generally wet weather of the last two years.

Trees in Britain are affected by a variety of well-known biotic and climatic factors. The impact of these factors varies from place to place and from year to year, and fluctuations in crown density, either annually or on a longer cycle, are to be expected. The most important causes of damage since 1987 have been storms, drought and defoliation by insects. The first two in particular have had widespread and lasting effects on several species, and the decline between 1989 and 1992 in four of the five species surveyed was probably largely due to these two factors. Most problems involve single species and have only local effects, although these may be severe. This produces a background fluctuation in crown density which is well illustrated by the results for Sitka spruce. These results probably reflect the effects of the green spruce aphid (*Elatobium abietinum*) which is the single most important cause of defoliation in this species. Norway spruce, which is affected by a wind-related, lethal condition known as top-dying, provides another example. This is a progressive, climatic–physiological disorder which may be initiated by increased exposure and exacerbated by drought. Since the disorder is progressive within affected stands it can lead to large and persistent differences in the crown density of trees in affected and unaffected plots, that may be in close proximity. Dramatic local differences like this are a common feature of many damaging agents. They make it difficult to identify and interpret spatial trends.

Survey results from participating European countries are published jointly by the UN Economic Commission for Europe and the European Union. Concern has been expressed that trees in Britain show levels of defoliation similar to those in parts of Europe affected by high levels of atmospheric pollution. For example, figures comparable to those shown in the graph (expressed as means for all species in 1993) for Britain, the Czech Republic and Poland were 54.0%, 53.0% and 50.0% respectively, whereas values for Denmark, Norway and France were 33.4%, 24.9% and 8.3% respectively. However, the survey report cautions against comparison between countries because of differences in species and methodology. These methodological differences primarily concern the choice of reference trees used to provide standards against which defoliation is assessed. In 1993, in order to facilitate comparison, trees in Britain were assessed using the method most commonly used in other European countries. On this basis, the proportion of trees in which crown density was reduced by more than 25% was only 16.9%, compared to 54.0% using the original method. The two methods are compared in a Research Information Note (251) issued by the Forestry Commission in 1994. In future assessments, both methods will be used in order to maintain the existing time series shown in the graph.

There is an increasing doubt about the existence of a general forest decline in Europe and the role attributed to air pollution as a cause of widespread damage (Skelly, 1992; Skelly and Innes, 1994). In Britain, all the evidence suggests that while air pollution may have some influence on tree condition, apart from rare acute events with only local effects, its role is small relative to the effects of biotic and abiotic factors such as wind, insect defoliation and drought. There is no evidence for long-term pollutant damage of the type identified for some forests in central Europe.

DEREK REDFERN

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RIVER BANK SURVEY FOR *PHYTOPHTHORA* ROOT DISEASE OF ALDER

A survey for Phytophthora root disease (Plate 7) was conducted between July and September 1994 on riparian alder in an area of southern England and east Wales which encompassed the known centres of disease. The full survey procedure will be described elsewhere but, in brief, it was based on non-tidal rivers over eight metres

wide at normal winter height (such rivers are represented with a double blue line on the Ordnance Survey 1:50000 map) and a river was eligible for survey if it lay within five km of a network of 25 km grid centres. Three 100 m plots were then established upstream of points of public access and information collected on the alders within 10 m of the water. As alder is frequently coppiced, the basic unit of the survey was either a maiden tree with a stem measuring more than 7 cm diameter at breast height (dbh), or a coppice stool with at least one stem of the same size. Table 7 shows the data in terms of numbers of alders recorded in various 100 km squares. Three measures of ill health are shown: the numbers of dead trees; the numbers showing crown symptoms typical of *Phytophthora* (small, yellow, sparse leaves); and the numbers showing both crown symptoms and stem symptoms in the form of tarry or rusty spots.

Overall 1.2% of the trees were classed as dead, i.e. they possessed no living stems over 7 cm dbh. They could have died for a variety of reasons. Just under 4% had *Phytophthora* crown symptoms, and stem symptoms were recorded on approximately half of these. In this connection it should be noted that, because of inaccessibility, not all the trees with crown symptoms could be subjected to close inspection of the stem. The highest number of trees with *Phytophthora* crown symptoms was found in square SO but the highest incidence of disease was found in more easterly squares. It was possible to extrapolate from the plot data to the 100 km squares within which they lie by using the Ordnance Survey maps to obtain information on the total length of rivers over eight metres wide in such squares. This procedure gave an estimated total of 580 000 alders for the seven 100 km squares within which at least 15 plots were surveyed. Of these trees an estimated 8700 were dead, 24 700 had *Phytophthora* crown symptoms and 10 200 had both crown and stem symptoms.

JOHN GIBBS

Table 7. Incidence of dead alders and alders with symptoms of Phytophthora root disease

100 km square	*No. of plots*	*No. of alders*	*Dead alders*		*Alder with* Phytophthora *crown symptoms*		*Alder with* Phytophthora *crown and stem symptoms*	
			No.	*%*	*No.*	*%*	*No.*	*%*
SK	27	244	3	1.3	2	0.8	1	0.4
SO	33	726	12	1.6	33	4.5	12	1.6
SP	21	15	0	0	3	20.0	2	13.3
TL & TM	30	39	3	7.7	8	20.5	2	5.1
ST & SS	21	284	3	1.1	6	2.1	2	0.7
SU	27	255	0	0	7	2.7	6	2.4
TQ	30	140	0	0	8	5.7	6	4.3
All	**189**	**1703**	**21**	**1.2**	**67**	**3.9**	**31**	**1.8**

PLANT PRODUCTION

INTRODUCTION

Plant Production Branch's responsibilities are divided between statutory seed testing related to the Forest Reproductive Material Regulations, advisory work and scientific research to improve woody plant propagation.

A recent Visiting Group highlighted the considerable synergy which exists between the testing, advisory and research roles. In the last year, the importance of the link between seed testing and research in particular has been clearly demonstrated. Three European institutes specifically invited the branch to partner bids for EU research funding, because our successful coupling of research with our role as an Official Seed Testing Station gives us unequalled experience of how varied the characteristics of different seedlots of the same species can be.

The year has also seen the Branch expand its communication role and we gave seminars and workshops to nursery managers of Forest Enterprise and Tilhill Economic Forestry. In addition, new links were established with the Royal Botanic Gardens, Edinburgh and the Henry Doubleday Research Association. We look forward to close future co-operation with these organisations.

Finally, a research contract on behalf of the Overseas Development Administration (ODA) into multipurpose tropical legume tree seed pretreatment was successfully completed.

PETER GOSLING

OFFICIAL SEED TESTING STATION

In 1994–95, we tested 151 seedlots from Forest Enterprise, 26 lots from the Oxford Forestry Institute, 200 seedlots of tropical species from Cuba on behalf of the ODA, and 227 lots from seed merchants, nursery managers and other agencies.

YVONNE SAMUEL AND PETER GOSLING

DORMANCY CHANGES DURING STORAGE OF PRECHILLED THEN REDRIED SEEDS OF SITKA SPRUCE

Over 90% of all commercial seedlots of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) exhibit conditional dormancy (UK Official Seed Testing Station, unpublished, 1990). Seeds will germinate at optimum test temperatures but germinate faster and better over a wide range of temperatures after a dormancy breakage treatment. The usual treatment given before sowing to most conifer seeds, including Sitka spruce, is a moist cold treatment, commonly referred to as a prechill (Gosling and Aldhous, 1994). The prechill can be carried out in several ways. Current recommendations suggest treatments of 6–12 weeks with a moisture content of 30% should be given to prevent premature germination during the prechill (see Jinks *et al.*, 1994). If seeds made non-dormant by a prechill could be redried and stored without losing the dormancy breakage effects of the prechill, non-dormant seeds could be stored and sown whenever required. To determine the effects of redrying and storage, seeds of a Sitka spruce seedlot (Forestry Commission identity number 83(2017)) were prechilled at a seed moisture content of 30% for 12 weeks at 3°C to break conditional dormancy. The seeds were then redried to the original storage moisture content (8%) and stored for up to 52 weeks at +3°C in sealed containers. Samples taken during storage were then tested at 10°C; this approximates to UK soil temperature at normal spring sowing time, and is also the best temperature for assessing conditional dormancy. Non-dormant Sitka spruce seeds will germinate during a 42-day test at 10°C, but dormant seeds will not (Jones, unpublished).

Figure 12 shows the germination capacity for untreated Sitka spruce seeds from seedlot 83(2017), 12-week prechilled seeds, seeds prechilled and then redried, and seeds prechilled, redried then stored for 6, 12, 18, 24 and 52 weeks. In addition the corresponding

viability (%) of the seeds is also shown. The loss in the ability to germinate at 10°C (reimposition of conditional dormancy) can be described by a negative exponential equation (formula $y = a + br^x$; where a = the lower asymptote (19.3), b = the difference between the intercept (a + b) and the lower asymptote (70.7), and r = the rate of loss of b (0.9274)). Therefore, after redrying and just 13 weeks of storage, the ability to germinate at 10°C had fallen from 90% to 45%. So the dormancy removed by prechilling Sitka spruce seeds was not reimposed by drying but was reimposed when redried seeds were stored.

From a practical point of view, the reimposition of dormancy following redrying and storage at 3°C is somewhat disappointing and means that seeds cannot be dry-stored for long in the non-dormant condition. However from the viewpoint of understanding seed dormancy the result is fascinating and totally unexpected. Dormant Sitka spruce seeds at this moisture content (6–8%) are not sufficiently hydrated to lose dormancy (i.e. become non-dormant), yet under the same storage conditions, prechilled then redried (non-dormant) Sitka spruce seeds revert to the dormant state. This phenomenon of reimposition of conditional dormancy has not been recorded in Sitka spruce seeds before, nor has it been so clearly demonstrated for any other conifer seeds. The results for the above Sitka spruce seedlot have been repeated and are reproducible in other Sitka spruce seedlots (Jones, unpublished). Although the mechanism of this dormancy reimposition has not been studied, further work investigating the biochemistry and molecular biology of the changes in dormancy of prechilled and redried seeds would be worthwhile.

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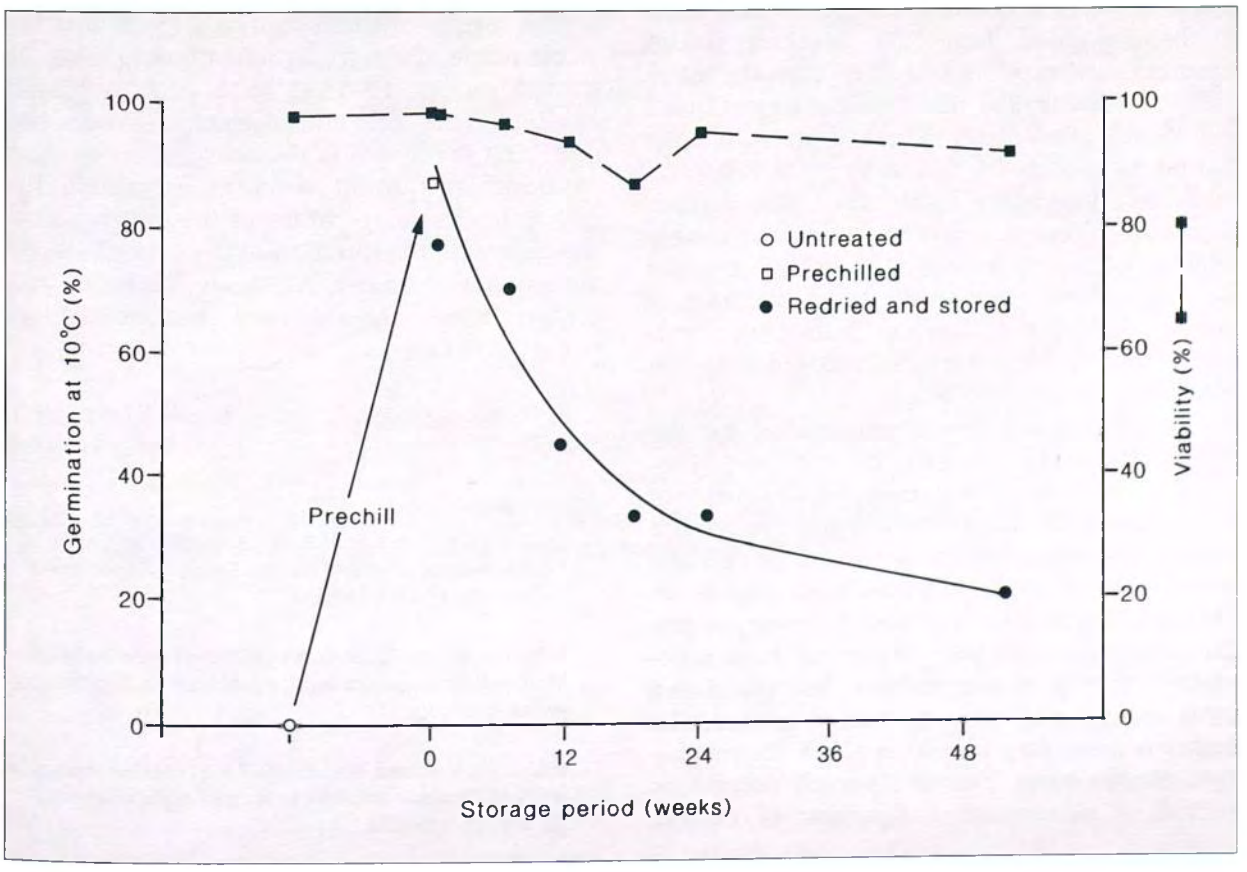

Figure 12. The change in the ability of Sitka spruce seeds to germinate at 10°C after prechilling, redrying and storage for up to 52 weeks. Seed viability is also shown.

THE EFFECT OF STRATIFICATION MEDIUM AND TEMPERATURE ON THE GROWTH OF ASH (*FRAXINUS EXCELSIOR* L.) EMBRYOS DURING THE WARM PHASE OF PREGERMINATION TREATMENT

Ripe ash fruits are deeply dormant and need extensive pregermination treatment (pretreatment) before the seeds are able to germinate. However recommended pretreatment schedules are not always reliable. Three mechanisms are apparently involved in ash dormancy: incomplete elongation of the embryo at harvest or dispersal; inhibition by the pericarp tissues; and embryo dormancy (Suszka *et al.*, 1994). The best available pretreatment is a two-stage process consisting of a warm phase lasting between 6 and 16 weeks, followed by a cold phase of 12 to 16 weeks. The warm phase is necessary to allow the embryos to reach full size. The subsequent chilling temperature breaks physiological dormancy. Two methods are currently recommended for pretreating ash fruits. In the traditional method, fruits are mixed with a moist stratification medium, usually peat and sand, and the mix is then stored at the appropriate temperatures for pretreatment. The medium helps to maintain a high fruit moisture content during the lengthy pretreatment; however it is bulky, and seeds may have to be separated from the medium before machine sowing. More recently, pretreatment of fruits at a controlled moisture content without any stratification medium (naked pretreatment), has been recommended (Suszka *et al.*, 1994). As well as dispensing with the stratification medium, naked pretreatment allows greater control of the dormancy breakage process because the fruit moisture content can be precisely controlled to prevent premature germination of the least dormant seeds during the final stages of the cold phase.

Typical temperatures recommended for the warm phase are between 20 and 25°C (e.g. Gordon and Rowe, 1982). However the effects of incubation temperature on ash embryo growth have not been studied in detail and, as part of a wider investigation of ash seed dormancy for an EU funded project on tree seed dormancy, a preliminary experiment was carried out to measure embryo growth at temperatures between 5 and 25°C, using the naked pretreatment method. The embryos grew very slowly at all of the incubation temperatures over a 24-week incubation period. A subsequent comparison of embryo growth in fruits pretreated either naked or in a peat and sand medium showed that the medium was essential for embryo elongation (Figure 13). Embryos incubated at 15°C in peat and sand nearly doubled in length from 6.8 mm to 12.3 mm over 20 weeks, while the naked pretreated embryos only grew by 2.0 mm over the same period. The pericarp remained more or less intact throughout naked pretreatment, whereas considerable degradation occurred in fruits mixed with peat and sand. Other studies have shown that the pericarp inhibits embryo growth (Villiers and Wareing, 1964).

The measurement of embryo growth at different temperatures was repeated using fruits mixed with peat and sand and incubated at 5, 10, 15, 20 and 25°C. Embryo length was measured at four-weekly intervals for 20 weeks. Embryos from fruits incubated at 5°C did not elongate at all over the 20 week pretreatment period (Figure 14). However at 10°C embryo length increased by nearly 60% from 7.7 mm at harvest to 12.4 mm. Fastest embryo growth occurred at 15°C with embryos reaching just over 13 mm by 20 weeks. At 20°C embryo length was not significantly different from 15°C at 4 and 8 weeks, but thereafter embryo growth at 20°C was lower than at 15°C, resulting in embryos which were about 10% shorter at 20 weeks. Little increase in embryo length occurred at 25°C.

The results of these studies suggest that the warm phase of ash fruit pretreatment should be carried out at 10–15°C in a peat and sand medium. This maximised embryo growth rate and kept the length of the warm phase as short as possible. Current work is examining the effects of the temperature of the warm phase, together with the duration of the cold phase, on subsequent germination. Much improved recommendations for ash seed pretreatment are expected to emerge.

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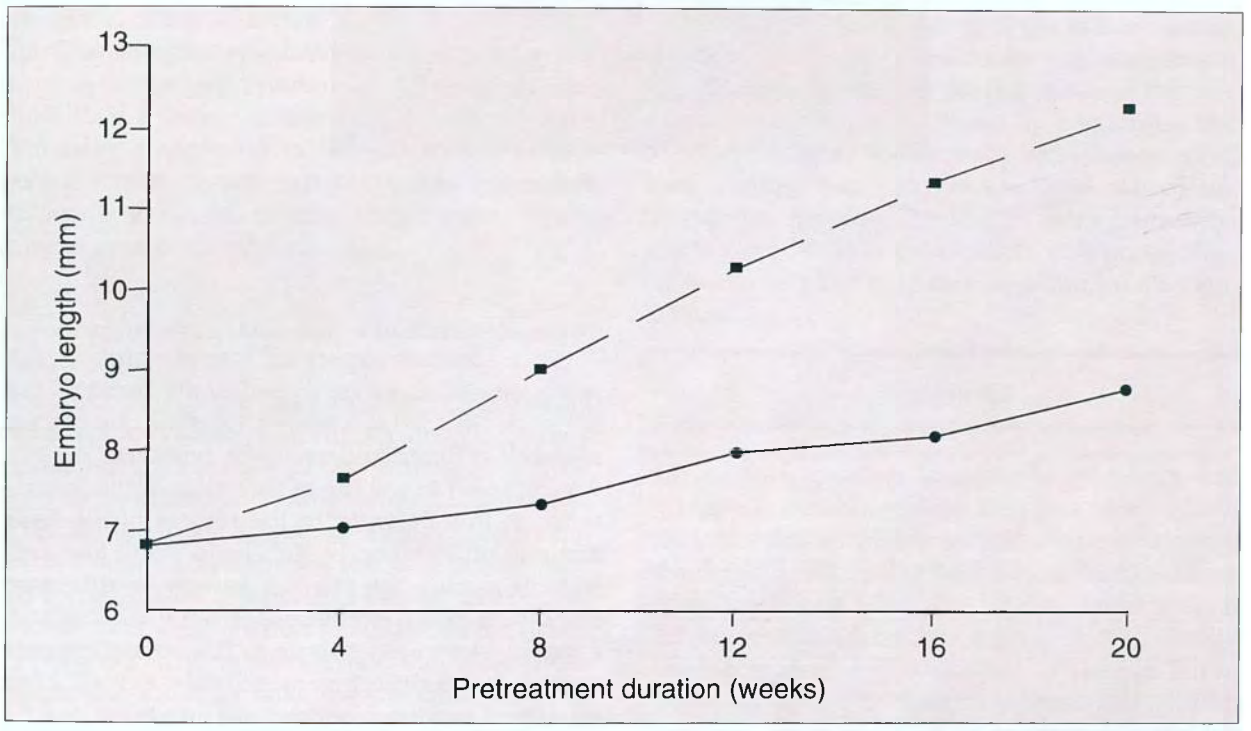

Figure 13. The effects on embryo growth of pretreating ash fruits in peat and sand (■) or naked (●) during the warm phase (15°C). Average seed length was 14.8 mm.

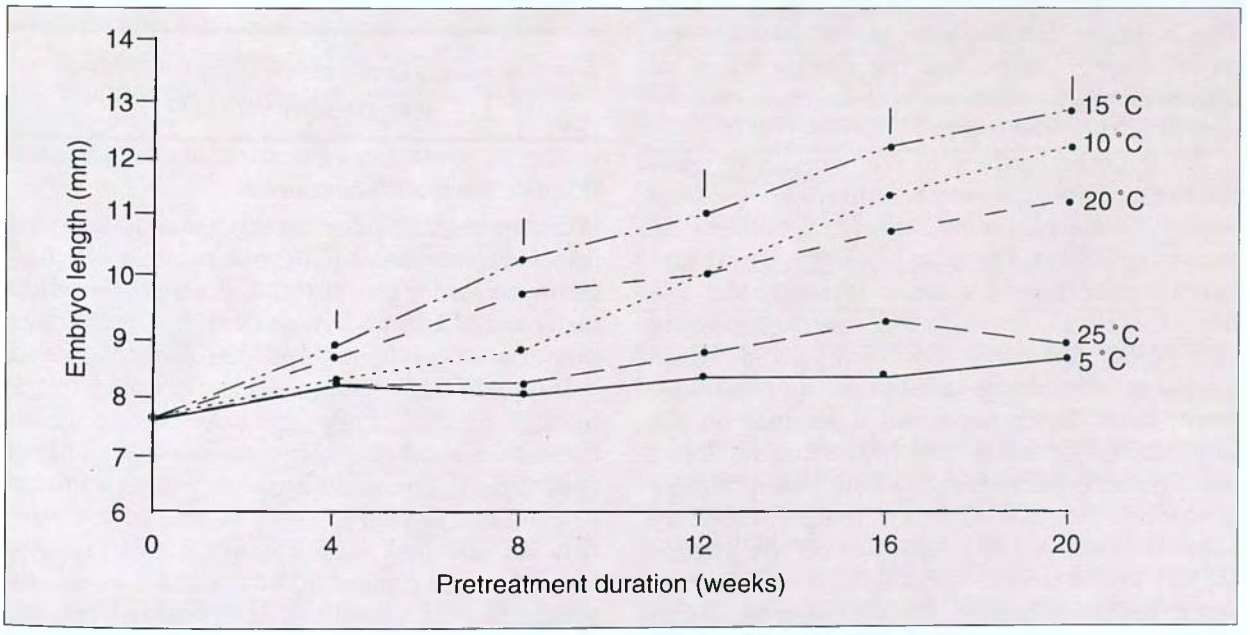

Figure 14. The growth of ash embryos in fruits incubated in peat and sand at different temperatures during the warm phase. SEDs are shown as vertical bars. Average seed length was 15.3 mm.

SILVICULTURE NORTH

Overview

Our silvicultural research seeks to sustain the productivity and profitability of forests in northern and western Britain while enhancing their social and environmental value. The programme is structured around six main topics, namely: planting-stock quality and establishment; nutritional aspects of sustainability; farm and community woodlands; damage to forests by wind; natural regeneration and silvicultural systems; and silviculture of native woodlands. It is pleasing to report progress in all of these areas and some examples are given in the reports below. The expertise that has been gained has allowed us to attract outside funding from a range of organisations for research both in the core subjects and in related topics.

An important aspect of our work is to communicate current research findings in a useful form to foresters, policy makers and other customers in Britain. For example, Chris Quine and Barry Gardiner held a series of successful one day workshops to update Forestry Authority and Forest Enterprise field staff on developments in windthrow prediction and management; Janet Dutch organised a seminar on the implications of whole-tree harvesting for forest management; John Morgan and Helen McKay developed a Plant Quality Testing Advisory Service which advises managers on the physiological and morphological quality of planting stock and its suitability for use under particular establishment conditions; James Simpson organised a meeting for the Timber Growers' Association entitled *Establishment of small woodlands in northern Britain;* Chris Nixon arranged the annual meeting of the Native Woodlands Discussion Group in the Cairngorms; while Mike Riley gave several talks to groups concerned with land reclamation to forestry in northern Britain. The increasing demand for such targeted seminars and meetings is a welcome recognition of the appropriateness of our research efforts to the needs of our customers.

An important aspect of our research is the ready access to forest experiments through the network of field stations staffed by forest research officers and research workers. We are very pleased to see the recognition of the importance of this network in the review of the field stations undertaken by Dr David Rook and colleagues during the year. A review of this type engenders considerable uncertainty in staff and I would like to pay tribute to the outstation personnel for continuing to provide a very high quality of service despite these pressures.

BILL MASON

Use of geographic information systems in windthrow studies

Windthrow monitoring areas

We have been developing the use of geographic information systems (GIS) in a number of windthrow-related topics through the use of a cell or raster-based GIS known as IDRISI. GIS are computer-based systems that can store, analyse, manipulate and display data referenced to the Earth's surface. They are powerful tools for those who need to manipulate large amounts of spatial data. The windthrow monitoring project (Quine and Reynard, 1990) is one such area – data on site and crop characteristics are captured through ground survey and the onset and progression of windthrow is monitored through aerial photography. Such data are stored and can be combined within the GIS to explore relationships between variables or simply to summarise data. Figure 15 gives an example of a map of windthrown pockets in a monitoring area in Kielder. The map was produced by the GIS following interpretation of vertical aerial photos on to an acetate 1:10 000 compartment map and digitising of the outlines of the pockets. Subsequent analysis of the mapped information is far simpler than by manual methods. For example, Table 8 summarises the gap size frequency and compactness ratios of these gaps

produced using standard modules within the GIS. The compactness ratio is the square root of the area of the gap divided by the area of a circle with the same perimeter and declines with increasing complexity of the gap shape. In this example the lower ratios (more complex shapes) are found in the larger gaps, while smaller gaps tend to be circular.

Topographic variables and windthrow hazard class

The GIS has also proved valuable in calculating topographic variables from Ordnance Survey digital terrain models (DTM) rather than from field measurements. We developed software to calculate the topex sector values required by the revised scoring system for the windthrow hazard classification (Quine and White, 1993). The programmes were created to study the impact of the revised scoring system in the windthrow monitoring areas by enabling the calculation of windthrow hazard class distribution under the original and revised scoring systems (Quine and Wright, 1993). We have subsequently used these programmes to calculate the windiness scores for the whole of upland Britain (Bell *et al.*, in press). Combination of windiness scores with database soils codes has been used to update the windthrow hazard classes in the Forest Enterprise sub compartment database.

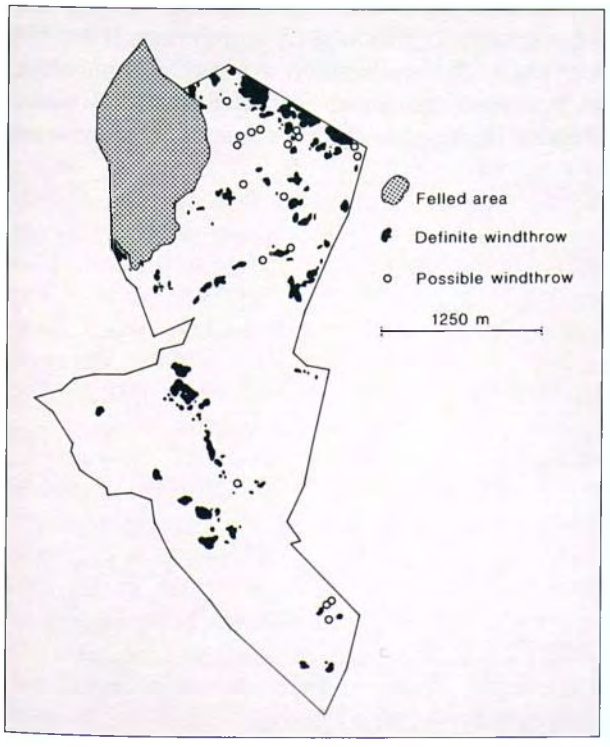

Figure 15. The distribution of windthrow pockets in Bellingburn windthrow monitoring area, Kielder Forest District, identified from aerial photographs taken in 1994.

An example of the power of the system is that we have been able to calculate the windthrow hazard class distribution for the whole of the private woodland area in Wales by combining the digital windiness scores with soils information used during the last census, and woodland boundaries provided by the Forestry Authority grants records. This information will prove useful in running the next private sector production forecast.

Table 8. Summary statistics on the windthrow pockets in Bellingburn windthrow monitoring area from Figure 17

a. Windthrow pocket size distribution (definite windthrow only)

Pocket size (ha)	*No. of gaps*	*Total area (ha)*
0.00–0.01	34	0.34
0.01–0.03	39	0.93
0.03–0.07	12	0.57
0.07–0.15	20	2.04
0.15–0.31	15	3.39
0.31–0.63	10	4.14
0.63–1.25	8	7.11
1.25–2.50	1	1.57
2.50–5.00	1	3.06

b. Windthrow pocket compactness ratio distribution

Compactness ratio	*Frequency*
0.15–0.40	8
0.40–0.60	32
0.60–0.75	28
0.75–0.85	34
0.85–0.90	38

In addition to these applications we have been investigating the use of alternative topographic indices. Hannah and Quine (1993) identified the potential of topex to distance (1–3 km) and of negative values for topex. These indices should permit the isolation of local exposure/shelter effects and distinguish, for example, a hilltop from a plain – at present both would score zero under the topex conventions. The method used to calculate these indices was to perform the trigonometric calculations on elevation values read from 1:50 000 contour maps; while this was practical for the small number of anemometer sites used it was not appropriate for larger datasets. We have now modified the standard topex programmes used in the calculation of windiness scores so that varying distance threshold can be investigated, and negative topex values used. We have investigated topex to distance for a range of distance thresholds for the 1100

flags used by Quine and White (1993) and preliminary results indicate that topex to 1 km is an improvement over standard topex.

CHRIS QUINE, PATRICK BELL AND ANGUS MACKIE

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DAMAGING GUSTS OVER FORESTS

Allen first pointed out in 1968 that wind flow over and within forest canopies is dominated by large scale intermittent gusts, but his observations were largely ignored and forest meteorologists continued to treat canopy flow as a statistical process governed by local gradients. However, evidence has accumulated to show that transport within canopies is driven by gusts of the scale of canopy height which override local gradients and which move heat, moisture and CO_2 in short intermittent bursts (Denmead and Bradley, 1985). Although the traditional statistical approach works well for averaged processes of the order of an hour, it cannot deal with processes on the short time scale of gust passage.

To date the most complete work on the nature of these gusts over forests has been carried out by Shaw and co-workers at Camp Borden, Ontario (Shaw *et al.,* 1989). They have shown that the gusts are characterised by a downward burst of fast moving air which is also cold, dry and CO_2 rich. The implications for the physiological response of plants are just beginning to be worked out but already it has been shown that transpiration flux responds directly and immediately to the passage of gusts across the canopy top (Hollinger *et al.,* 1994). Treating atmosphere–plant–soil processes as a continuum will not be appropriate; rather, plants will be adapted to this intermittence in atmospheric conditions.

For British foresters the most important aspect of these gusts is the damage caused to forests when the wind speed becomes too high. Stem breakage occurs when the wind-imposed stresses on the tree stem are greater than the wood can sustain: windthrow occurs when the overturning moment due to the wind is greater than the maximum resistive moment provided by the roots. The movement of trees in the forest is closely linked to the passage of gusts across the canopy (Gardiner, 1995) and the maximum loading during a gust is approximately eight times the mean loading on a tree during a storm (Gardiner *et al.,* in preparation). Recent theoretical calculations (Figure 16) suggest that, on average, spruce trees

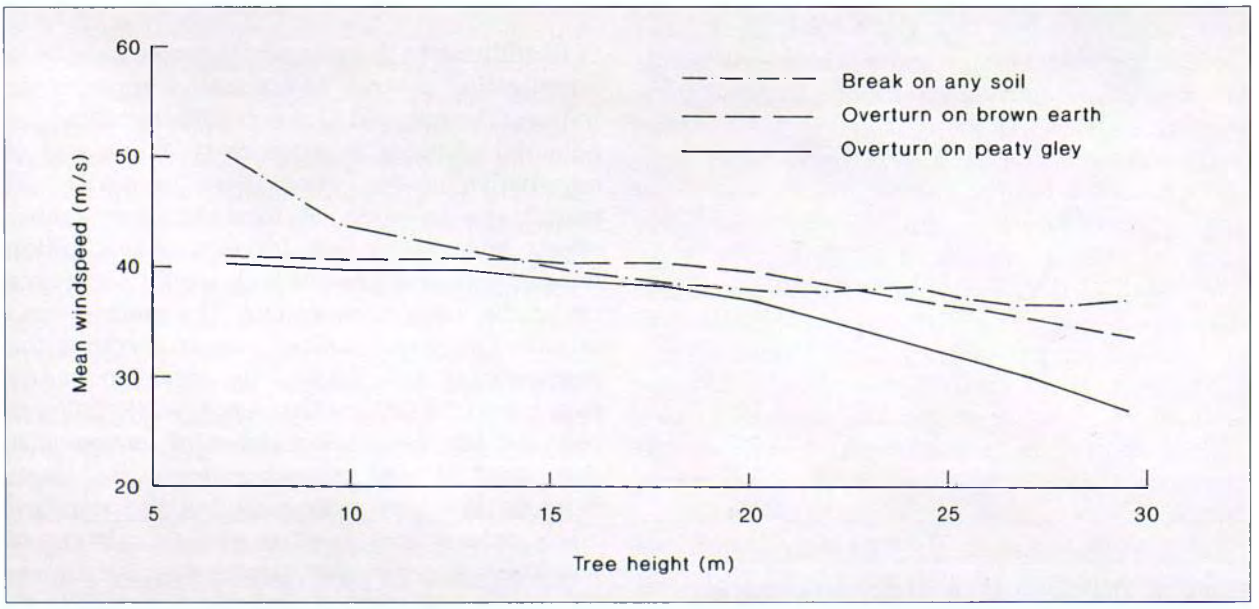

Figure 16. Predicted mean wind speed required to break or overturn Yield Class 14 Sitka spruce on peaty gley or brown earth soils as a function of tree height. Wind speeds are calculated at 10 metres above the canopy.

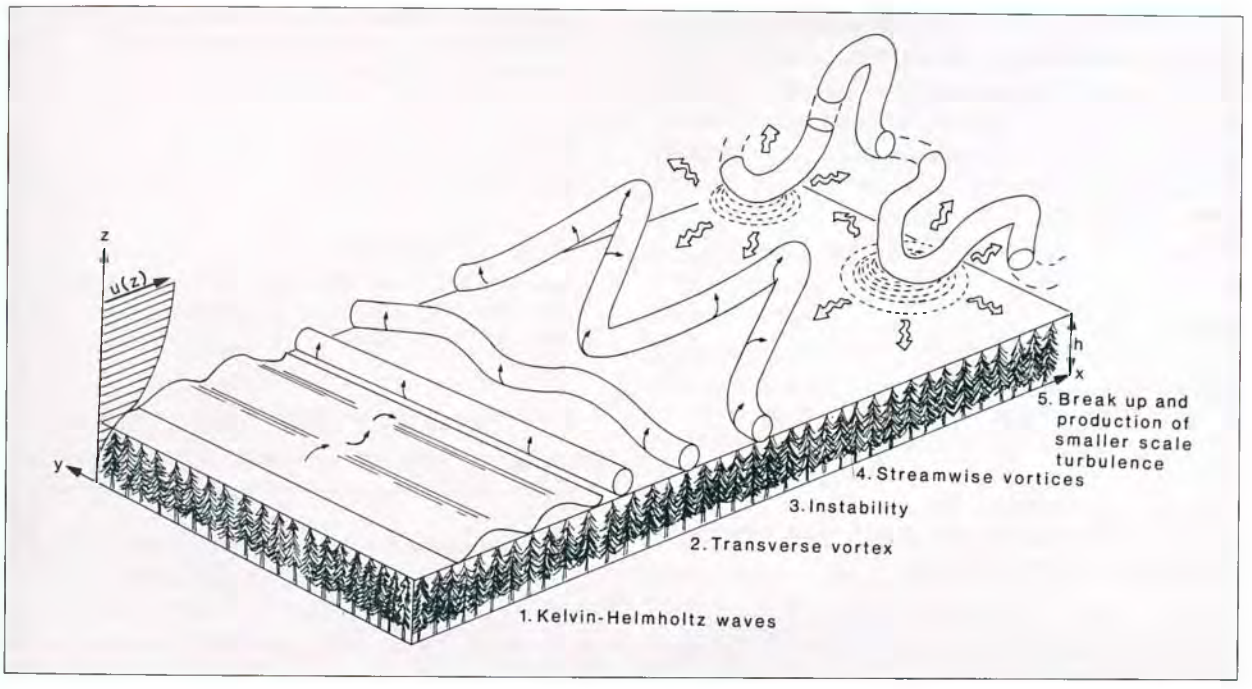

Figure 17. Schematic representation of the formation of damaging gusts over forests (after Finnigan and Brunet, 1995).

will fail when the mean wind speed at 10 metres above the canopy is between 30 and 40 metres per second (60–80 knots). The calculations account for the relationship between mean wind speed at 10 metres above the canopy and the extreme gusts which actually cause the damage. The critical wind speed for overturning is a function of soil type and appears to decrease slowly with increasing tree height. For brown earths, which allow better root development than gley soils, the risk of damage from breakage or overturning appears to be equal for trees over 15 metres in height and this indicates that the tree design is optimised for resisting wind damage. However, these calculations are preliminary and will require thorough verification against data obtained from the Forestry Commission's eight windthrow monitoring areas (Quine and Reynard, 1990).

What do these damaging gusts look like and can they be influenced by the way we manage our forests? The work reported by Shaw *et al.* (1989) and Gardiner (1994 and 1995) has given some indication of the structure of the gusts. They cover a small area (a few tree heights long and a tree height across) and are sloped vertically along the mean wind direction. However, we must turn to the wind tunnel to obtain a better three dimensional picture. Finnigan and Brunet (1995) have provided the most complete description based on extensive wind tunnel measurements over a simulated wheat canopy and comparison with mixed layer flows studied in the laboratory. Their conceptual picture of the formation of damaging gusts is reproduced in a simplified form in Figure 17. The inflexion in the wind speed profile at canopy top is dynamically unstable and the air immediately begins to distort into Kelvin-Helmholtz waves (1). These in turn roll up into bands of concentrated vorticity across the mean wind direction (2) and then begin to distort themselves (3) until there are a series of hairpin vortices aligned with the mean wind (4). These vortices or gusts are able to travel for substantial distances across the forest canopy (hundreds of metres) and because they are a similar size to the trees are particularly effective in moving trees about. Eventually the vortices become so distorted that they disintegrate in a burst of small scale turbulence (5).

In mixed layer flows, the scale and intensity of the gusts is set by the distance over which there is shear (a change of fluid velocity along a particular direction). In the even-aged dense forests typical of most British upland plantations the change in wind speed is very severe and concentrated at canopy top (Gardiner, 1994). In forests with a greater spread of tree heights the shear will be less severe because the wind speed will decrease more gradually into the canopy. Will the gustiness of the wind over such forests be reduced and lead to reduced extremes in wind loading on the trees? Irvine (1994) has shown that canopy structure modifies the periodicity of gusts and data from the wind tunnel suggest that at wider spacings, where the shear is also weaker, the ratio between the maximum and

mean wind loading on trees is reduced (Gardiner *et al.*, in preparation). To test these ideas a series of wind tunnel experiments, using model forests that vary from uniform to an irregular structure, are planned next year with funding provided by the Scottish Forestry Trust.

BARRY GARDINER

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THE STRUCTURE OF SEMI-NATURAL OAKWOODS

Previous work on the age structure of the native pinewoods of Scotland has highlighted the large range of tree ages present in many woods, even in remnant stands dominated by trees of similar size (Nixon *et al.*, 1994). A project to describe the structure of two areas of semi-natural oak woodland in north-west Scotland was carried out during the summer of 1994 in order to widen the scope of the earlier studies. The project was carried out by Josep Maria Espelta from the Autonomous University of Barcelona in Catalonia, Spain and funded by the British Council. Approval to study the Letterewe woodlands was kindly granted by the owner Mr van Vlissingen and valuable assistance was provided by local staff of Scottish Natural Heritage.

Both the woodlands surveyed lie on the shores of Loch Maree in Wester Ross. At each site the number, size and age of all the trees within a 50 x 50 m plot were assessed within fenced exclosures which were erected in the early 1960s to promote natural regeneration.

Table 9. Information on the oak component of the Letterewe and Talladale woodlands

Overstorey	*Letterewe*	*Talladale*
Trees per ha (all spp.)	272	216
% oak in overstorey	100%	80%
Mean age (years)	162	149
Age range (years)	111–245	105–229
Mean height (m)	21.7	19.9
Mean diameter (cm)	45.1	51.7
Mean annual diameter growth (mm)	1.15	1.47
Natural regeneration		
Sapling density per ha (height > 1.3 m but < 7 cm dbh)	250	nil
Seedling density per ha (height < 1.3 m)	1000	5937

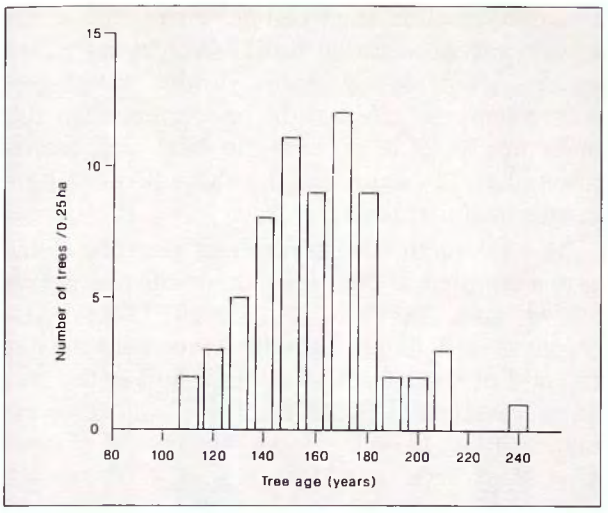

Figure 18. Age distribution of trees at Letterewe.

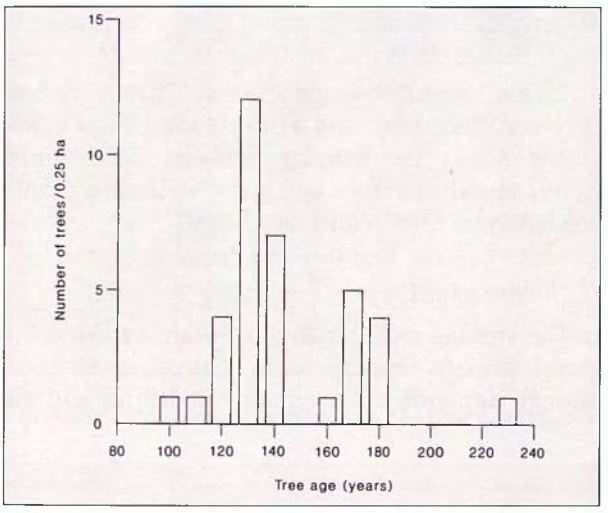

Figure 19. Age distribution of trees at Talladale.

The results show interesting differences in the structure of the two woodlands. At Letterewe, on the north-east shore of the Loch, the overstorey was completely dominated by oak with a mean age of 165 years (Table 9). A significant characteristic of this woodland was the fact that within the tree age range present (111–245 years), trees in almost every 20 year age class were represented (Figure 18). This contrasted with the situation at Talladale, a more accessible woodland to the south-west of the Loch, where despite a similar range of tree ages being present (105–229), the age structure was found to be much less diverse (Figure 19). The woodland at Talladale was more open, probably as a result of greater numbers of trees having been removed by felling. As a result of the gaps in the cover of mature oaks, other species such as birch and rowan occupied around 20% of the canopy.

The greater variation in the ages of trees present in the more remote woodland at Letterewe reflects the pattern seen in comparative studies in the native pinewoods. The results suggest that, in the absence of catastrophic damage, less disturbed native woodlands (e.g. Letterewe) are characterised by the presence of wider variation in tree age as a result of continual replacement by natural regeneration. This continuous dynamic replacement of trees is illustrated by the presence of sapling sized regeneration at Letterewe and its absence from Talladale. Under stable environmental conditions the spatial variation of tree age throughout the woodlands also tends to be smaller scale. The greater stability of the Letterewe woodland is also demonstrated by the stronger relationship between the diameter and age of the trees in the stand (Diam = 44.35 + 0.546 x Age, R^2 = 0.64) as compared with the more open, and disturbed conditions at Talladale (Diam = 7.55 + 0.398 x Age, R^2 = 0.36).

The results show that the variation and spatial distribution of tree ages within undisturbed native woodland are different from those found in managed or disturbed woods. In some cases these differences may be imperceptible in terms of the physical woodland structure and size distribution of trees. Further studies of this nature will enable more accurate structural guidelines for native woodland creation and management to be developed.

CHRIS NIXON, JOSEP MARIA ESPELTA, PAUL ARKLE, COLIN EDWARDS AND PETER CAIRNS

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PLANT TYPES, STORAGE AND ESTABLISHMENT OF BIRCH

Recent years have seen a rapid increase in the areas of birch planted in upland Britain. Birch accounts for 12% of all planting under Woodland Grant Scheme in Scotland (2600 ha). Unfortunately, birch has earned a reputation as a species which is difficult to establish (Brodie, 1991). We have been investigating aspects of birch establishment since 1990. There are now some dozen experiments to investigate planting stock types, storage of stock and establishment including fertilisation on restock sites. Results from these studies provide us with a better understanding of how to achieve good establishment of birch.

Lifting and planting dates and cold storage

Lifting dates and cold storage of birches have not been systematically studied in this country. Cold storage is common practice in Finland where prescriptions are the same for both *Betula pendula* and *B. pubescens* (Raulo, 1987).

We compared different treatments using a range of silver birch (*B. pendula*) plant types from Scottish seed origins. Plants were either lifted and cold stored in co-extruded bags or lifted and planted immediately (fresh lifted). All our experiments have used direct cold stores operating at +1° to 2°C.

Physiological condition of plants for the Gwent experiment (Table 10) was measured before and after storage using root electrolyte leakage tests (McKay, 1991). Highest leakage values in fresh-lifted plants occurred in May, and, to a lesser extent, in November (Figure 20). Lowest values occurred from December–March with no differences between these months. Bare-root transplants tended to have higher leakage values than cell-grown stock but results were generally not significant.

There was no deterioration in physiological quality of plants cold stored between November and March so data have not been presented. Both plant types suffered some deterioration when stored until May, particularly when lifted in February and March (Figure 20). Bare-root plants lifted in December and January suffered less deterioration than cell-grown plants, when both types were stored until May. As container plants were overwintered under polythene where temperatures would be warmer than the open nursery, it is possible that cell-grown plants had not achieved the same level of dormancy as transplants.

The interaction with different planting dates was examined at two restocking sites in South Wales and one site in Moray (Table 11). Survival and height growth were measured at the end of one season at all sites and at the end of two seasons at two sites. There was no detrimental effect of cold storage on survival of trees after short-term cold storage. Long-term storage was only detrimental when some treatments were planted in June.

Height growth was unaffected by short-term cold storage. Although long-term storage was slightly detrimental to growth after June planting, this has little practical significance.

These results suggest that birch lifted between December and mid-March can be cold-stored safely for lengthy periods. Cold-stored plants should survive and grow well after planting between March and late May.

Different plant types

In the storage experiments all plant types withstood storage equally well. Tolerance to cold storage depends on dormancy at lifting and all

Table 10. Details of the experimental sites

Experimental site	*Elevation, rainfall and exposure*	*Soil type and geology*	*Site history*	*Site preparation*
Brecon 44 P93	330 m 1250 mm moderate	Upland brown earth and Devonian old red sandstone	Restocking Norway spruce/Scots pine	Scarified and fenced
Brecon 50 P94	190 m 1200 mm moderate	Upland brown earth and Devonian old red sandstone	New planting ex-unimproved grassland	Screef/direct plant/cut turves and fenced
Gwent 11 P94	475 m 1200 mm moderate	Upland brown earth and Devonian old red sandstone	Restocking Sitka spruce/Japanese larch	Scarified and fenced
Moray 42 P94	190 m 825 mm exposed	Podzolic ironpan overlaying old red sandstone	Restocking Scots pine	Scarified and fenced
North York Moors 69 P92	220 m 800 mm moderate	Upland brown earth over passage bed	New planting ex-hill grazing	Agricultural plough/ uncultivated
North York Moors 70 P92	60 m 650 mm moderate	Surface water gley over soft limestone	New planting ex-improved grassland	Agricultural plough/ uncultivated
Cowal 9 P92	76 m 1300 mm moderate	Upland brown earth over mica schist	New planting ex-hill grazing	Mounded and fenced

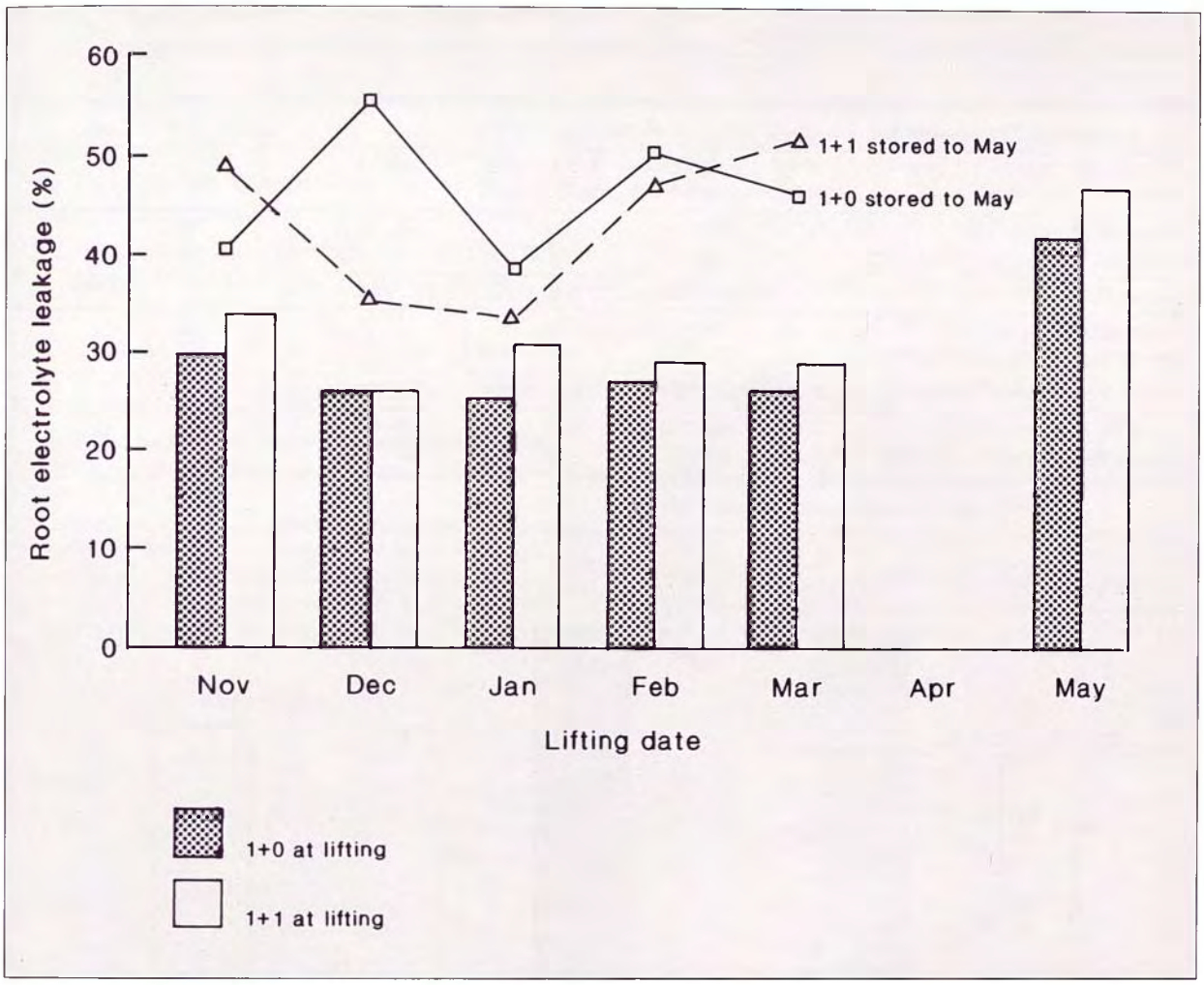

Figure 20. Root leakage of bare-root (1+1) and cell-grown (1+0) birch; condition at lifting or after cold storage until May.

plant types will be most dormant between December and January (Figure 21). Hardiness of cell-grown stock is improved if plants are moved outdoors towards the end of the growing season.

Size of planting stock varies according to the age and type of plant. Bare-root one-year-old seedlings and cell-grown stock grow well on sites which are cultivated and weed free (e.g. Morgan, 1994). Two-year-old stock is taller and plants have larger root collar diameters. Root systems must be well developed in proportion to shoots for plants to grow well.

These experiments confirm general conclusions by Kerr and Jinks (1995); bare-root and cell-grown broadleaves which are of good quality survive and grow equally well following cold-storage in spring.

Protection

On many sites, early growth and survival of birch is improved by planting in treeshelters (Nixon, 1994). We have collaborated with staff of the Brecon Beacons National Park to compare establishment techniques on a fenced, unimproved grassland site in South Wales (Table 11). Survival and growth was better in shelters and guards, which prevented moisture loss during dry conditions after planting, compared with unguarded controls (Table 11). In contrast, there was very little improvement in growth and survival when quills and shelters were used at two very different fenced sites in Yorkshire (Table 11).

Weeding and cultivation

Growth of birch benefits from weed control using mulch mats or herbicides (Tracy and Nelson, 1991). Both survival and growth are influenced by the method of cultivation carried our prior to planting. Ground preparation replaces the need for weeding on some sites whereas the wrong choice of cultivation is detrimental on others.

Birch is particularly sensitive to damage from contact herbicides such as glyphosate. Weeding must follow recommended guidelines for herbicides used as directed applications (Willoughby and Dewar, 1995).

Survival of a range of plant types was as high without weeding as with weeding on mounds at

Table 11. Survival and height growth of birch with or without guards in three experiments (means across different cultivation treatments)

Experiment and assessment	*Protection treatment*			*LSD @ P < 0.05*
Brecon 50 P94	*1.2 & 0.6 m shelters*	*1.2 & 0.6 m clear guards*	*Control*	
Survival at 1 year (%)	74	67	56	10.0
1st year height increment (cm)	18.1	13.3	5.4	6.7
North York Moors 69 P92	*0.6 m shelters*	*0.6 m quills*	*Control*	
Survival at 3 years (%)	98	94	91	ns
3 year height increment (cm)	131	113	127	ns
North York Moors 76 P92	*0.6 m shelters*	*0.6 m quills*	*Control*	
Survival at 3 years (%)	98	100	100	ns
3 year height increment (cm)	67	82	60	13

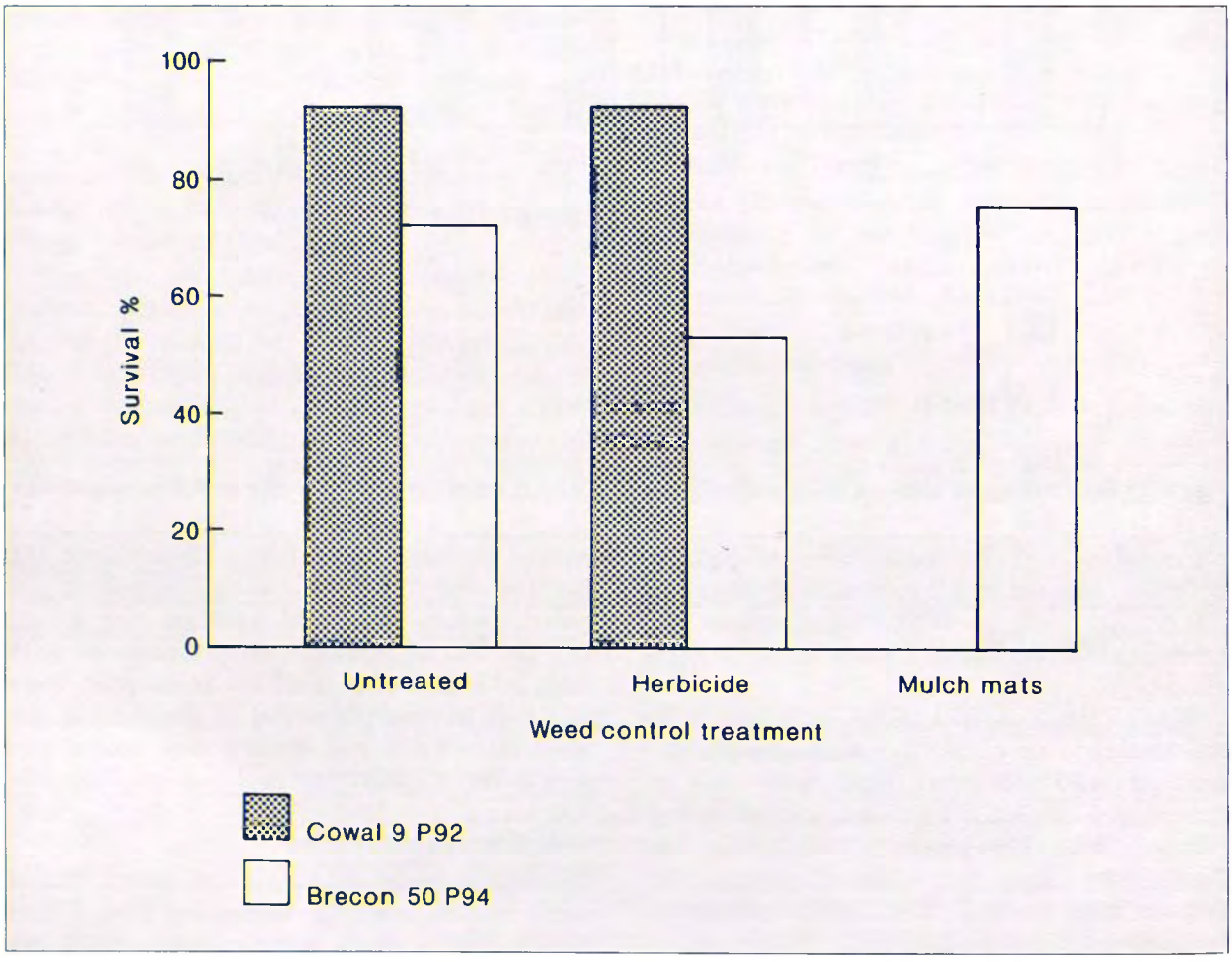

Figure 21. First year survival of birch with weeding.

a new planting site in Cowal (Figure 21). In the Brecon Beacons experiment chemical weeding was actually detrimental to survival compared with mulch mats or no weed control (Figure 21). Trees which were directly planted and planted in screefs survived drought better than those on cut turves.

We have no evidence to support recommendations for specific plant sizes relative to vegetation height, as described by Brodie (1991). The most important attributes should be that plants have well balanced root:shoot ratios and must be in good physiological condition.

Conclusions

It has been claimed that birch is a difficult species to establish, but a high level of success

is achievable, by following the steps set out below.

- Cultivate sites to improve soil conditions and avoid weed competition.
- Plant trees with high root:shoot ratios and low root electrolyte leakage into weed-free planting positions between February and June.
- Use herbicides to control vegetation only when it competes for moisture, nutrients or light.

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SILVICULTURE SOUTH

Overview

Silviculture of broadleaves

Our native ash, *Fraxinus excelsior,* is second only to oak in frequency of planting under the Woodland Grant Scheme. Because of its increasing importance, a review of the silviculture of ash in southern England has been published in *Forestry* (Kerr, 1995) and an experimental programme launched to improve our advice on establishment techniques, use in mixtures, nutrition and thinning.

The Royal Forestry Society's James Cup was awarded for an article on beech in treeshelters, published in the *Quarterly Journal of Forestry* (Kerr and Evans, 1994). Gary Kerr presented a paper on *The silviculture of beech in the UK,* at the IUFRO symposium held in Denmark in September 1994.

Work funded by the Department of the Environment on broadleaved planting-stock quality and the effect of cold storage was published as two arboriculture research notes (Kerr and Harper, 1994; Kerr and Jinks, 1995), and an article in *Forestry* (Kerr, 1994).

National Forest

The planting of three woodland areas totalling 34 ha in the National Forest (*Report on forest research, 1994*) has been successfully completed, incorporating a wide range of ideas and investigations on farm and community woodland establishment. Themes included are natural colonisation, direct seeding, native and exotic tree species, poplar spacing, energy coppice, spacing of oak and ash, new native woodlands, ground preparation, and nursing mixtures. The three areas will provide a valuable resource for the new National Forest Team to encourage the establishment of appropriate new woodlands, while producing valuable research results.

Farm woodlands

A new series of farm woodland trials has been laid down to incorporate tree species which might take advantage of fertile lowland sites. The trials include species which produce specialist high value timber readily marketable in small quantities, for example pear (*Pyrus communis*) and laburnum (*L. anagyroides*).

Monitoring of the success of direct seeding using a cover-crop has continued at Ledbury and Cirencester, and two new trials have been laid down within the National Forest demonstration areas at Church Gresley and Desford. Early results are encouraging, but reliable methods of weed control have yet to be defined, and browsing by mammals may necessitate expensive fencing.

Weed control

Improved recommendations for control of *Deschampsia flexuosa* will result from the final analysis of a trial of contact herbicides at Thetford Forest in Norfolk. A full list of herbicide products approved for use in forestry is available in Research Information Note 246 (Edwards, *et al.,* 1994).

The possibility of sowing less competitive vegetation between farm woodland trees as an alternative to the repeated use of herbicides is being investigated in a new trial at Radcot Farm in Oxfordshire, in association with Willmot Pertwee Ltd.

Herbicide evaluation

Further experiments to assess the safety and efficacy of herbicides for forest weed problems were carried out, under contract, on container-grown plants at Long Ashton Research Station, Bristol.

Selective herbicides are needed to control weeds in newly planted farm woodland. The tolerance of six broadleaved and two coniferous species to five foliar-acting herbicides applied at leaf flush either in spring or in August was evaluated. Pyridate at both dates showed promising selectivity on all species.

In an investigation of the susceptibility of six annual weed species to residual herbicides used in forest nurseries, lenacil, metamitron, metazachlor and napropamide were generally more effective than chlorthal-dimethyl and diphenamid. Such work will enable better

selection of herbicides where particular weed species are a problem.

Further work was done to evaluate herbicides for the control of heather (*Calluna vulgaris*) in nurseries. Seven herbicides gave complete control when applied pre-emergence but only cyanazine and oxadiazon were effective on heather seedlings.

Imazapyr was found to be effective as a pre-planting herbicide for the control of woody weeds, including *Rhododendron ponticum*. There was a need to confirm that residues of imazapyr in woody debris do not persist and damage newly planted tree species. Three woody species (bramble, birch, and *R. ponticum*) were sprayed with imazapyr in August and the dead material incorporated into the soil before planting ash and spruce in spring. No damage to the tree species was observed during the following growing season.

Two papers on tree tolerance to herbicides were published (Lawrie and Clay, 1994a and 1994b).

Poplar

The potential for exploitation of the new Belgian poplar clones prompted a second conference hosted by the Royal Agricultural Society of England at Stoneleigh Park, on 24 October 1994. Early results from the field trials were published in the proceedings (Tabbush, 1994). Four new trials have been laid down as part of a European Union contract, and these include 12 new Italian and three new Dutch clones along with the most important of the new Belgian clones. Under the contract, a database has been constructed with details of over 100 poplar experiments in France, Belgium, Luxembourg and the UK, to include soil, climate and growth data. This is being used to give an insight into the site preferences of the clones, and the factors which most influence yield. A second EU contract was begun (Poplar for farmers) coordinated by the School of Agricultural and Forest Sciences, University of Wales, Bangor, and this will exploit the poplar database as a basis for economic models.

SURVEY OF NATURAL REGENERATION

Natural regeneration describes the establishment of trees and woodlands from seeds produced and germinated *in situ*. It covers both restocking of existing woodland and the extension of woodlands onto previously unwooded areas. Use of natural regeneration has never been widespread in British forestry but it now attracts grant aid under the Woodland Grant Scheme (WGS) and has become an increasingly popular method of restocking. It is thought to be more desirable than planting because it can conserve local genotypes, create more diverse woodlands and produce a wide choice of stems for selection. However, it can be unpredictable, and sometimes difficult and expensive to achieve; much British experience of natural regeneration is based on information from the continent that can be inappropriate under domestic conditions. The survey was carried out to quantify the success or failure of broadleaved natural regeneration in terms of site, parent crop and management practice.

The sites surveyed were distributed throughout the south of England and had management plans for natural regeneration approved under the WGS. Sites selected were all greater than 0.5 ha and only included those in which ash, beech, birch, oak, sycamore and mixed broadleaves were named as regenerating species. Each site was visited once between July and September in either 1993 or 1994. A brief general survey of the site was made including soils, aspect, management and the species of parent trees present both on the site and in the immediate vicinity. Detailed observations of tree seedlings were made in 2 x 2 m quadrats distributed over the site using a stratified random sampling method. The number of quadrats depended on size of the site and varied from 12 to 28 for sites between 0.5 and 4.7 ha in area. Seedlings of all tree species less than 2 m tall were counted, as were the number browsed.

The sites visited were on a wide variety of soil types including sandy podzols, heavy clays and rendzinas over chalk; soil pH varied between about 3.5 and 7.5. Examples of management known to promote natural regeneration were rare; for example ground preparation on sites with deep litter was not observed. Many sites had little canopy cover and few good seed trees.

The species of parent trees found on or near the sites are listed in Table 12; there were 24 broadleaves and 11 conifers. No species were found on all sites; oak, ash and birch were the most common broadleaves; larch, Scots pine and yew were the most frequent conifers. If parent trees of a particular species were present, on or near a site, then there was often a good chance of finding some seedling regeneration; most sites with birch and holly had some seedlings. However, seedlings of less-common parents such as wild cherry and alder were rarely seen, and those of crab apple, lime and wild service tree were never found.

Table 12. Species of regeneration seen during the survey

Species	*Present (+) or absent (–)*
Alder	+
Ash	+
Aspen	+
Beech	+
Birch	+
Crab apple	–
Field maple	+
Hawthorn	+
Holly	+
Hornbeam	+
Horse chestnut	+
Lime	–
Norway maple	+
Oak	+
Poplar	+
Robinia	–
Rowan	+
Sweet chestnut	+
Sycamore	+
Whitebeam	+
Wild cherry	+
Wild service tree	–
Willow	+
Corsican pine	+
Douglas fir	+
Larch	+
Lawson cypress	+
Norway spruce	+
Other conifers	+
Scots pine	+
Sitka spruce	+
Western hemlock	+
Western red cedar	+
Yew	+

There was large variation in the total numbers of seedlings of each species recorded. The minimum stocking density found was 100 seedlings per hectare but it was generally several thousand per hectare. Where ash and birch occurred they tended to be very abundant and on some small areas number exceeded 250000 per hectare. Conifer seedlings were relatively infrequent compared with broadleaved species but this is probably due to the criteria for selection of sites.

Although sites often had large numbers of seedlings many of these were in their first year of growth and were less than 15 cm tall.

Abundant regeneration was associated with sparse herbaceous vegetation and poor regeneration with tall dense bracken, bramble and luxuriant herbaceous weeds. However, many of the sites were covered by a dense ground flora of bramble, bracken and other competitive weeds and few showed evidence of any weed control aimed at encouraging natural regeneration by reducing competition from weed species. The principle that the overstorey can be used as a method of weed control did not seem to be well understood. Often felling had occurred in anticipation of regeneration rather than because sufficient advance regeneration was present.

Browsing damage was seen at almost all sites where seedlings more than one year old were present. The species of animal responsible were not identified but evidence of deer and rabbits, or both, was usually seen. The regenerating seedlings were often browsed to the level of the surrounding vegetation and few sites had many seedlings 30–200 cm tall. The future of the seedlings is uncertain as few of the sites had any effective protection against browsing.

The observation that the more common broadleaved species regenerate naturally on at least some sites suggests that natural regeneration is a potential method for restocking woodland. However, on many sites successful establishment will only be achieved if action is taken to prevent excessive losses from weed competition and browsing.

RALPH HARMER AND GARY KERR

YIELD MODELS FOR ENERGY COPPICE OF POPLAR AND WILLOW

Background

In his statement on 20 December 1994 the Minister for Energy agreed to support three projects for gasification of energy crops and forest waste and announced his support for a programme of research into coppice yield to be undertaken by the Forestry Commission. New subsidies to the grower through the Set Aside and Woodland Grant Schemes were announced in August 1994, and these measures are expected to 'stimulate substantial commitment to coppicing'.

Previous work has shown that poplar and willow clones offer the best potential, and has indicated the yields that might be expected. Yield information has been based on a restricted dataset, as there have been insufficient trials to cover the variation in site type of land suitable for energy coppice. Sound yield predictions will be needed by potential investors in wood-fuelled power stations.

A major contract has been awarded to us by the Energy Technology Support Unit of the Department of Trade and Industry to establish field experiments covering a wide range of site types and to draw up predictive yield

models. This forms Phase I of a seven-year contract; Phases II and III will be funded jointly by the interested government departments and by industry, as represented by British Biogen.

Objectives

- To establish six major experiments on a range of soil types and climatic conditions to contain a wide range of clones of both poplar and willow. There will be a relatively intensive programme of measurement of site and climatic factors at these sites (the intensive sites).
- To establish 42 field experiments on a wider range of soil types and climatic conditions (the extensive sites), but with a restricted range of clones. Sixteen of these experiments will include plots with clonal mixtures. Of the total, 22 will be established in spring 1995, and 20 (under Phase II) in spring 1996.
- To examine the yield data and construct yield models based on easily measurable site and climatic factors.
- To confirm the identity of the clones used by DNA analysis.

Yield modelling

The yield from any given clone will vary according to site and climatic factors, spacing, silvicultural practice, age of the coppice stools, and length of the cutting cycle. There will be different responses to these factors depending on the characteristics of the clone. In these experiments, cultural factors will be held constant as far as possible by adopting standard recommended practices throughout. Sites will be carefully characterised through detailed recording of soil physics, chemistry and hydrology, and by measurement of climatic factors. To produce yield models, it will be necessary to assess yield annually, and to develop yield assessment techniques that can be applied without destructive harvesting.

Observed yields will be used to construct descriptive yield models, and be related to site factors. It is difficult to extrapolate such models to include clones or sites not included in the original dataset, and to overcome this limitation process-based modelling is being considered. An understanding of the physiological factors underlying clonal differences should allow yield predictions to be made for new clones and for sites with environmental characteristics which go beyond the original dataset.

There is some evidence that mixing clones can lead to increased yields, and that rust diseases are less damaging to clones in mixtures. Therefore, mixture treatments have been included in 16 of the extensive trials, and monitoring of disease incidence will form part of Phase II.

Progress of the project

Phase I of the project ended on 31 March 1995. Seventy-eight sites were offered, from which 28 sites (Figure 22) were selected and planted under Phase I. The sites were classified by climatic zone using an Ecological Site Classification (Pyatt, in prep). In choosing sites the major aim was to cover the range of identified climatic zones, defined in terms of moisture deficit and accumulated temperature.

Each intensive experiment has a fully automatic weather station installed on site; each extensive experiment is fitted with automatic rain gauge and temperature monitoring device.

Detailed soil survey is being undertaken by Environmental Research and Woodland Ecology Branches.

Samples of reference material for the poplar clones that will be planted in the experiments have been collected from the national poplar collection at Alice Holt and sent to Tree Improvement Branch at the Northern Research Station for genetic fingerprinting. The DNA

Figure 22. Yield models for energy coppice of poplar and willow: locations of experiments established in spring 1995.

profiles produced from this work will be used to check the identity of the planting material used in the experiments. Almost all the clones could be distinguished from one another using seven primers. Long Ashton Research Station has been commissioned to provide similar information for the willow clones.

A contract has been agreed with Department of Agriculture for Northern Ireland to establish one intensive experiment, one extensive (pure) experiment and one extensive (with mixture) experiment in Northern Ireland, to the common protocols.

Draft protocols have been written by Robert Matthews of Mensuration Branch for minimally destructive sampling, and these techniques are being tested in existing Forestry Commission coppice experiments at Arthur Rickwood Farm at Mepal in Cambridgeshire, Alice Holt Research Station in Surrey, and Long Ashton Research Station, Avon. The experimental treatments include a range of poplar clones, initial spacings and cutting cycles, and since the plots are scheduled for harvesting, accurate estimates of dry matter are available for comparison.

ALAN ARMSTRONG

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TECHNICAL DEVELOPMENT

The aim of the Branch is to develop and evaluate safe and efficient equipment and methods of work, to maintain and expand output information and to provide a technical trouble shooting service. The Branch carries out work on a wide range of forest management and harvesting operations on behalf of the Forestry Authority and Forest Enterprise, as well as for a number of clients outside the Forestry Commission. Technical reports for managers are the main output of the Branch and a list of reports produced in 1994/1995 is given at the end of this section. The following paragraphs describe some of the work which staff carried out in this reporting year.

HERBICIDE SPRAYING SYSTEMS

Following a study of options, a forwarder-mounted upland sprayer was modified with new agricultural technology to improve accuracy, safety, weed penetration and area out turn, by reducing drift and improving the weather window. Attention then focused on the fleet of agricultural tractor-based sprayers that did not allow speed to be readily adjusted to ground conditions, so outputs were constrained by speed over the roughest terrain.

A desk study was carried out which suggested that certain advantages of the upland equipment could also be applied to the lowland units, particularly by linking herbicide flow to ground speed. Forest Enterprise Mechanical Engineering Services fitted a flow-based control system and other equipment to a trial unit and a radar-like ground speed sensor was fitted for comparison with the integral system of the tractor, which had an in-built wheel sensor.

Studies at Thetford indicated that an increase in output of 25% could be achieved on destumped areas and *c.* 20% on other areas, with a significant reduction in herbicide requirement. The wheel ground-speed sensor system was generally more accurate than the radar system but could be affected by wheel slip in wet conditions. Further developments are being considered for 1995, including the introduction of improved boom suspension leading to significantly higher outputs. Low drift hydraulic spraying systems, that should reduce lost spraying time due to wind conditions, will also be tested.

A further project considered the use of tractor-mounted sprayers in farm woodlands. This type of equipment makes up *c.* 80% of the spraying machinery in the UK, with the balance being largely of the self propelled type. The main methods used in new farm woodland tractor-mounted spraying are band application from above, and applications from one or both sides of a row. Nozzle requirements differ.

Most sprayers can be used for spraying two rows by folding up the boom extensions and blanking off excess nozzles in the centre section. However, 1.2 m treeshelters or tree growth of a similar height will prevent application beyond the two rows bordering the tractor-mounted sprayer, because of the height to which booms can be raised. Future work will include field study to obtain data on system set-up, conversion costs, accuracy and outputs. Row spacing of less than 2.5 m will restrict tractor access and even this is greater than the spacing recommended for growing hardwood timber of 1.8 to 2.0 m. Therefore, further work is investigating the use of sprayers and weed wipers mounted on all-terrain cycles.

PROTECTION AGAINST PINE WEEVIL

In areas with a high rainfall it is not always possible to apply a top up spray to young trees protected against *Hylobius* weevil attack by dipping or Electrodyn treatment using Permethrin insecticide. Studies by entomologists of the effectiveness of Marshall Suscon granules, a slow release carbosulfan formulation, showed that this product could replace the top up spraying element of protection. A project was commissioned to indicate the additional time taken to apply the granules at the time of planting to permit a cost comparison to be made.

The time taken to plant trees whilst applying granules to the root zone was *c.* 80% greater than when no granules were applied. When the cost of the granules was included the cost of granular protection increased the planting operation cost by £270 or 400%. However, assuming that top up spraying was not an option because of weather constraints or large programmes, it was possible to calculate the proportion of trees that would need to fail and be replaced before granular protection would be cost effective. It was concluded that application of Marshall Suscon granules at planting, costing £593 per hectare as opposed to £325 per hectare for planting only, could be justified when weevil attacks were likely to produce kills of 30-40% over two or more years. Development work on applicators is planned for 1995.

Forest residue recovery

In recent years there has been increasing interest in the use of harvesting residues as biofuel, mulch or an extra source of wood fibre. Residues can be recovered from conventional shortwood harvesting sites as a separate operation or, in cases where nutrient status and soil conditions permit, by extracting and processing the whole tree at roadside.

Forest Enterprise sponsored an investigation into the quantity of residue which could be removed from a conventional upland Sitka spruce harvesting site. Previous work had shown that recovery was very dependent on the cut-off diameter dictated by the timber specification and on site factors such as the number of dead trees. Two mechanised shortwood harvesting options and three residue extraction options were evaluated.

The harvesting options comprised the standard system in which all residue was placed into strips, and a modified method in which tops were placed to one side for subsequent selective recovery. The extra cost of placing all tree tops to one side for subsequent extraction was found to be negligible. Therefore, neither the standard nor the modified harvesting methods could be discounted on harvesting cost.

The extraction studies were a comparison of complete recovery of normal harvester residue drifts, removal of only the top part and removal of tops only from the dedicated drift method of harvesting. The intention of the latter two methods was to avoid contamination of residue with grit from trafficking; grit should be minimal if the residue is to be used as a biofuel.

Studies of forwarder extraction gave the following results:

- removal of the whole residue drift – 11.55 tonnes per standard hour (shr)
- selection of the upper part of normal drifts – 9.99 tonnes per shr
- removal of tops placed in a separate drift – 6.13 tonnes per shr.

All outputs refer to a haul distance of 100 m. A civil engineering dump truck loaded by an excavator was also tested, as unloading time might be reduced. Output was measured at 9.58 tonnes per shr during removal of the whole residue drift.

Contamination of residue with stones and grit was much less than anticipated, whether as a result of trafficking or of inadvertent collection of surface soil during loading by grab. Therefore the main comparison was between the forwarder and dump truck extraction of whole drifts. The dump truck team was at a disadvantage in terms of interdependence of excavator and dumper and inability effectively to repair residue drifts on which to run. The dump truck was also much more limited in terrain ability because it was less stable than the forwarder. However, it would be possible to improve efficiency.

The conclusions of the project were that residues can be presented separately with little cost penalty. Forwarders were the most cost effective method for recovering residues with costs of *c.* £4 per tonne over 100 m extraction. Extracting only tops and dead wood reduced the quantity available by 44%. The mean total residue that could be recovered by the whole drift method was 110 tonnes per ha, although there were wide variations due to moisture content and site. Cutting residues to 5 m or less was found to be important in loading efficiency.

A separate trial was commissioned to investigate the quantity of residue that could be recovered from an upland, Sitka spruce, whole-tree harvesting site and how this varies with crop characteristics and conversion practices.

Two unthinned Sitka spruce crops were studied with yield classes of 14–16 and 18 and average tree volumes of 0.15 and 0.16 m^3. Following stratification of the sites, groups of trees forming loads were measured for top height and diameter at breast height (dbh). These were then felled by clambunk skidder, extracted to roadside, and processed. The residue was loaded onto lorries for weighing. The green weight of residue varied from 211 kg per m^3 of standing timber at 21 m top height and 17 cm dbh, to 549 kg per m^3 at 17 m top height and 14 cm dbh.

Plate 1. Vegetation surveying in 1994 at the Alice Holt Environmental Change Network site.

Plate 2. Soil sampling at the Alice Holt site of EU Level II forest monitoring network.

Plate 3. Åkerman harvester used for the mechanised felling, de-branching and cross cutting of logs from conifer plantations.

Plate 4. Heavy bark loss on pine sawlogs that can sometimes result from mechanised harvesting.

Plate 5. Final volume measurement of a wind damaged Norway spruce permanent sample plot in Glenbranter Forest. All measurements are entered into a portable computer for calculation and checking in the field.

Plate 6. A Sitka spruce permanent observation plot in Inverlever Forest newly established at Level II within the European programme for intensive monitoring of forest ecosystems. The plot contains an existing Mensuration Branch permanent sample plot which will provide increment data for the European programme.

Plate 7. Riverside alder showing thin yellow foliage typical of Phytophthora root disease.

Plate 8. Guy Blackburn, who is studying for his Ph.D., attaching a strain gauge transducer to a tree stem. The transducer measures the wind loading on the tree, in a joint project between the Forestry Commission and Manchester University aimed at understanding the adaptive growth of trees.

Plate 9. The stump of a 47-year-old Sitka spruce tree being pulled horizontally while continuously measuring and logging the applied load and soil root plate movement. The information will help the stability project team to understand and model the factors which determine a tree's resistance to overturning.

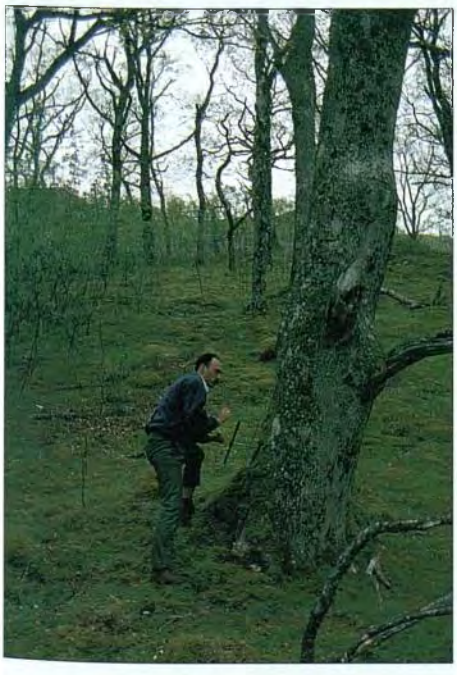

Plate 10. Extracting an increment core from a mature tree in the Letterewe oak woods, Wester Ross.

Plate 11. Preparing a reaction mixture for DNA analysis of poplar tissue by the RAPD technique.

Plate 12. Downloading temperature data from an automatic logger used to monitor conditions during pollination of larch induced to flower in a polythene house.

Plate 13. Time study of proprietary mulch mat fixing methods and costs.

Plate 14. Extraction of small roundwood by all-terrain cycle.

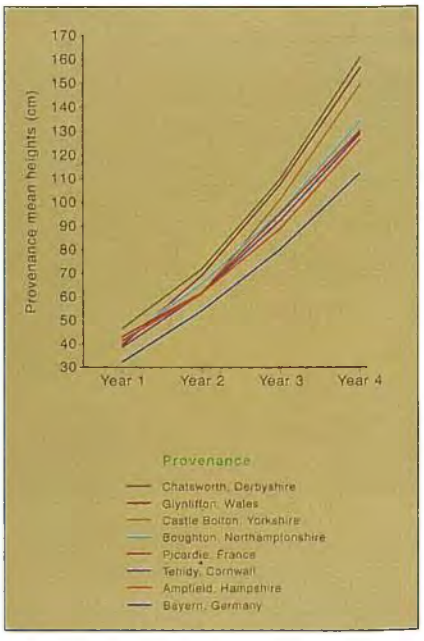

Figure 25. Sycamore provenance performance over four years, Riseholme farm forestry site.

Statistical analysis showed that a good correlation (i.e. >99% significance) existed between residue weights and top height (correlation coefficient -0.93) and also, separately, residue weight and tariff number (-0.92 each). The relationships of residue weight to mean tree volume and to diameter were both -0.89. The green weight of residue recovered ranged from 84 to 135 tonnes per ha for mean tree sizes of 0.20 to 0.10 m^3. This included a proportion of conversion loss. Further work would be required to determine quantities available from dead trees.

The study demonstrated that mean tree volume is a good predictor of residue weight but that further work would be required to validate and extend the relationship to other sites.

MICHAEL WALL

The following titles were published during 1994.

Reports

1/94 Harvesting and comminution of short rotation coppice: selection of equipment for initial testing
2/94 Equipment for all-terrain cycles
3/94 Tree mulch field trial
4/94 Small scale forestry: Elmia 1993
5/94 Valmet 860 forwarder
6/94 Respacing by Bruunet/Berti horizontal shaft flail
7/94 Small scale thinnings processors for use with agricultural tractors
8/94 Streets Lane: cultivation trials at an opencast coal site
9/94 Feller clambunk whole tree extraction and roadside processing system in Wales
10/94 Timberjack 1210 12T forwarder
11/94 First field trials of short rotation coppice harvesters
12/94 Evaluation of planting machines for farm woods
13/94 Options for the modification of the upland Ulvaforest
14/94 Evaluation of the Mulag RM 50 tracked mower
15/94 Clambunk trials: Kielder
16/94 Silvatec 555 MD60 harvester head
17/94 Forestry wood working machinery

Technical Notes

1/94 The Donaren 280 scarifier: changes to the mechanical specification
2/94 Chainsaw evaluation
3/94 Appraisal of the Menzi Jolly 1300T small walking excavator
4/94 Electrodyn operating manual
5/94 The Gardstefrasen sowing drill
6/94 Glenfinnan log chute
7/94 Short rotation coppice planting machines
8/94 Tractor-mounted sprayers for farm woods
9/94 Marshall Suscon insecticide application
10/94 Prototype conversion of a Vauxhall Brava for ranger use
11/94 Blakemere moss harvesting options (R)
12/94 Horse extraction of large hardwood logs
13/94 RGL plant rhododendron and woody weed flail

Information Notes

1/94 Biodegradable chain oil
2/94 Ecoshelter
3/94 Ulva+
4/94 Doscocil gun guard for all-terrain cycles
5/94 Kolpin gun boot for all-terrain cycles (R)
6/94 Kombi drag
7/94 Protecting innovation
7/94 Addendum: protecting innovation
8/94 Cooper Peglar Series 2000 sprayers
9/94 Treeshelter market summary
10/94 Creation of severance cuts with the MKR70K flail unit
11/94 Bastion 15 knapsack sprayer
12/94 Harvesting machine census 1994

A free publications list is available from the Forestry Commission, Technical Development Branch, Ae Village, Dumfries, DG1 1QB

TREE IMPROVEMENT

Overview

In January, G. C. Webb, FOIII officer-in-charge at the Shobdon field station, retired after more than 35 years with the Branch. Loss of such experienced staff inevitably means changes in duties and changes to the way parts of the agreed research programme are carried out.

In July 1994, a Visiting Group under the Chairmanship of Professor E. C. Cocking of the University of Nottingham examined the activities being carried out by the Branch. In general the Visiting Group strongly endorsed the work of the Branch but made a number of valuable recommendations that are being followed up; some are noted below. The Visiting Group wished to see a stronger commitment to the concept of maximising delivered genetic gain per unit time in the Sitka spruce breeding programme. They recommended that the future research plans on flowering be evaluated critically to review prospects of success and likely impact on the breeding/production programme. The Visiting Group recommended that since rejuvenation or maintenance of Sitka spruce genotypes in a juvenile state would generally enhance prospects for clonal forestry, it is possible that cryopreservation could play a major role in future, and this area of research should be examined further.

The jointly funded Ministry of Agriculture, Fisheries and Food/Forestry Commission project on genetic improvement of broadleaves for farm forestry was completed and a final report submitted. A summary of results is presented below. Due to changes in the funding for this work (in the short term, at least) it was decided to consolidate Tree Improvement Branch staff at the Northern Research Station (NRS), and Dr Cundall transferred from Alice Holt in August. The two other members engaged on the project at Alice Holt were transferred to other branches when the project terminated in November. Work is still continuing on genetic improvement of broadleaves with the effort mainly concentrated on *Betula pendula*, and on *Fraxinus excelsior* and *Acer pseudoplatanus* with selection of plus trees and their subsequent propagation.

This year seed crops of major commercial species were very light which reduced the demand for registration of new seed stands. Interest in poplar clones for use in short rotation coppice has increased and since *Populus* spp. are covered by the Forest Reproductive Material Regulations all poplar stool beds must be registered. The Branch assumed responsibility for this aspect of the Regulations two years ago and has, over the past 18 months, inspected and documented all poplar stool beds used for marketing of material. A new register of stool beds was published in 1994, as well as an update of the register of basic material.

Contract work continues to occupy a significant part of the Branch programme. The EU Northern Conifers project is the largest, and the first half of 300 Douglas fir families have been planted; the remainder are being raised in the nursery. The studies in larch flowering indicate that with protection against low temperatures and strong winds flower numbers and, more importantly, the number of full seeds can be greatly increased. The Branch was host for the annual meeting of Tasks 1 and 2 of that project and 18 scientists met for a week to present results to date and discuss the programme for the next 12 months. This project provides a good example of the benefits from collaboration obtained in some EU programmes.

In a second EU project methods of vegetatively propagating older horse chestnut trees are being investigated. Various methods of propagation are being employed including grafting, and macro- and micro-propagations. To date the most successful has been grafting using wedge, saddle or apical side veneer types of grafts.

Members of the Branch undertook two consultancies on behalf of the Food and Agriculture Organization. Steve Lee spent a month at Jabalpur in India providing advice on provenance research, while Alan Fletcher went to the Caspian Region of Iran to draw up a breeding strategy for their broadleaved species. In addition there was continued involvement in

the Overseas Development Administration project in China on the improvement of Japanese larch and larch hybrids. Alan Fletcher together with John Morgan of Silviculture North travelled to China for workshops and discussions in Quinyan County in Laioning Province. Seed of hybrid larch from the pollinations carried out by the Chinese scientists at NRS in 1994 has been extracted and sent for raising in China.

ALAN FLETCHER

MOLECULAR MARKERS FOR GENOTYPIC ANALYSIS

The repertoire of biochemical marker systems available to the tree improver has been enhanced in recent years by the development of techniques for analysis of the genome directly. Previously, the most commonly used markers were isozymes, which are primary transcription products of DNA; and secondary compounds such as terpenes, further removed biosynthetically from the genetic material and therefore subject to significant environmental modification. Both these marker systems have the additional drawbacks of representing only a fraction of the total genome. Furthermore, only a small number of isozyme systems are available for routine analysis and these often show a strictly limited degree of polymorphism. DNA-based markers have the benefits of being virtually unlimited in number – the entire genome is available for sampling – and of being truly genotypic and hence unaffected by the environment. In addition, plant cells contain three distinct genomes (nuclear, chloroplast, and mitochondrial) differing in size, rates of evolutionary change, and inheritance characteristics, making them ideal for studies of gene-flow and mating systems in both natural and domesticated populations.

There are several types of DNA markers with potential applications to tree improvement. At NRS we are using one of the least technically demanding and most cost-effective, known as the RAPD (random amplified polymorphic DNA) technique. DNA is extracted from suitable tissue, and the DNA molecules are randomly sampled by the use of short synthetic primers of arbitrary base-sequence which bind to complementary sequences on the DNA and initiate replication of short fragments. These fragments are amplified exponentially in the polymerase chain reaction (PCR) until they are sufficiently concentrated for analysis by electrophoresis on agarose gels. The fragments produced in a given sample appear after staining as a series of bands which fluoresce in UV-light. Polymorphism between samples arises as a result of differences in DNA base-sequence which affect primer binding and hence the production of specific amplified fragments.

RAPD markers are especially well suited to indicating genotypic distinctions at the clonal level, since an increasing proportion of the total genome can be sampled by the use of additional primers until genotypic differences are discovered. They have therefore proved to be particularly useful for authenticating the identity of commercially available genetic material for legal purposes, and for resolving cases of disputed identity or mislabelling which frequently occur in the implementation of tree improvement programmes. Diversities of populations can also be measured, and taxonomic relationships evaluated on the basis of similarities between individuals or populations.

We have used RAPD analysis to identify clonal markers in both Sitka spruce and poplars. Several Sitka spruce seed orchard clones represented in the breeding programme were analysed. The best source of DNA for RAPDs is generally young actively growing tissue, but good quality DNA was successfully extracted even from one-year-old needles; dormant buds gave mucilaginous extracts which were difficult to handle. It was found to be important to optimize the PCR reaction conditions, since the concentrations of various components (e.g. magnesium, and the ratio of primer to DNA) and the thermal cycling protocol can radically alter the fragment band patterns. Twenty primers were screened for their ability to detect clonal polymorphism. Certain primers, e.g. Operon A-03 and A-11, showed no polymorphism although they gave distinctive banding and are therefore likely to be valuable as higher taxonomic markers. The most informative primers for clonal separation were A-01, A-09 and A-17. For small numbers of clones (*c.* 5–10), the use of a single informative primer may be sufficient for complete separation; for larger numbers, a combination of two or three primers will generally suffice.

Repeatability was tested in several ways. Duplicate PCRs of the same DNA extracts of several clones showed excellent consistency even for minor bands which are generally excluded for consideration as markers. Repeatability between ramets was tested by analysing four ramets from each of four clones; again there were no significant differences in band patterns after amplification by several primers. Both time of sampling and site were

shown to be unimportant by comparing results from needles sampled in February and in May, and by collecting from young ramets raised locally and from planted seed orchard material at both Glencorse (Lothian) and Ledmore (Perthshire).

This work will form the basis for developing markers for the authentication of Sitka spruce clones in seed orchards; and for characterising genetic relationships, assessing the diversities, and authenticating the origins of breeding populations.

RAPD markers have been developed for a range of poplar clones widely used as commercial material for short rotation energy coppice. Many are impossible to distinguish morphologically, yet identification is crucial since traits such as canker resistance are genetically determined and can dictate the planter's choice. Molecular methods offer the only means of genotype authentication for such assemblages of clones, many of which may be very closely related. Some 15 clones were sampled from each of two local sites. For successful DNA extraction it was essential to use very young leaves or expanding buds, and to modify the extraction protocol. A wide range of primers was screened, and many were effective in distinguishing individual clones or groups of closely related clones (Figure 23). Repeatability was good providing conditions were strictly standardised. Band patterns correlated with the taxonomic relationships between the clones (Figure 24). Outstanding primers for separation were Operon A-01, A-02, A-16, A-20, C-04 and E-14. Eleven primers were necessary to separate all possible pair-wise combinations; the majority of clones could be uniquely identified by using only two or three primers.

These results have been applied in a commercial context of disputed identity, and have been extended into a wider project involving the DNA-fingerprinting of recently developed poplar clones. This project has shown:

1. even large numbers of clones can be individually characterised by the use of small numbers of selected primers;
2. closely related clones (e.g. full-sibs) can be separated by informative primers; and
3. there is a strong correlation between RAPD band pattern and taxonomic affiliation, from the species level down to full-sibs.

DNA marker technologies, including RAPDs, are transferable to all species, are rapidly developing in technical capability and diversity of application, and promise to revolutionize procedures for the genotypic characterisation and improvement of tree breeding material.

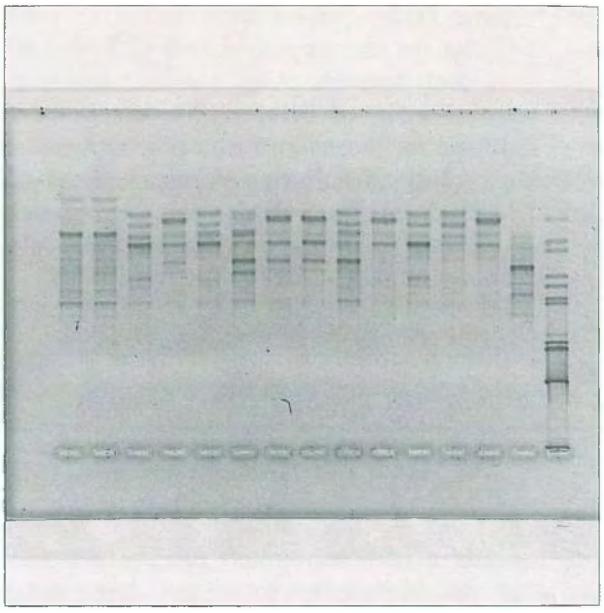

Figure 23. RAPD markers for poplar clones. Stained agarose gel in UV-light showing electrophoretic separation of DNA fragments from 14 clones amplified with primer Operon E-14. Lane 15: reference marker containing fragments of known molecular size. There is considerable polymorphism, but certain closely related clones give similar band patterns, indicating that within the amplified regions of DNA they have identical base-sequences.

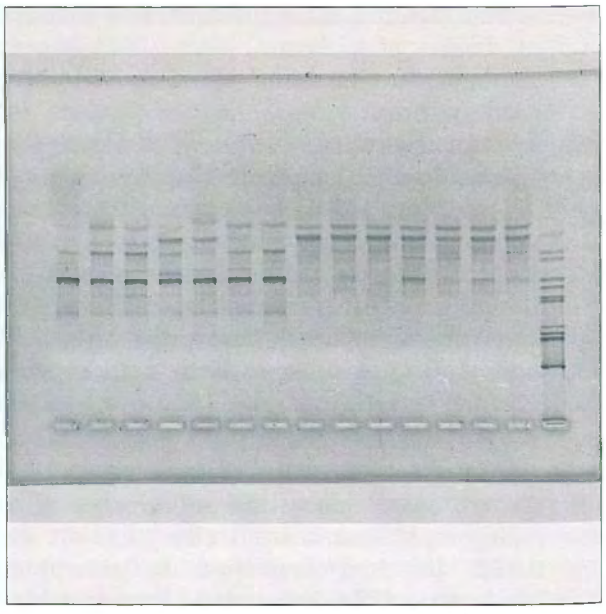

Figure 24. RAPD markers for a second group of poplar clones, amplified with primer Operon C-01. Lanes 1–7: P. nigra *varieties and crosses. Lanes 8–14:* P. deltoides *x* trichocarpa *crosses (the last four are full sibs). The two major taxonomic groups are distinct, but there is polymorphism within each.*

IAN FORREST AND JOAN COTTRELL

GENETIC IMPROVEMENT OF ASH AND SYCAMORE

New planting of broadleaves in the United Kingdom has increased from less than 1000 hectares in 1983 to more than 10 000 hectares in 1993/94 (67% of the new woodland area). Restocking with broadleaves over the same period increased from less than 1000 hectares to more than 5000 hectares. Previous genetic improvement of broadleaves was focused on oak, beech and silver birch, but this work is now being expanded to include other broadleaved species suitable for lowland sites.

Compared to conifers only minimal progress has been made in improving broadleaved species in Britain. The increased interest in broadleaves prompted a decision to undertake new research on ash, *Fraxinus excelsior* L. and sycamore, *Acer pseudoplatanus* L., for farm forestry. These projects were funded 50:50 by the Ministry of Agriculture, Fisheries and Food (MAFF) and by the Forestry Commission, between 1990 and 1994. Ash and sycamore are considered particularly suitable for farm forestry as they are valuable whitewoods which can be grown on relatively short rotations on lowland sites. Little genetic improvement had been done previously, and neither species is at present covered by Forest Reproductive Material Regulations.

Provenance testing, that is the identification of the best geographic sources of seed, is the initial phase of most tree improvement programmes. An extensive survey in 1990 and 1991 evaluated 248 stands of ash and sycamore throughout England and Wales. Only 4% of ash and 5% of sycamore stands were assessed as potential seed-stands (Cahalan *et al.*, 1995) and these phenotypically superior stands are now being assessed in provenance trials. The selection criteria for the seed-stands were that they were of above average form and had good growth rates. The provenance trials will be assessed for form (straightness of trunk, persistence, fine branching) height increment, volume growth, wood quality, and resistance to disease.

Eleven sycamore provenances (seven native and four continental) were planted on five farm forestry sites in 1991. Measurements after the 1994 growing season showed that height increment on fertile lowland sites over three years had been encouraging (Figure 25, with plates) and was no longer significantly correlated with nursery height. The provenances from Glynliffon and Chatsworth were the most vigorous at all sites, and there was no significant provenance x site interaction. The provenance from Bayern, Germany was the slowest growing, this seed source being at an altitude of over 400 m. There are strong arguments for using native planting material for commercial broadleaved forestry. However given the potential impact of global warming (Houghton *et al.*, 1990) it seems prudent to include a range of continental European provenances of both ash and sycamore in commercial trials. Some exotic sources may prove to be better adapted and more productive than native sources as the climate changes.

Ash provenance trials were planted in 1993 and 1994 consisting of up to 15 seed sources (six native and nine continental) at five farm forestry sites, four of which were in common with sycamore. Measurement of height at the end of the 1994 growing season assessed two years' growth in the field for the continental ash provenances. At this stage, height in the field was generally significantly correlated with nursery height, but there was nevertheless a significant provenance x site interaction. Ash provenance trials will be planted at two more sites in 1995. Altogether eleven British and 10 continental ash provenances are under test.

Assessment of the ash and sycamore field trials at age 10 should allow provisional recommendation to be made of the better seed sources for commercial use.

In commercial clonal forestry the rooting of softwood cuttings from stock hedges is the most widely used method of multiplication. Consequently optimal conditions for the rooting of ash and sycamore cuttings have been studied in cooperation with Plant Production Branch (Cahalan and Jinks, 1992; Jinks, in press). A total of 142 clones of ash and 173 clones of sycamore have been established at Alice Holt in field stock hedges. These are not all from selected plus trees but include nursery selections and material collected for vegetative propagation experiments. A successful programme of clonal selection depends not only on the establishment of a wide range of diverse germplasm but also on its testing over a range of sites to at least half rotation age.

A small clonal field trial with 22 sycamore clones which was established at Alice Holt in 1993 was scored for time of bud-burst in 1994. Correlation between 1994 field results and 1993 greenhouse results was $r = 0.447$, $P < 0.05$. Time of bud-burst in the field will continue to be assessed; if it is found to be more strongly correlated with early greenhouse data, then greenhouse results can be used for early screening.

Phenology (times of bud-burst and leaf-fall) is thought to be related to climatic variables and data are being collected on both bud burst and

leaf fall for all clones in the ash and sycamore stock hedges.

Seed production in grafted clonal seed-orchards is a cheaper source of improved planting material than rooted cuttings for both species. Seed-orchards will comprise a wide range of selected clones grafted onto seedling rootstocks. Various methods of bud-grafting, and apical side-veneer grafting were investigated. The latter gave 77% survival at the end of the first growing season in ash, and may be preferable to bud-grafting for both species.

Flowering in ash is complex; some trees produce purely male or female or hermaphrodite flowers, while others have a mixture of flower types, and some possess flowers of a transitional form. Mitchell (1974) suggested that trees may change sex with time and Evans (1984) states that male trees often have better form than females. Since these characteristics would affect genetic improvement of ash, a study of flowering was made in two stands, one of 50-year-old trees and the other of 104-year-old trees. There was a considerable difference in the distribution of flower types between the two stands (Table 13) and the results were consistent with a trend for older ash trees to display female characteristics. Differences between flower types with respect to total height, timber height, diameter, clear stem length and volume were analysed by means of multivariate analysis of variance. No significant relationships were found in either stand. There was some indication that male trees were straighter than female trees but a more discriminating system of assessment would be needed to confirm this observation.

Although MAFF funding of these ash and sycamore genetic improvement projects finished in 1994, work will continue on the selection of plus trees of these species from a wide geographical range and their establishment in clone-banks, and on the maintenance and recording of existing provenance and clonal trials and stock hedges.

NED CUNDALL

Table 13. Percentage distribution of flower types in two ash stands of different ages

Flower type	*50-year-old trees*	*104-year-old trees*
Female	27.1	47.0
Male	46.9	7.0
Hermaphrodite	16.7	33.0
Mixed flowers	4.2	7.0
Non-flowering	5.2	6.0

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WOODLAND ECOLOGY

Overview

Following a review of branch structure the Division's Wildlife and Conservation Research Branch, based at Alice Holt, and Wildlife Ecology Branch, based at the Northern Research Station and Ardentinny Field Station, have been amalgamated. This will allow the development of woodland ecology research strategy and programmes on a GB basis, and the application of the diverse skills in the branch to key research issues in multi-disciplinary teams.

The work of the branch is organized into eight work programmes:

1. woodland ecosystem assessment and monitoring
2. habitat/predator/prey relationships in woodland ecosystems
3. woodland habitat management
4. decision support systems for sustainable forest management
5. squirrel management in woodlands
6. deer population ecology
7. tree protection
8. the impact of changing hydrology in forests.

Programmes 1 to 4 contribute to the Division's Biodiversity Research Programme (BRP) which aims to provide information for policy makers and woodland managers seeking to meet international commitments to biodiversity protection and enhancement.

SIMON HODGE

Squirrel management in woodlands

Work continues on the refinement of techniques to protect vulnerable trees from grey squirrel damage and to prevent further decline of the red squirrel.

A trial in the Lake District to test grey-squirrel-only Warfarin hoppers in an area containing both red and grey squirrels found no evidence of red squirrel entry to the hoppers. This work is one of a series of research studies which aim to develop reliable methods of selectively feeding red squirrels and controlling grey squirrels in areas where grey squirrels are expanding into remaining red squirrel range.

A three-year contract has been let to the University of Sheffield to explore the potential for grey squirrel immuno-sterilization. Recent advances in technology have allowed the creation of vaccines that cause a reaction in the female against proteins on the male sperm. The vaccine causes an immune response against the male sperm, the same mode of action as a disease vaccination. Three main problems are being addressed:

1. identifying grey squirrel antigens (proteins that provoke an immune response) that are specific to sperm;
2. ascertaining that a strong immune response can be obtained that inhibits fertility after oral vaccination; and
3. ensuring that any vaccination/delivery system is effective only on grey squirrels, and that the vaccine is humane and non-toxic.

A contract was let to the University of London (Queen Mary and Westfield College) and the University of Southampton (Geodata Institute) to extend an existing geographical information system (GIS) for the red squirrel reserve at Thetford Forest. This reserve is the focus of a collaborative species recovery programme for the red squirrel involving English Nature, Forest Enterprise, Forestry Commission Research Division and Queen Mary and Westfield College. The GIS will be used to assess red and grey squirrel population numbers in relation to conservation management, and to model future trends in response to planned management activities.

Verification work on developing a method of predicting the likelihood of severe grey squirrel damage (see *Report on forest research 1994*) continues. Five training days on grey squirrel management were held in conjunction with the Forestry Authority England.

HARRY PEPPER

DECISION SUPPORT SYSTEMS FOR SUSTAINABLE FOREST MANAGEMENT

During 1994 the Ecological Site Classification (ESC) (*Report on forest research, 1994*) was used in several case study areas, including Allean, South Rannoch and Grampian Region, North Wales and Sherwood, as a foundation for woodland development strategies. A new project is examining the potential of decision support systems to aid forest management for biodiversity. The project seeks to integrate computer-based systems being developed by the Division and elsewhere, including forest floor sunlight model, succession models and decision support systems for ecological site classification and deadwood management. The potential for linking with a geographical information system will be explored.

GRAHAM PYATT AND DUNCAN RAY

ASSESSING BIODIVERSITY IN MANAGED STANDS

In response to the Rio declarations on the conservation and enhancement of forest biodiversity (UNCED, 1992), European forestry ministers met in Helsinki and produced *General guidelines on the sustainable management of forests in Europe* (Ministerial Conference on the Protection of European Forests, Helsinki, June 1993). In response, the Forestry Authority launched its Biodiversity Initiative (FABI) with the dual aims of enhancing and producing standards for biodiversity in GB plantation forests (Ratcliffe, 1993). The Biodiversity Research Programme (BRP) is a major part of FABI.

Relatively little is known about the effects of current management regimes on biodiversity in the major GB plantation forest types at a stand scale (Thornber *et al.*, 1993). Such information is important as most forest management operations are carried out at this level. The majority of plantation forests in Great Britain have been established relatively recently and it is still unclear how they will develop ecologically. Thus it is difficult to define the target levels of biodiversity that should be achievable. One way round this problem is to compare managed plantations with analogous undisturbed or semi-natural woodland types (Ratcliffe, 1993; Peterken *et al.*, 1992). Whilst this approach can be pursued to a certain extent with British woodland types (e.g. native pinewoods compared with pine plantations) there is a lack of comparative material for conifer plantations of non-native species (e.g. *Picea sitchensis, Picea abies*).

This project seeks to address these issues by undertaking a standardized series of assessments across a range of selected forest site/species types defined by Ecological Site Classification methodology. It represents a core component of the BRP, and will provide data for a number of other studies.

Objectives

1. To appraise the relevance of using levels and types of biodiversity in semi-natural forests as models for increasing biodiversity in comparable plantation forests of the same tree species and site types.
2. To review the role of chronosequences in biodiversity research, and develop site selection procedures which minimise any perceived risks associated with adopting this approach.
3. To establish chronosequences of different stand ages in major GB forest types currently under patch clear-fell management.
4. To collect base-line information on levels of biodiversity within and between these chronosequences, against which improvements brought about by alternative management practices can be judged.
5. To identify possible indicators of biodiversity in GB plantation forests. This study will be followed by research designed to test the reliability of these possible indicators before they are offered for practical use in monitoring biodiversity in GB plantation forests.

Site selection

Seven forest types will be assessed, corresponding to the major plantation forest types in Great Britain (Table 14). If resources permit, three further forest types will be assessed (shown in parenthesis in Table 14). For each forest type, at least two replicates of a three-age-class chronosequence – pre-thicket (5 to 15 years), pole stage (20 to 50 years), and mature (economic maturity) – will be assessed for two years. In the first year plots will be set up in the upland and lowland spruce and pine types. Plots in the other four major forest types will be set up in the second year.

In addition to the chronosequences, examples will be sought which are considered to be of exceptionally high conservation value for the forest type. These will be ancient semi-natural examples for native species. For an introduced species, old and structurally diverse stands will be assessed, along with literature review of the species in its native range. Parameters for the selection of these stands will be developed during the first year.

Table 14. Forest types targetted for assessment of biodiversity in managed stands

Broad ESC climatic zone	*Uplands (< 40 mm moisture deficit)*	*Foothills (40–100 mm moisture deficit)*	*Lowlands (> 100 mm moisture deficit)*
pine		Scots pine	Scots pine Corsican pine
spruce	Sitka spruce	Sitka spruce (Norway spruce)	Norway spruce
oak			oak spp.
beech			(beech)
Douglas fir		(Douglas fir)	

A single one hectare plot will be established in each of the above stand age-categories, selected to minimise internal heterogeneity in terms of stand structure, species composition, topography and hydrology. A standardised system of assessment stations will be established within each plot to maximise potential comparisons between measured attributes and to minimise disturbance during sampling. Plots will be permanently marked, and locations and details of data-sets published.

Assessments

Protocols have been developed for each factor to be assessed, normally using published methodologies. Physico-chemical aspects of the sites and their biota will be assessed to define the characteristics of the habitat.

- Qualitative and quantitative site assessment – recording of plot topography, hydrology, broad soil type, and signs of disturbance.
- Mensurational assessment – top height and diameter at breast height of a sample of trees at selected locations within the survey plot.
- Vegetation structure – assessment of vertical cover and crown projection in delimited structural layers; this requires measurement of total vegetative cover in standardised height bands roughly corresponding to field, shrub, lower-canopy and upper-canopy layers. More detailed assessment will be carried out for the shrub layer using foliage height diversity (FHD) measures (Ferris-Kaan and Patterson, 1992).
- Deadwood – assessment of the size, quantity and decay state of deadwood on the forest floor, in standing dead trees and in living trees.

Packham *et al.* (1992) identify three key sub-systems within forest ecosystems and assert that ecosystem health and sustainability depend on the effective functioning of these inter-related sub-systems: plant sub-system, herbivore and carnivore sub-system and decomposer sub-system. Certain species groups are found associated with these different sub-systems. The project will examine taxa within each of these, including primary producers, primary, secondary and tertiary consumers, and elements of the decomposer system. The number of different taxa to be assessed has been decided partly on the basis of resources and technical expertise available. With most groups the higher taxon approach to assessing diversity will be adopted (Williams and Gaston, 1994).

Assessments will cover the following areas.

- Floristic composition (vascular plants, bryophytes and lichens). In order to minimise subjectivity in assessment methods, cover assessments will be avoided. Preference will be given to frequency measures obtained from presence–absence assessment in 4m x 4m quadrats.
- Seed bank assessment. Potential vegetation on the site may be predicted from the reserve of buried propagules. Sample collection will be from litter and from soil layers to a depth of 10cm.
- Fungal diversity. Macrofungi fruiting bodies will be monitored during the autumn on a presence or absence basis. This will involve several visits to each plot during the autumn of each of the two years of assessment.
- Invertebrate diversity. Sampling will aim to make comparisons of insect guilds in three strata within each forest type: canopy, ground surface and deadwood. Each stratum will be sampled over the two years of assessment using methods suited to the corresponding guilds. This represents the most substantial part of the assessment programme and is likely to yield unique data on insect diversity in the major GB plantation forest types.
- Presence of large herbivores. Deer and lagomorphs are a part of forest diversity but can also have a dramatic impact on vegetation

composition and structure. The presence of large herbivores in the compartments containing the assessment plots will be ascertained by faecal counts.

- Abundance of small mammals. Longworth traps will be used to monitor the abundance of small mammals over two years using mark–recapture methods.
- Songbird abundance will be assessed by point count and territory mapping methods, with a number of visits being made to each site during the spring.
- Gross assessment of below-ground fungal and microbial activity.

RICHARD FERRIS-KAAN AND JONATHAN HUMPHREY

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THE INVERTEBRATE FAUNA ASSOCIATED WITH BIRCH IN SPRUCE FORESTS

Sitka spruce forests are often considered to be poor in invertebrate diversity when compared to semi-natural native broadleaved woodland. Trees such as birch or oak are thought to have over three times as many associated phytophagous insect species as spruces (Strong *et al.,* 1984). Allowing birch to become established in upland Sitka spruce forests may therefore yield benefits for invertebrate diversity. As part of the Biodiversity Research Programme and in conjunction with Scottish Natural Heritage, commissioned survey work was carried out by the Institute of Terrestrial Ecology and Forest Insect Surveys to examine this.

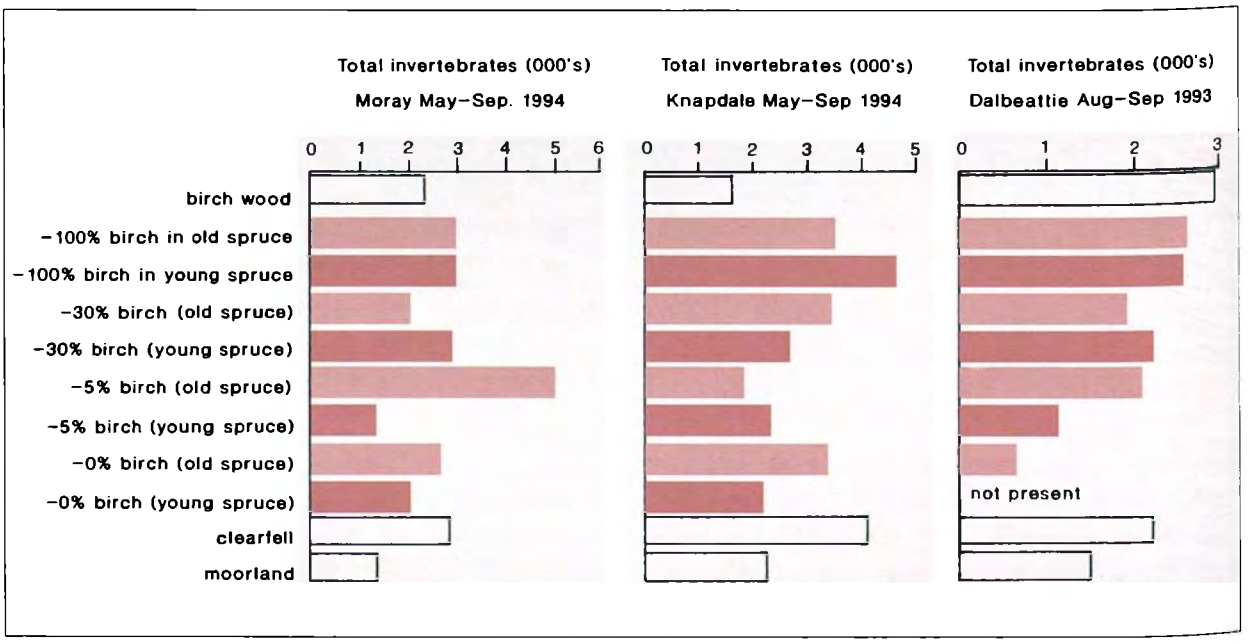

Figure 26. Abundance of insects and other invertebrates sampled in Moray (left), Knapdale (centre) and Dalbeattie (right) by Malaise trapping (10% sub-sample). Plantation plots with older spruce are shown as light red bars, younger spruce plots are dark red, and non-plantation plots are open bars.

Three forests were selected: Dalbeattie Forest in Dumfries and Galloway (NGR 8857 5579), Knapdale Forest in Argyll (NGR 1811 6898), and Teindland Forest in Morayshire (NGR 3331 8538). At each, invertebrate monitoring plots were set up within Sitka spruce stands of different ages (early thicket and mid rotation) containing different densities of birch, ranging from a canopy cover of 0% to 100% (clumps >30 m across). Control plots were set up in semi-natural birchwoods, clear-felled areas and semi- natural unimproved grasslands. Both foliage and predatory insects were sampled using a variety of techniques such as Malaise and pit-fall traps for ground dwelling beetles, flies and wasps, and light traps for night flying insects such as moths. Sampling was carried out at regular intervals from May to September during 1993 at Dalbeattie and 1994 at Knapdale and Teindland.

Over 200 000 individuals were trapped in each forest and more than 20 orders and suborders of insects and other invertebrates were recorded, ranging from beetles, to wasps and hoverflies (Figure 26). Trends in abundance in relation to treatment showed marked variation between forests. At Dalbeattie (1993), invertebrates were most abundant in the three plots where birch was a major stand component and least abundant in spruce stands with little birch. In contrast, invertebrate abundance at Knapdale (1994) was lowest in the semi-natural birchwood, and declined slightly in spruce stands with decreasing amount of birch. Surprisingly, invertebrate abundance at Moray (1994) was highest in the mature spruce stand with only a minor birch component.

Of all species groups, only landbugs (Hemiptera) and beetles (Coleoptera) were more abundant in the semi-natural birchwood plots than in the spruce plots. Spruce forests with a minor birch component seem to be as suitable for flies (Diptera), wasps, bees and ants (Hymenoptera), and springtails (Collembola) as nearby birchwoods. Certain groups such as the psocids (Psocoptera), bristletails (Thysanoptera) and mites (Acari) tended to prefer older spruce stands independent of birch abundance.

The presence of birch within spruce stands also had little influence on the species diversity of hoverflies (Syrphidae). Older, pure spruce plots were the most species rich, although overall abundances were higher in the younger pure spruce plots. The semi-natural birchwoods were comparatively species poor. These trends follow much of what is known about the feeding habits of hoverfly larvae, which utilise amongst other substrates, aphids and decaying tree roots which are more common in the shaded, danker conditions of spruce stands. Many of the species recorded are of conservation interest, either locally uncommon or nationally notable.

At Knapdale and Moray the two most common families of beetles (Coleoptera) were the ground beetles (Carabidae) and rove beetles (Staphylinidae). Abundances of both groups were greatest in the semi-natural birchwood and clearfell plots, although species diversity values in these plots were similar to those in birch/spruce plots. The high abundances in the semi-natural birchwood plots were due to the presence of very high numbers of one or two birchwood specific species.

At all three forests, moth (Lepidoptera) diversity was highest in the semi-natural birchwood plots and lowest in the older pure spruce plots. Diversity increased strongly with incidence of birch in the younger spruce plots, and diversity in the plots with highest birch cover was comparable to diversity in the semi- natural birchwood. The moths were categorised in terms of their dependency on birch as a food source, ranging from the polyphagous moths (generalists) to monophagous species (specialists) which feed only on birch foliage. The diversity of birch specialist moths increased in proportion to the amount of birch in the stand with the semi-natural birchwood plots and the 100% birch in old spruce plots yielding the highest values. The diversity of birch specialist species appears to be positively related to the occurrence of older birch. Younger stands attract a generalist moth fauna synonymous with scrub and more open, unwooded habitat.

Judging by the results obtained from this study, previous assertions that spruce forests have an intrinsically low insect diversity appear to have been over pessimistic. Spruce forests may not cater for those species specific to semi-natural birchwoods, but they possess their own distinctive fauna which, as this study has shown, can be further enhanced by the inclusion of a birch element. In addition, different stand ages cater for different suites of invertebrates. In broad terms, the open moorland/ grassland sites were much poorer for invertebrates than the wooded sites both in terms of abundance and species richness, although they have their own characteristic communities.

Work is continuing to translate these survey results into practical prescriptions for forest management. With sampling carried out at only three sites, the general applicability of the results should be treated with caution. However some general principles can be observed.

- Insect abundance and diversity can be increased in spruce forests by retaining a

birch component in restock areas in some compartments.

- In most upland spruce forest, birch naturally colonises restock sites and there should be no need to introduce it artificially.
- Spruce stands with varying densities of birch should be aimed for, with some stands maintained as pure spruce. A small number of areas should contain clumps of birch over 30 m across, particularly in those forests where semi-natural birchwoods already occur.
- Creating a mixture of both spruce, and birch/spruce stands of different ages should be considered at the whole forest scale.

Work continues on the analysis of data and further monitoring in spruce stands will be undertaken as part of the project on assessing biodiversity in managed stands.

JONATHAN HUMPHREY

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ESTIMATING DEER POPULATIONS

Research Division is seeking to provide a sustainable basis for deer management. To achieve this, reliable methods of deer density estimation are required. Current research on an established method, faecal pellet counting, and a novel method, thermal imaging, is described.

Faecal pellet counts

Faecal pellet counting has been used for some time for population estimation of red (Ratcliffe, 1987) and roe (Ratcliffe and Mayle, 1992) deer. There are currently two principle methods of estimating deer density by faecal pellet counts.

- In areas with high deer densities, clearance sampling techniques have been developed to remove the need to monitor decay.
- In areas with low deer densities, transect sampling techniques have been developed to improve the accuracy of population size estimation. However, these involve the need to monitor dung decay rates in the range of forest habitats encountered.

Experience with faecal pellet transect sampling has highlighted the potentially wide variation in faecal pellet decay rates between and, in some instances, within habitats. Research has been initiated to refine the methodology to improve the accuracy of this technique by:

- identifying the relative importance of physical, climatic and microbial factors in dung decay;
- determining the impact of deer diet on dung decay; and
- investigating the use of convenient substitutes for dung in decay rate determination.

In addition, a study is under way to provide practitioners with a ready-reckoner for dung decay rates by deer species, climatic zone, and vegetation type.

Thermal imaging

Night use of thermal imaging equipment for distance sampling to estimate deer density is being investigated. Thermal imaging equipment enables the observer to detect deer with minimal disturbance to the animals, thus reducing the risk of biased density estimates. Initial night trials indicate that roe deer allow observers to approach to within 15 to 50 metres before taking flight.

Previous studies using aircraft-mounted thermal imaging equipment to count woodland deer have not proved viable; long-wave radiant energy emitted by the mammals is deflected by vegetation and therefore not visible through green canopy foliage. This investigation used hand-held thermal imaging equipment providing a lateral view into pole-stage and mature forest stands. The investigation examined the factors which are likely to bias a line transect estimate of density.

Equipment was provided by Thorn EMI Electronics Ltd, and was a prototype LITE direct view imager with an electrically cooled detector array, powered with a 12 volt DC battery belt and fitted with a x9 magnification lens. This model is sensitive to electromagnetic radiation between 8 and 12 micrometers in wavelength (encompassing the range of wavelengths emitted by homeotherms) and is capable of resolving temperature differences down to 0.015°C. The imager is light enough to be held (3.9 kilograms). Surface temperature variation shows as differences in brightness in the viewfinder; deer and other mammals are conspicuously brighter than almost all other natural objects.

Three line transect sampling methods were investigated.

1. Parallel transect lines, spaced 300 m apart and running across the forest at a bearing of 45–225°, which were walked.
2. Transect lines consisting of existing roads and rides which were walked.

3. Transect lines consisting of existing roads which were followed with an open-topped vehicle.

When walking the observer always worked into the wind. When this proved impossible, the transect samples were subsequently excluded from analysis, to minimise the risk of distorting the distance estimate. The compass bearing and estimated perpendicular distance to the transect line was recorded for all observed deer, and their position marked on a map. Behaviour and any apparent alertness directed at the observer was recorded. The previous position of a moving deer could sometimes be located, if it had been lying, from the heat radiation from the ground. Observations were disregarded if this was not possible and the animal had been disturbed. Direction of movement was always noted to eliminate repeated observations of disturbed deer. Deer were classified wherever possible into sex and age class (adult or juvenile). Antlers were usually readily visible during the study period (January 15–31).

Density and precision estimates were made using software (DISTANCE) provided by Professor S. T. Buckland (Department of Statistics, University of St Andrews). Seven blocks of Alice Holt Forest (Hampshire) were surveyed as separate strata, although distance data were pooled across strata to estimate a combined detection function. Generalised linear models were used to examine the influence of visibility and sampling effort on detection, frequency and distances.

Line transect estimates

1. Parallel transect lines. Movement through the forest was found to be slow and too noisy in some stand types, resulting in frequent disturbance and a marked peak in sightings at short distance (15–30 m) from the transect. This method was discontinued before completing the whole forest.
2. Walked rides. A slightly higher number of detections was obtained between 15 and 30 m, suggesting some disturbance effect, but beyond 30 m detection probability declined steeply up to 100 m. A few deer were detected at greater distances where rides or vantage points provided longer view. The density estimated was 24.1 per km² with a 95% confidence interval of 17.3–33.6.
3. Vehicle. The vehicle provided an elevated view resulting in a slightly greater detection distance and a wider effective strip width. The detection rate was slightly lower. Roads provided less access to the forest than rides resulting in conspicuously higher or lower density estimates for several blocks.

Response to an observer

Most deer (79.8%) seen were stationary; 3.9% were seen or heard running away, although 14.0% had already alerted towards the observer when first detected. The usual response of the deer was to look in the direction of the observer for some moments before deciding to walk or run away, enabling the observer to identify the animal and its location.

Table 15. Summary of the vegetation types, visibility and numbers of deer seen in each type

Vegetation type and age since planting	Area	Visibility (m)		Deer seen	Deer seen/km²
		Ground (45 cm)	Standing (105 cm)		
Restock 1	21.1	99	204	17	80
Restock 2–3	40.8	72	152	27	66
Restock 4–5	27.9	44	95	14	50
Restock 6–8	24.4	25	55	9	37
Conifer thicket 9–23*	101.6	25	33	9	9
Broadleaved thicket 9–23	30.0	13	16		
Conifer pole 24–41	107.1	47	78	20	19
Conifer mature 42+	58.1	35	111	25	43
Broadleaved pole + mature 24+	254.5	45	65	69	27
Car parks + picnic sites	54.4	80	150	17	31
Rides	49.6	>100	>100	37	75
Fields	32.3	>100	>100	8	25

* Includes 17.8 ha of older stands with a thicket understorey.

Visibility

Visibility varied in relation to plantation age (Table 15), and declined as a quadratic function of age of restocked stands but increased again during the thicket stage. In thinned conifer stands ground visibility decreased but standing visibility increased with age. In broadleaf stands (mostly oak or ash with an understorey of hazel or hawthorn), no significant change in visibility with age was found, although thicket stage stands were denser than pole and mature stands. Vegetation density at ground and standing height was significantly related to both detection distance and deer seen per unit area. An increase in observation effort did not result in significantly more sightings per area.

Discussion

Both vehicle and walked ride censuses yielded a progressive decline in detections with increasing distance from a transect line, indicating that detection function can be fitted reliably and that density can be estimated with little or no bias. There was, however, a peak in observations in the vehicle census at distances greater than 135 m (mainly deer feeding in fields at the forest edge), but deleting these observations had little effect on density estimates. When transect lines within stands were walked, increase in observer noise resulted in a marked reduction in detections close to the transect line. This sampling method requires a clear understorey or transect lines that are carefully brashed and cleared beforehand.

Irrespective of sampling method, there was a marked reduction in observations as stands approached the thicket stage suggesting that distance methods are unlikely to be practical in areas of extensive thickets. More deer were observed on newly restocked sites and rides than in tree stands. Faecal pellet based studies of habitat selection indicate that these are preferred forest habitats and deer, which are often disturbed during daylight hours by walkers and stalking, and so need to exploit open areas for feeding at night.

Observations of deer behaviour supported the conclusion that observer disturbance prior to detection was minimal. However, this was only the case when wind direction was favourable and the observer was able to move quietly. Deer did not show any increase in alertness when the census was done by vehicle. Weather seemed to influence deer activity, as deer appeared to use shelter more in cold, wet or very windy weather. Censusing was avoided during bad weather as the thermal imager does not work well in heavy rain. The influence of weather requires further investigation.

Conclusions

Hand-held thermal imaging equipment appears to offer good potential as a tool for estimating woodland deer populations. Vehicles offer an efficient way of conducting distance sampling censuses where road access is not limiting. Alternatively, walked census routes using roads and rides could be used. Where ride access is insufficient, easily traversable transect lines must be cleared through stands. The effect of differing vegetation density on detection rates and distances, patterns of habitat selection at night and the factors affecting them, will be the subject of further investigation. The accuracy of sexing and ageing animals and measuring observer–animal distances will also be studied. In hilly terrain thermal imagers are capable of detecting deer at distances of up to 1500 m; in these situations the potential for night vantage point counts will be determined. Studies comparing distance sampling using thermal imaging equipment with other census methods for deer are continuing.

ROBIN GILL AND BRENDA MAYLE

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COMMUNICATIONS

Research Advisory Service

This service provides access to specialist staff who can give expert advice or current information on a wide range of subjects related to forest research and management of trees and woodlands. Initial response to enquirers by phone or by despatch of an information note is free of charge. More detailed advice or assistance is subject to a modest scale of charges.

Total enquiries exceeded 3000 during the year: 28% were from within the Forestry Commission, 17% from the private forestry sector, 7% from local authorities and other government departments, nearly 40% from private individuals, and the remainder arose from media enquiries or miscellaneous sources.

JOHN PARKER

Library and Information Service

The Library at Alice Holt Lodge has seen continued demand for its services by Research Division staff, the rest of the Forestry Commission and outside users. A collection of over 100 videos on forestry subjects is prominently displayed for reference by Commission staff. Over 600 scientific and technical journals are received on subscription or through worldwide exchange agreements. The *Current awareness* listing on electronic mail generated over 4500 requests from the Department of Forestry, The Forestry Authority and Forest Enterprise. The Library at the Northern Research Station has seen further improvements to its reference collection in the past year and some weeding of stock.

The new information technology area in the East Reading Room at Alice Holt Lodge has proved very useful. It provides a convenient and central area for access to the CD-ROMs and to the library catalogues on adjacent terminals. These are connected to the Alice Holt local area network and also link into the Forestry Commission's electronic mailing system. In addition to the CD-ROMs for *TREE-CD* and *CAB-CD* (now covering 1984 to 1992), *Current contents for agriculture, biology and environmental sciences* on disk is available, and search profiles for specific subjects are set up for researchers. A non-bibliographical service, *Autoroute plus,* was recently installed to help in journey planning.

Assistance to users is being developed with the distribution of help notes on the CAIRS Information Management System. CAIRS not only has the Library's catalogues of books, reports and articles but, during the year, the Research Division photo slide library catalogue was also imported from a separate CAIRS system. These are now available to everyone with access to the local area network, including staff at the Northern Research Station. Training of users in search techniques to improve subject retrieval from the CD-ROMs and the in-house catalogues is planned.

CATHERINE OLDHAM

Photography and graphic services

Two photographers, one at Alice Holt Research Station and one at the Northern Research Station, provide a professional photographic service to support the recording and documentation of research projects, experiments and field trials. On occasions, photography may be undertaken on behalf of other parts of the Forestry Commission or, exceptionally, for external customers. A photographic library of over 41 000 transparencies is maintained, primarily of scientific and technical research subjects related to forestry, wildlife and the environment. Copies of slides are available for sale or loan. Many requests are received for use of material as illustrations in books, journal articles, leaflets and magazines.

A comprehensive computer graphics service provides 35 mm transparencies, overhead projector acetates, and paper prints in black and

white or colour, from input data or original illustrative material. The Division's monthly newsletter for staff, promotional leaflets on the work of the research branches and on the information and advisory services, publicity posters, contract reports, etc., are now produced in colour to the stage of final lay-out using computer-based design programs.

GEORGE GATE

PUBLICATIONS

The following titles were published during the year ending 31 March 1995.

Reports

Report on forest research 1993 (£18.00).

Report on forest research 1994 (£20.00).

Bulletins

110 Reclaiming disturbed land for forestry (£12.95).

111 Forest nursery practice (£25.00).

113 Management of forests for capercaillie in Scotland (£6.00).

Guidelines

Forest landscape design (2nd edition) (£5.75).

Handbook

10 Wildlife rangers handbook (revised) (£15.95).

Technical Papers

5 The private woodlands survey (£5.00).

6 Provisional yield tables for poplar in Great Britain (£4.50).

7 Champion trees in the British Isles (4th edition) (£5.00).

8 Managing forests for biodiversity (£5.00).

Miscellaneous

Identifying Phytophthora root disease of alder (free leaflet).

Research Information Notes

244 Lifting times for larch establishment.

248 Stump treatment against Fomes – a comparison of costs and benefits.

249 Using tatter flags to assess exposure.

250 Estimating the age of large trees in Britain.

251 Forest condition 1993.

252 Dutch elm disease in Britain.

253 Protected-zone surveys in Great Britain.

254 Merlins and forestry.

255 Red squirrel conservation: field study methods.

256 Using waste materials in the forest: the implications of recent legislation.

257 An improved understanding of windthrow: moving from hazard towards risk.

258 Phytophthora root disease of common alder.

262 Forest condition 1994.

KATHY DAVIES

STATISTICS AND COMPUTING NORTH

Available staff resources this year meant that independent statistical and computing work had to be curtailed, and effort concentrated on our service role. In statistics, this included work on tatter flags, seed germination, DNA fingerprinting, tree pulling, root systems, and mycorrhizal experiments. In computing, most effort was directed towards providing user support and improving our system and working methods.

DATABASES

The Experiment Register Database contains establishment details on over 7000 field experiments. Information held on the database has been updated and routines have been written to allow more user-friendly access to the database. Progress has been made on simplifying the process of data collection and entry.

In the past, Silviculture North and Tree Improvement Branches were the only ones routinely supplying information for entry onto the database. From this year, all branches within the research station will provide information on field experiments of more than six months duration. This development required an up-to-date, reliable, central register of current experiments to provide more control of resources and better management. It can be used to alert project leaders of plans to sell forest blocks as part of the Forestry Commission's disposals policy.

A computer program has been written which will give lists of experiments within a specified area of a central grid reference. A new system for initiating experiments allows the next available experiment number at a site to be reserved from desktop PC or terminal, and keeps the on-line database of experiments up to date. Lists of new experiments can be quickly identified for administrative action.

A database for plans of operation has been developed and installed at each field station. This is currently used by field station staff as a management tool, enabling them to plan and cost their work schedules. Full details are held on all work and assessment operations carried out on each experiment and a menu system has been developed to facilitate extraction of information from the database.

OTHER COMPUTING

Data input was moved from PCs to the UNIX server. The advantages included simpler backing up of datasets, a reduced risk of losing work, and additional flexibility through one operator being able to verify data while they are entered by another. Logging of datasets through the various data preparation stages was computerised. Users can now identify datasets currently being processed and check the progress of particular jobs.

The wide area network link to headquarters was used experimentally for data transfer to and from field stations. This has proved very useful especially when quick turn around of data was required.

The introduction of a system of automatic handling of standard updates such as changes to start-up files eliminated the need to deal with 60 PCs individually.

COURSES

Courses were held on use of the network, the database for plans of operation, Structured Query Language, and several other software packages.

IAN WHITE, WAYNE BLACKBURN AND ALVIN MILNER

STATISTICS AND COMPUTING SOUTH

Modern developments in computing and statistics create opportunities for new experiments, analyses and insights, and these contribute to the scope, quality and reliability of research.

For example, the Computing Section has increasing experience with optical scanners and will be working to support Silviculture South Branch in making comprehensive measurements of root growth with a scanner and image analysis software.

Andrew Peace, a senior statistician, has given advice on the sampling, monitoring and assessments of the Biodiversity Research Programme. The challenges include identifying efficient techniques for the methodology, assessment and monitoring of biodiversity on large representative scales, as well as at the stand level. Statisticians also have to consider the extent to which assessment methods for forest biodiversity can be simplified for practical application.

Andrew has applied new methods of analysing data on pretreatment and seed dormancy using Weibull functions. The parameters of the Weibull function represent the quantities of interest: maximum germination, germination rates and the lag in the onset of germination. He is also developing methods of analysing categorical data generated in experiments by Plant Production Branch.

There has been considerable work on estimating deer populations from the quantity of dung and it is essential to know the longevity of dung. Andrew has developed a number of models for estimating decomposition rate. These innovations make it possible to answer new questions and to provide more accurate and reliable answers to old ones.

Lesley Halsall, of the Programming Section, has developed data-capture programs for experiments in seeds research. These provide entry forms and make numerous checks on the data entered on the Husky hand-held computer. They also provide the correct date, carry out preliminary calculations and format the output. Jon Taylor, a statistician, has been developing more incisive statistical analyses of the same data, built into a package with comprehensive error checking and flexible options. Together, the two projects provide an integrated system for data entry and analysis which minimises the risk of transcription errors, validates entries, and performs appropriate analyses. These developments maximise the value of the experiments and display features in the data that could otherwise not be seen.

The data preparation staff have prepared data-entry programs to make checks on data quality and on their own accuracy. Each data item can be checked to see that it is of the right type and lies within an appropriate range. They now enter some data directly into Oracle databases whose flexibility increases the range and complexity of feasible analyses. Our experience with Oracle has proved useful, most notably in two major European Union (EU) projects.

During the year, the modelling section started a new project funded under the EU Environment programme to study the *Long-term effects of elevated CO_2 and climate change on European forests.* This involves 14 research groups across Europe and the major effort is modelling the response of forests to possible changes: increased drought in the Mediterranean region and rising temperatures in boreal forests. The aim is to understand mechanisms of acclimation and feedback processes at tree and stand level. Tony Ludlow is one of the four co-ordinators of the project.

As part of a contract with the Food and Agriculture Organization, another of our statisticians, Tracy Houston, spent a month in China advising on statistical design and analysis. The brief was to review the design, layout and analysis of current experiments, to run a workshop to train local staff in relevant aspects of experiment design and analysis, to review the computing arrangements and to make recommendations for future developments.

She reviewed almost 60 current experiments, checking many of them on the ground in Naiman, Tongyu, Zhangwu and Jinxian in the Three North Region within a day's journey of Tongliao. The soil types in this region are mainly sandy semi-desert or saline-alkaline. The purpose of the project is to provide new forest cover, and it is being undertaken on a

vast scale. The main species used are poplar and Scots pine, and the experiments are largely concerned with testing clones and provenances.

Since almost all of the current experiments in the project are single factor randomised block designs, there were relatively few statistical problems. The most common failures were lack of randomisation or lack of replication, and these basic principles of statistics were covered in the workshop. The project leaders wanted to introduce more complex designs to include planting dates or depths. These were finalised with the two other international consultants working on the project, and Tracy explained them during the workshop, using her own statistical software to provide randomised layouts.

The computing arrangements for storage and analysis of experiments were planned during the visit, and programs in SAS were due to be written to perform analyses. However, few people understood English well enough to use the Western keyboards and a Chinese consultant will set up a system to accept project data and give prompts in Chinese. Tracy gave advice on the structure and format of the proposed data files to make them easily accessible to SAS, and suggested two possible approaches to setting up the system, depending on whether or not a permanent analyst/computer operator becomes available. Statistical programs will be written when the system design is agreed.

TONY LUDLOW

POLICY STUDIES DIVISION

SOCIO-ECONOMIC RESEARCH

The Forestry Commission's Policy Studies Division is not part of the Research Division, but is responsible for commissioning and undertaking research into the social and economic impact of forestry. Further information about this research may be obtained from the Policy Studies Division at the Forestry Commission's Headquarters in Edinburgh.

WORK COMPLETED IN 1994/95

Marketing hardwoods as a local product

This study examined the scope for enhancing the value of domestic hardwood by promoting it as of local origin. It used case studies, based on examples of local initiatives that are seeking to promote woodland products in this way. It concluded that there is little evidence that consumers (other than local authorities and tourists) are willing to pay premium prices for local products.

Marketing large volumes of low value timber

This study examined the nature of low value timber markets in Britain and the scope for their development. It identified options for utilising large volumes of low-grade timber and identified the most promising new markets for low-grade timber as energy production, engineered structural products and flooring.

Marketing woodland products from woods close to towns

This study identified potential markets for goods and services that could be produced from community woodlands. In particular the study concentrated on the likely scope for production of final goods within the local area.

Marketing of coppiced chestnut products in south east England

This study examined traditional markets for coppice chestnut products and the extent to which they had been taken over by substitutes. It looked at the scope for recapturing these lost markets (e.g. through promotion and good design), and for gaining access to new markets (e.g. charcoal, tree stakes, door sills, flooring, rustic garden furniture and river/canal revetments).

Cost–benefit analysis – twelve community forest projects

The Division played a leading part in preparing cost-benefit analyses for the 12 community forest projects in England. As well as marketed costs and benefits, the analyses incorporate valuations for carbon sequestration and recreational use. Recreational value (which is the most important benefit) was assessed using contingent valuation surveys carried out in the three lead project areas (Forest of Mercia, Thames Chase and Great North).

Private Woodlands Survey

This completes the surveys of private sector timber production costs carried out over the period 1989–1992 by the universities of Aberdeen, Bangor and Oxford and is published as Forestry Commission Technical Paper 5.

Rural property market: the influence of woods on property values

An analysis of 135 questionnaires returned by land agents and valuers throughout Britain in 1993 showed that woods on farms and estates can increase their value by up to 10% (as high as 30% in Scotland).

Forest Employment Survey

This updated earlier work carried out in 1988/89 and examined employment levels within the forestry industry in Britain. A sample survey of woodland owners, forest management companies and timber harvesting companies was carried out; the analysis will be published in 1995. Preliminary results indicate a small reduction in the number of people employed in the industry.

Surveys of consumption of British grown roundwood

These surveys are conducted annually on behalf of the Home Grown Timber Advisory Committee, Supply and Demand Sub-Committee. Aggregate results were published in a press notice and showed:

	Softwood		*Hardwood*	
	1992	1993	1992	1993
Sawlog consumption ('000 m^3 ub)	3135	3247	303	238
Total consumption of British grown roundwood ('000 green tonnes)	5792	6067	828	688

Public Opinion Survey

Sixteen questions were included in an omnibus survey of about 2000 British residents aged 16 and over to assess the level of public knowledge about forestry and the opinions held of forestry. The report (to be published as a statistical bulletin) indicates that, for many people, provision of wildlife habitats and prevention of global warming are the most important reasons for providing public support for forestry. Half the respondents wanted to see more woodlands created in their own area.

UK Day Visits Survey

This collaborative survey estimates the number and nature of leisure day trips to British town and countryside. The 1993 survey indicated that there were more than 200 million visits to woodland during the summer six months; summary results were published in 1994 in *Countryside Recreation Network News* and a full report is being prepared by the Centre for Leisure Research, for publication in 1995. A similar survey was run for the full year in 1994, with results to be published in 1995.

National Parks All Parks Survey

This collaborative survey in 1994 investigated the number and nature of visits to the ten national parks, the New Forest and the Broads. Results are due to be published towards the end of 1995.

NEW RESEARCH (TO BE COMPLETED IN 1995/96)

Strategic review of roundwood marketing

This collaborative project aims to identify and evaluate factors that influence private sector harvesting and marketing of roundwood and to assess the relative importance of different methods of selling and buying roundwood. It will make recommendations on ways in which the marketing of roundwood might be improved at national and regional level.

Valuation of the management of Britain's forests for biodiversity

The management of forests for increased biodiversity may incur significant costs. This study seeks to value the benefits arising from measures to enhance biodiversity in forests, using focus group analysis and a contingent valuation/ranking survey.

Farmers' attitudes to tree planting and management in Wales

The uptake of Woodland Grant Scheme grants by Welsh farmers is relatively low. This collaborative research will explore the reasons for this. It is in two parts: a study of farmers' attitudes towards forestry; and an economic study on the financial viability of farm forestry.

Role of woodland in meeting planning objectives in Britain

This research will examine the scope for using the current statutory land use planning system to promote the interests of forestry.

The potential for community participation in forest management in rural areas

This project seeks to assess the potential role of community-based participation in forest management in rural areas.

DAVID HENDERSON-HOWAT

PUBLICATIONS BY RESEARCH DIVISION STAFF

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RESEARCH DIVISION BRANCHES AND THEIR PROJECT GROUPS[1]

APPENDIX 2

	Project leader(s) at 31 March 1995
Entomology	
Advisory and taxonomic	T.G. Winter
Beech bark disease	D. Wainhouse
Biodiversity	C.I. Carter
Dendroctonus micans	N.J. Fielding, D. Wainhouse
Elatobium abietinum	C.I. Carter
Hylastes and *Hylobius*	S.G. Heritage, R. Moore
Impact	N.A. Straw
Panolis flammea	S.G. Heritage
Plant health services	N.J. Fielding
Stress	D. Wainhouse
Environmental Research	
Air pollution	M.S.J. Broadmeadow, D.W.H. Durrant, P.H. Freer-Smith, A.J. Moffat
Chemical analysis	E. Ward
Effects of trees on sites	A.J. Moffat, T.R. Nisbet
Forestry and environmental change	M. Broadmeadow, P.H. Freer-Smith, D.A. Waddell
Hydrology: water quality	T.R. Nisbet
Instrumentation	T.R. Nisbet
Lowland production forestry	A.J. Moffat
Reclamation	A.J. Moffat
Forest Products	
Preservation	J.F. Webber
Quality and value enhancement	J.F. Webber
Wood and timber properties	J.F. Webber
Mensuration	
Management services	J.M. Methley
Measurement studies	J.M. Methley
Sample plots	J.M. Methley, J.C. Proudfoot
Site yield	R.W. Matthews
Yield modelling	R.W. Matthews
Mycorrhiza Research	
Mycorrhizas	C. Walker
Pathology	
Damage monitoring and risk assessment	J.N. Gibbs, S.C. Gregory, D.B. Redfern, R.G. Strouts
Disease diagnosis	D.B. Redfern, D.R. Rose, R.G. Strouts
Dutch elm disease	C.M. Brasier
Fomes root rot	B.J.W. Greig, J.E. Pratt, D.B. Redfern
Oak dieback	B.J.W. Greig
Poplar diseases	D. Lonsdale
Stem decays	D. Lonsdale
Plant Production	
Nursery research	R.L. Jinks
Seed research	P.G. Gosling, S.K. Jones
Seed testing	P.G. Gosling, Y.K. Samuel
Silviculture North	
Crofter forestry	A.L. Sharpe
Farm and community forestry	J. Simpson
Nurseries and establishment	J.L. Morgan
Nutrition and site yield	J.C. Dutch
Planting stock quality	H.M. McKay
Reclamation (north)	M. Riley
Root growth and form	B. Nicoll
Species and long-term experiments	W.L. Mason
Stability	B.A. Gardiner, C.P. Quine
Stand structure and natural regeneration	C.J. Nixon

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

	Project leader(s) at 31 March 1995
Silviculture South	
Ecology of native broadleaves	R. Harmer
Energy coppice, urban and community forestry	A. Armstrong
Establishment and stand silviculture	G. Kerr
Farm woodlands and weed control	I. Willoughby
Poplars	P.M. Tabbush
Species and arboreta	J.E.J. White
Statistics and Computing South	
Forest growth process modelling	A.R. Ludlow
Tree Improvement	
Biochemical variation	G.I. Forrest, J. Cottrell
Flowering	J.J. Philipson
Forest reproductive material regulations	A.M. Fletcher, C.J.A. Samuel
Improvement and propagation of farm forestry broadleaves	E.P. Cundall
Micropropagation	A. John
Origin	C.J.A. Samuel
Production: clone banks and orchards	W. Brown
Rejuvenation	A. John
Testing progeny and clones, and genetic gain trials	S.J. Lee
Woodland Ecology	
Assessing biodiversity	R. Ferris-Kaan
Biodiversity Research Programme	S.J. Hodge
Decision support systems	D.G. Pyatt
Deer population ecology	B.A. Mayle
Forest bird ecology	S.J. Petty
Impact of forestry on peatlands	A.R. Anderson
Mammal damage to woodlands	R.M.A. Gill
Mammalian predators	A.H. Chadwick
Soil water management in forests	D. Ray
Squirrel management	H.W. Pepper
Woodland habitat management	J.W. Humphrey

NET EXPENDITURE OF RESEARCH DIVISION 1994/95

APPENDIX 3

£000s

Branch	*Expenditure by branch direct (a)*	*Net value of in-house services less those provided (b)*	*Commissioned research (c)*	*Expenditure attributable to branch*
Entomology	659	135	35	829
Environmental Research	453	143	43	639
Forest Products	72	12	222	306
Mensuration	239	24	–	263
Mycorrhiza Research	44	17	–	61
Pathology	674	168	52	894
Plant Production	190	89	–	279
Silviculture North	1868	–44	8	1832
Silviculture South	1152	89	31	1272
Tree Improvement	963	262	14	1239
Woodland Ecology	611	204	148	963
Communications	542	–184	–	358
Stats & Computing North	308	–300	–	8
Stats & Computing South	523	–421	–	102
Experimental Workshops	194	–194	–	–
Total	**8492**	**–**	**553**	**9045**

Notes:

(a) All directly incurred expenditure on wages and salaries, pension provisions, travelling and subsistence, materials, equipment, etc., plus office costs, common services and overheads of £2.509m less income of £1.529m for contract services provided to outside parties.

(b) 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.

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

CONTRACT WORK DONE BY RESEARCH DIVISION

APPENDIX 4

Brecon Beacons National Park	Silviculture and establishment of birch
British Coal	Opencast coal spoil reclamation Amenity tree health monitoring in England Demonstration and research in the National Forest
Countryside Commission for Wales	Feasibility of upland wood creation Silviculture of native woodlands in Wales
Department of the Environment – Arb VI	Development of plant quality index for broadleaved trees Health monitoring in non-woodland trees Minimising pavement damage from street trees Production of manual on decay and safety in trees
Department of the Environment	Effects of trees on urban air quality GM biopesticides: policy review Potential for woodland establishment on landfill sites Research and demonstration in the National Forest
Department of Trade and Industry (Energy Technology Support Unit)	CO_2 fixation by native woodlands Coppiced trees as energy crops Initial spacing in short rotation coppice Yield models for energy coppice of poplar and willow
Department of Transport	Alternatives to peat Backfill studies
English Nature	Goshawks in northern England
European Union	Assessment of risks from pinewood nematode Forest condition surveys Interdisciplinary research for poplar improvement Long-term effects of elevated CO_2 and climate change on European forests Short rotation coppice Tree nutrition and sustainability Tree seed dormancy
EU/AFOCEL	Northern conifers in fast growing conditions – a step towards an adequate wood supply for industry
EU/Casale Monferrato	International research for poplar improvement
EU/Danish Forest and Landscape Research Institute	Tree root architecture
EU/Finnish Forest Research Institute	Modelling risks to forests
EU/Highland Birchwoods: Life '94	Restoration of relict pinewoods
EU/IBN/DLO Holland	Mixed forests
EU/Imperial College	Chemical control of bluestain
EU/Institute of Virology and Environmental Microbiology	Transgenic poplar

EU/Macaulay Land Use Research Institute	Agroforestry
EU/Madaus AG	European *Aesculus* cultivation system
EU/University of Wales, Bangor	Poplar for farmers
EU/University of Edinburgh	The likely impact of rising CO_2 and temperature on European forests
EU/University of Kent	Restoration of environmental diversity by effective ecosymbiont monitoring (REDEEM)
FAO	Research design in afforestation, forestry research, planning and development in the three northern regions of the Republic of China
Grampian Regional Council	Ecological site classification for Grampian
Griffin (Europe) SA	Root control in container seedlings
Joint Nature Conservation Committee	Thermal imaging for deer census
Kemforschungszentrum (Germany)	Spruce root stock
Lothian Regional Council	Transplant performance
MacFarlane Smith	Animal repellent studies
Ministry of Agriculture, Fisheries & Food	Provenance testing Vegetative propagation Yield assessments
Niko Chemical Co Ltd	Animal repellent studies
ODA	Nutritional aspects of Chinese fir Tropical legume seed pretreatment
ODA/ECTF	China larch tree breeding project
Pilkington Trust	Control of *Ophiostoma novo-ulmi* by the d-factor
Scottish Enterprise	Condition of large planting stock
Scottish Forestry Trust, via TGA	Physiology of native Scots pine Private woodlands squirrel questionnaire 1991 Soil classification
Scottish Natural Heritage	Review of below-ground biodiversity Seed vitality in the Mar Lodge pinewoods
Scottish Wildlife Trust	Peatland restoration
Sierra UK	Fertilization of birch
Southern Water Services	Short rotation coppice/sewage sludge
Strathclyde Greenbelt Co	Mycorrhizas in spoil heaps Species choice on reclamation sites Use of sewage sludge
Wessex Water	Biogran dried sludge granules in land reclamation

RESEARCH CONTRACTS AWARDED BY RESEARCH DIVISION

APPENDIX 5

Avon Vegetation Research	Herbicide evaluation
Building Research Establishment	Application of GREENWELD technology to British timbers Distortional stability of Sitka spruce Improved machine grading Modelling strength properties of Sitka spruce Testing British grown hardwoods for British standards Testing British grown softwoods for European standards
Dundee Institute of Technology	Genetic engineering of English elm
Ecoscope Ltd	Deadwood management
Environmental Management Consultants Ltd	Introduction and establishment of understorey vegetation in woodlands
Forest Insect Surveys	Invertebrate fauna of birch in spruce forests
George Peterken	New native woodlands
Imperial College, London	Biological control of decay in utility poles Greenwood preservative treatments Potential of entomopathogenic nematodes for control of restocking pests
Institute of Hydrology	Effects of afforestation on water resources
Institute of Terrestrial Ecology	Capercaillie breeding ecology Invertebrate fauna of birch in spruce forests Riparian zone vegetation assessment
London University	Red squirrel habitat analysis
M. Thomas	Thermal imaging for deer census
National Rivers Authority (Welsh Region)	Effects of forestry on surface water acidification
Royal Greenwich Observatory	Modelling light conditions in forests
Royal Society for the Protection of Birds	Golden eagle ranging behaviour
Tweed Foundation	Fauna of a small stream
University of East Anglia	Windspeed prediction in complex terrain
University of Edinburgh	Genetics of Scottish aspen
University of Lancaster	The physiological impact of long-term exposure of trees to elevated CO_2
University of Nottingham	Development of transformation systems for Sitka spruce
University of Portsmouth	Management of bluestain in sawn timber
University of Sheffield	Immunocontraception of grey squirrels
University of Wales, Bangor	Crown development and timber quality Effect of provenance and silviculture on timber quality of oak
University of Wales, Cardiff	Conifer seed as a food for vertebrates

STAFF ENGAGED IN RESEARCH DIVISION AT 31 MARCH 1995

APPENDIX 6

RESEARCH DIVISION

Director J. Dewar, B.Sc., M.I.C.For. (*FC Headquarters, Edinburgh*)

Director's Secretary Mrs K. Morrice

Chief Research Officer (North) D.A. Rook, B.Sc., M.Sc., Ph.D., F.I.Biol. (*Northern Research Station*)

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

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

Head of Alice Holt Station. General responsibility for research south of the Mersey/Humber line, with specific responsibility for silvicultural research in the lowlands, and throughout Britain for research in environmental science, pathology, entomology, plant production, mensuration and research communication.

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J. W. Humphrey, B.Sc., Ph.D.
S. J. Petty, Ph.D. (*Ardentinny, Argyll*)
D. G. Pyatt, B.A., B.Sc., Ph.D., M.I.Soil Sci.
D. Ray, B.Sc.

INDUSTRIAL STAFF

The number of full-time equivalent industrial employees in Research Division at 31 March 1995 was 94 plus 9 students.

STAFF MOVEMENTS

New appointments

Miss F. C. Baldwin, ASO, Pathology Branch, Alice Holt

M. J. Parratt, ASO, Plant Production Branch, Alice Holt

Transfers in

J. Dewar, Grade 5, from Forest Management Division, Forest Enterprise to Director Research

Mrs K. Morrice, Personal Secretary, from Forest Management Division, Forest Enterprise to Research Division

Promotions

S. J. Hodge, to Woodland Ecology Branch on promotion to Grade 7

S. J. Lee, Tree Improvement Branch, Northern Research Station to Grade 7

Transfers out

S. R. Abbott, FOIII, from Mensuration Branch to Somerset and South Devon Forest District

A. S. Gardiner, ASO, from Plant Production Branch to ITE, Merlewood

P. R. Ratcliffe, Grade 7, from Wildlife Ecology Branch to Environment Branch, Headquarters

Resignations

M. C. Dobson, HSO, three-year fixed term appointment, Environmental Research Branch

I. W. Martin, Grade 7, Statistics and Computing North Branch

End of period appointment

P. Jokiel, HSO, end of three-year period appointment, Mensuration Branch

Retirements

D. A. Burdekin, Grade 5, Director Research, Alice Holt

I. D. Mobbs, Grade 7, Statistics and Computing South Branch, Alice Holt

D. Steele, AO, Office Services, Alice Holt

G. C. Webb, FOIII, Tree Improvement Branch, Shobdon

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Forestry Commission
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