FORESTRY COMMISSION

REPORT ON FOREST RESEARCH

for the year ended March 1965

LONDON
HER MAJESTY'S STATIONERY OFFICE
1966

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Forest Research Station, Forestry Commission, Alice Holt Lodge, Wrecclesham, Farnham, Surrey (Bentley 2255).

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All the photographs are taken from the Forestry Commission's own collection. The line drawings have been supplied by the respective authors.

INTRODUCTION

By J. R. THOM

Director of Research

Organisation and Staffing

Although not full implemented within the period under report, the major reorganisation of the Forestry Commission's headquarters may be mentioned here. Since this involved the creation of a functional-type headquarters to replace the almost purely administrative headquarters and the territorial directorates, the Commission should now have much improved machinery for the translation of research findings into practice and policy. The Director of Research now answers to the permanent Commissioner for Forest Management.

Mr. A. Watt, Director of Research, took up new responsibilities as Commissioner for Forest Management in June 1965. He was succeeded as Director by Mr. J. R. Thom, lately Director of Forestry for England, on the abolition of that post.

There are no important changes in domestic research organisation. The Report continues as a matter of convenience to cover certain of the activities of the headquarters agencies concerned with Research and Development. (Marketing, Planning and Economics, and Work Study.)

New appointments include D. A. Burdekin (Senior Scientific Officer) to Forest Pathology, and R. Stickland (Experimental Officer) who has joined us from Warren Springs Laboratory to take charge of the new Workshop Section.

Other staff changes are:

Transfers In:	A. Whayman (District Officer) to Work Study
	R. B. Ross (Mechanical Engineer) to Work Study
	A. H. A. Scott (District Officer) to Work Study
	Miss C. M. Davies (Executive Officer) to Library
	P. Hamilton (Executive Officer) to Establishment Section
	J. J. Richardson (Executive Officer) to Finance Section
	S. H. Sharpley (Executive Officer) to Publications and Library
Transfers Out:	J. W. L. Zehetmayr (Divisional Officer) from Work Study to West Scotland on promotion to Conservator
	S. Forrester (District Officer) from Work Study to West Scotland
	W. Henry (Executive Officer) to Hong Kong
	Miss E. Niven (Executive Officer) to H. Q. (Marketing)
	C. Ridley (Executive Officer) to H. Q. (Finance) on promotion
Promotions:	L. C. Troup (Work Study) promoted to Divisional Officer
	D. Bevan (Entomology) promoted to Principal Scientific Officer.

It is recorded with regret that M. V. Edwards (Silviculturist, North) was incapacitated by ill-health over much of the period under report.

Committees

The Advisory Committee on Forest Research (see page iii) met at Alice Holt on September 17th 1965. Officers from the Research Directorate continued to serve on a number of committees concerned with research in various fields

Conferences and Visits Abroad

1964 was a particularly busy season. Some of the principal meetings and travel assignments are listed below:—

Major Conferences etc. at Home attended by Research Staff

8th Commonwealth Entomological Conference, London, July 1964
Attended by Miss J. M. Davies (Entomology).

7th Commonwealth Plant Pathology Conference, London, July 1964.
Attended by D. H. Phillips (Pathologist).

12th International Entomological Conference, London, July 1964
Attended by D. Bevan.

FAO/IUFRO Symposium on Internationally Dangerous Forest Diseases and Pests. Oxford, July 1964.
Attended by D. H. Phillips, J. D. Low (Pathology).
D. Bevan, J. T. Stoakley (Entomology).

10th International Botanical Congress, Edinburgh, August 1964.
Attended by J. N. R. Jeffers (Statistician), R. M. G. Semple (Silviculturist (South)), J. M. B. Brown (Ecologist) and staff from Edinburgh Sub-Station.

Foreign Visits by Research Staff

D. Bevan (Entomologist), J. M. B. Brown (Ecologist) to Holland, Germany and Denmark, June 1964, to study *Dendroctonus micans*, *Ips typographus*, *Pristiphora abietina* and *Neomyzaphis abietina*.

D. Bevan to Swaziland in November 1964 to advise on *Hylastes* damage to pine plantations, under the auspices of the Department of Technical Co-operation. J. Jobling (Silviculture) to Holland and Belgium, June 1964, to attend meeting of a Regional Congress of the International Poplar Commission.

J. Jobling (Silviculture) to Cologne, January 1965 for the Regional Study Group on the Registration of Poplar Names.

J. N. R. Jeffers (Statistician) to France, June 1964, to attend course on non-linear programming at the NATO Advanced Study Institute Summer School.

J. N. R. Jeffers (Statistician) to Sweden, September 1964, with E. H. Bradford (H. Q.) to study application of mathematical methods to forest management.

R. Kitching (Soils Section) to Roumania, September 1964, to attend 8th International Congress of Soil Science.

J. R. Aldhous (Silviculture) to Canada and U.S.A., March 1965. Tour expected to last six months—to study provenance and seed supply of principal North American conifers planted in the United Kingdom, with especial attention to Lodgepole pine, *Pinus contorta*.

A. I. Fraser (Silviculture) to Republic of Ireland, March 1965, to study incidence of wind damage in plantations.

R. B. Ross and N. Dannatt (Work Study) to Finland and Norway, October 1964: Peeling machines and Lokomo draining plough, etc.

L. C. Troup (Work Study) to Norway, January 1965 Meeting to arrange FAO/ECE/ILO Joint Committee on Mechanical Barking.

L. C. Troup (Work Study) to Geneva, March 1965 to attend Joint Committee on Forest Working Techniques, Study Groups.

Visitors

The Minister of Lands and Natural Resources, The Rt. Hon. Frederick Willey, M.P., visited Alice Holt on 19th March 1965, accompanied by his Principal Private Secretary, J. E. Hannigan and the Parliamentary Secretary, The Lord Mitchison, and the Director General of the Forest Commission.

Other distinguished visitors to Alice Holt included the Director of the Czechoslovakian Forestry and Game Research Management Research Institute, Dr. J. Jindra. Also from overseas we had the pleasure of a visit by a party of Canadian Research Foresters, led by Mr. L. A. Smithers, who toured Scotland and Wales seeing experimental work in the field, and a party from the Association Forêt Cellulose 'Afocel' de Bordeaux, who visited Alice Holt and some southern forests; and also a party of Dutch forest officers. Officers from the Republic of Ireland toured in Scotland, studying provenance work especially, and others visited Alice Holt. We had the usual organised educational visits by forestry and other students to Alice Holt and field centres of Research.

We maintained and extended our contacts with other research establishments at home and abroad. Advisory work of all sorts now takes up a great amount of time, the load perhaps falling most heavily on the 'protection' sections, Entomology and Pathology.

REVIEW OF THE YEAR'S WORK

By R. F. WOOD

Conservator, Research Directorate

There is little change in the make-up of this *Report*.

The Season

The period April 1964 to March 1965 was not, fortunately, notable for any special climatic damage, though Britain had its fair share of gales, and the rather rapid alternations in weather over the winter of 1964/65 appeared to cause nearly as much blast damage to foliage as some much severer seasons have done. The rainfall followed the recent pattern by being abnormally low in the winter months, and rather more than adequate in the spring and early summer.

PART I

Seed

Service to the Commission and private forestry continues to bulk larger than research. The completion of the new seed extractory at Alice Holt is a notable event, but with poor cone crops much of the work so far has been in testing machinery and developing techniques.

In research on storage of *Abies* seed, after five seasons little improvement over conventional temperature and moisture control treatments has been effected by vacuum or gas (carbon dioxide) storage. This work continues.

Relatively large quantities of acorns are being stored at Alice Holt, for the first time.

Nursery Investigations

A few months after the period under report, Forestry Commission Bulletin No. 37, *Experiments on Nutrition Problems in Forest Nurseries*, by Miss B. Benzian of Rothamsted, was published. This is a milestone in nursery research. The Bulletin deals comprehensively with the collaborative programme of nursery research conducted by Rothamsted and the Forestry Commission between 1945 and 1962. This collaboration continues and various items from it are reported in Part II of this *Report*.

It has not been a particularly notable season in nursery research. In the North interest has centred on some of the new forms of fertiliser such as magnesium ammonium phosphate, and it seems likely that slightly soluble compounds such as this may have definite advantages. (See also Benzian, Bolton and Mattingly, Part II, page 88).

Some of our own long-term fertility experiments are nearing the end of their useful life and should be replaced with more critical experiments. It is doubtful whether they have told us much about the role of organic materials as such.

Work on herbicides continues, but without anything dramatically new in sight. Paraquat as a pre-emergent herbicide is dealt with by Aldhous in his first article in Part III, page 133. Work on the possible residues of simazine is also dealt with by Aldhous in his second article in Part III, page 141.

Whilst conifer seedlings are now being subjected to cold storage on some scale, and the more important species are giving little trouble, there are obviously a number of loose ends to tie up. Some preliminary investigations into root phenology are reported. Species appear to respond in very different ways.

Silvicultural Investigations

In our trial plantations at high elevations we have not as yet exceeded the levels at which plantations (at least of Sitka spruce) can be *established*, but it will be some time before much can be said about the *value* of some of the trial crops. An interesting and fairly recent indication that there has been a close connection between the nutrient status of trees and the effect of blast. This is being followed up experimentally. High elevation plantations in the North are dealt with by Neustein in Part III, page 169.

The useful flag-tattering technique of estimating exposure seems to have its limitations in Wales, where icing conditions are apparently more frequent than in Scotland.

A sufficiently formidable ploughing train has been assembled to make some impression on the indurated horizons typical of certain north eastern Scottish heaths. The immediate aims are experimental.

Nutrition continues to be a very active subject. Increasing attention is being paid to nitrogen in the North. In the South, detailed analyses have become available of the pole-stage manuring experiments and the indications are much more favourable than have appeared so far. Further work has been done on potassium deficiencies in peat soils.

Much interest has been stimulated by the exceptional growth achieved at Wareham, Dorset, by very full nutrition in the complete absence of weeds; (in fact one treatment in an experiment designed to show the effects of deficiencies in the major nutrients). Whether such optimum cultural treatments are economic or not, they are useful in providing some measure of the invariable factors of the environment, and it is the intention to extend them further.

We are now well advanced in an ambitious programme of experimental drainage covering the principal types, both organic and mineral, on which evidence of the economic effects of modern well-designed drainage systems is required. The main effort during the year lay in the two large experiments on deep peats at Clocaenog (Denbighshire) and Loch Ard Forest (Stirlingshire).

Under the general heading of *Regeneration*, work continues on a considerable variety of topics; overhead cover intensity in underplanting; size of felling coupe; cultivations in felled areas; brash disposal etc. Work in this field will undoubtedly increase year by year.

A number of long term mixture experiments laid down some ten years ago are beginning to produce information, not as yet of course on the main objects, but on the shorter term interactions of species in mixture. The experiment at Gisburn Forest in Yorkshire, which is being carried out jointly with the Nature Conservancy, is of interest at this stage in demonstrating very clearly the nursing effect of Scots pine on other species (Norway spruce and hardwoods) less tolerant of exposure. This experiment is particularly concerned with the ultimate effects of species on the site. A series of experiments in two-species mixtures, specifically designed to throw light on the vexed question of yield and value of species in mixture as compared with pure crops, and established some ten years ago, has also produced some interesting nursing effects. Western hemlock is markedly benefited in mixture with the faster-starting Sitka spruce. This is not surprising in a species so sensitive to exposure in its early years.

Provenance work with major species is now increasingly concerned with special environments, often on the margins of their useful range. However, work is also being done on a number of species now considered of secondary importance. It is satisfactory that we now have a comprehensive experiment in *Abies alba* in course of establishment. Many think this species has been neglected. The chief interest here will be in relative susceptibility of the various provenances to the harmful insect *Dreyfusia.* Modest work is also being done on *Abies grandis* and *Abies procera.*

Studies on the stability of trees to wind (in which the tree pulling technique has been one of the principal research tools) have reached the useful stage when they can be related to soil and topographical surveys to create (albeit tentative) maps of wind-throw hazard. (Pyatt, Part III, page 204). A start has been made on a large scale experiment to study the aerodynamics of wind flowing over forest crops of different densities.

Special observations are being made in Sitka spruce crops showing various crown symptoms thought to be associated with a fall-off in increment. In one approach, crops are being kept free from *Neomyzaphis* by spraying with malathion to obtain some estimate of the direct share of the insect in the reduction of increment.

The only two balsam poplars in regular cultivation (clones of *Populus trichocarpa* × *tacamahaca*) are now beginning to produce preliminary evidence on yield from ten-year-old trial plantations. They appear to be somewhat better than the average for the 'hybrid blacks' which are more commonly cultivated, and their useful range is greater. Work on spacing and pruning continues, and will shortly produce results of much interest.

While elm propagation by softwood cuttings in mist has reached a practical level of success, it seems difficult to increase the percentage 'take' much further. Hardwood cuttings are less successful. Experiments in the establishment of stocks raised from cuttings favour the relatively small and cheap plants raised by lining out one-year rooted cuttings for a season.

Ecology

Some interesting comments are made on the climatic conditions in the extensive pine woods at Thetford Chase (Norfolk and Suffolk) following regeneration fellings. It has been an article of faith amongst foresters that in many difficult environments 'it would be easier the next time round', but our faith is wearing rather thin. Here at Thetford it appears possible to create frost conditions if anything worse than those typical of the bare Breckland, and this factor may be important in the manipulation of crops in regeneration.

Mr. Brown has collaborated with the Entomologist in a study of the conditions in Sitka spruce plantations in Europe where the Spruce bark beetle *Dendroctonus* (not, fortunately, yet with us) has been a serious pest.

Forest Soils

(*Soil moisture, climate and tree growth.*)

Work on the water economy of major species continues. The observation that Corsican pine 'uses' more water than Douglas fir in the dryish south-eastern environment is further confirmed. It is going to be interesting to see what Sitka spruce does in comparison with pines (plots have now been established for this purpose). Traditionally it has 'high moisture requirements'. We now have good reason to suspect that we do not know what we mean by this!

Forest Pathology

One of the more important events is the replacement of creosote by sodium nitrite as a stump protectant against *Fomes*. The biological control method too (inoculation with the fungus *Peniophora gigantea*) is well proven, though confined to pines. Now we want a convenient mode of application, and a 'pill' is being developed.

The well-known defect of stem-crack in *Abies grandis* is for the first time being adequately surveyed and evaluated. Its incidence appears to be far less and—on preliminary appraisal—conducive to less degrade when it does occur, than has generally been believed. The degrade will however be further studied at the Forest Products Research Laboratory, Princes Risborough. The matter is of considerable importance, because at the present time the tree, which in addition to its relative insusceptibility to *Fomes*, is one of our most productive species, is very much under a cloud because of this particular defect.

It is of interest that there is still a 'hang-over' from the winter of 1962/63 in the progressive decline of trees damaged in that severe season. It is also notable that much milder winters, but with marked weather fluctuations, may be quite effective in producing various discolorations and blast symptoms in conifer foliage.

Forest Entomology

Work on the seed wasp *Metastigmus* on Douglas fir is described in Part III, page 185. Some brief notes on control measures for *Adelges* insects in seed orchards etc. are given. Work on the control of the Green Spruce aphis, *Neomyzaphis* aims to find a method which will serve as a research tool in analysing the part played by this insect in the loss of increment.

Mammals and Birds

Work on squirrels continues on the lines of the last few seasons. Experiments with warfarin have been made against voles and mice in the field; a practical method of control would be useful for local 'epidemic' populations.

Work on deer is aimed at collecting the necessary knowledge to manage populations for a low level of damage in the forest. Chemical repellents against birds in the nursery and animals in the woods continue to give rather disappointing results. Some development work has been done on fencing.

Forest Genetics

Work on flower induction since 1948 is reviewed in Part III, page 207.

The *Seed Register* is being revised and should be a more useful and practical document. Sitka spruce coned unusually heavily in the west of Scotland, although unevenly. This permitted the collection of seed from numbers of our candidate plus trees for progeny-testing, but also raised the question of home seed collection from this, our most important plantation species. The productive sacrifice in felling a sufficient number of heavily coning trees to obtain a year or two's requirements would not be great, and though the idea is somewhat unfamiliar to us, it should be kept in mind.

Our difficulties in obtaining 'North Pacific coastal' provenances of Lodgepole pine, *Pinus contorta*, have encouraged emergency programmes to ensure future home seed supplies with this species. Work on vegetative propagation of Sitka spruce by cuttings is beginning to yield more promising results. Difficulties here have handicapped the improvement programme.

Planning and Economics

The activities of this Headquarters' service branch are briefly reported here because of their research and development content. Work in Mensuration included the establishment of several new replicated thinning experiments. An important achievement was the completion of the new Management Tables for twenty conifer and hardwood species.

Plans for the new Census of Woodlands are described. It is of interest that the field data are to be recorded for both direct reading and automatic transfer to punched tape. This is one of several forestry applications for the document reading device 'Lector' which have been developed recently. In the field of Economics it is also stressed that advances are greatly dependent on modern methods of data processing.

The Soil Surveyor contributes a note on a study of potential wind-throw hazard under the forest conditions of the Scottish Borders. This is a topic on which there are close working relations with Silviculture.

Work Study

The Section is in process of expansion, and now has five teams in the field. An important advance is the addition of a Mechanical Engineer to the strength, for of necessity Work Study increasingly impinges on mechanical problems of all sorts. Studies in the production of pulpwood have bulked very large in the year's work, reflecting the growing importance of this side of the forest industry. Such investigations have included comparisons of transport 'systems', from the stump to the mill. The Section continues to produce information for management in various forms at a steady rate.

Utilisation Development

Brief notes are given on some of the projects recently completed in the joint programme of research with the Forest Products Research Laboratory of the Ministry of Technology at Princes Risborough.

Conversion studies of pruned and unpruned logs have clearly indicated that there may be a very considerable upgrading in the sawn timbers before time has allowed much production of 'clears'. This is instructive as the forester is apt to think of pruning purely in terms of clear, that is, knot-free, wood production. Besides this upgrading there may also be the objective of the removal of serious defects, such as black knots in Scots pine. It remains difficult to make reliable economic estimates of the value of pruning.

Plywood has been considered in the search for markets for poorer grade oak, and samples prepared by the Laboratory are promising technically speaking, though not all problems are solved. The cheap pre-drying kiln recently developed at the Laboratory should provide at least a modest contribution towards removing one of the worst complaints about home grown timbers, the lack of seasoning. Studies on the durability of small round wood fence posts are showing very clearly how extremely ephemeral is the life of untreated posts of many of the non-durable species. After only seven years less than a third remain sound, whereas no creosoted posts have failed. The experiments also highlight the differences between species, and also between soils, notably between peaty and mineral types.

Design and Analysis of Experiments

The Statistician surveys the work of the section and gives an indication of the current pattern of activities. From this it is clear that the field is steadily widening, as modern mathematical techniques and computational methods spread through research and development and outside to other aspects of the Commission's work. So far, the impact on management in the broad sense has been limited to a number of individual studies or model investigations (several of these will be seen listed in the Section papers appended). There is no reason why the process should stop here, but there is perhaps a difference in kind between the *use* of the available expertise and facilities for individual investigations, and the *adoption* by management of the new methodologies; interesting problems in communication, education and organisation will arise.

Statistics continues to maintain many mutually profitable contacts with other organisations over a diversity of subject matter.

One of the most important aspects of the year's work has been the attention given to data capture. One of our problems is that we have many different sorts of data, and we collect them under a great variety of conditions.

Publications and Library

The main activities in this field are briefly summarised. Special efforts are being made to keep field staff informed of the facilities available to them in the Commission's central library.

PART II

As usual this part carries progress reports on work supported by the Forestry Commission at Universities or other research establishments. Authors' summaries are available for the longer reports, and only very brief comment is necessary here.

From the Macaulay Institute, Aberdeen, J. B. Craig and H. G. Miller report on the long-term studies on nutritional and physical problems of Scottish forest soils. Much attention is being paid to nitrogen, the dune forest of Culbin being the chief centre of study. The basic studies on water relations in peat at the Lon Mor, Inchnacardoch Forest, add greatly to the interest of this classic peat experimental centre.

Several interesting reports from Rothamsted Experimental Station at Harpenden, deal with various aspects of the collaborative programme in nursery nutrition.

Miss Benzian, Dr. J. Bolton and Dr. G. E. G. Mattingly give an account of some of the forest experiments with the 'new' slow-release fertilizers in conifer seed beds. Such substances as potassium meta-phosphate and magnesium ammonium phosphate may well make the provision of adequate amounts of the main elements throughout the whole of the growing season a much simpler process, and less dependent on skill in forecasting the weather and the consequent necessity for top dressings.

The two interesting papers, by J. Bolton and J. K. Coulter, and G. E. G. Mattingly respectively, on the distribution and residual values of fertilizers in nursery profiles, illustrate that carefully conducted long-term nutritional experiments can make important contributions to soil science in addition to their primary role of supplying empirical evidence.

Also from Rothamsted, Dr. G. A. Salt reports on the continuation of his work on the Sitka spruce seedbed micro-flora and fauna. This work, in conjunction with the strictly chemical evidence, is clarifying the picture—albeit a most complex one—of the controversial pathological/nutritional border-land. On the purely practical aspect of seed economy, it is of special interest that seed-borne fungi may account for a considerable fraction of the missing numbers between those seeds viable (on test) and those seedlings actually emerging.

The last of the Rothamsted reports, by Dr. G. W. Heath, describes further progress in his investigations on the role of earthworms (especially) on the breakdown of leaf litter. Forestry Commission grants have encouraged a considerable range of studies in this very wide field of investigations in the last decade or so. It is, perhaps, a subject which may in future be considered better suited to the Natural Environment Research Council.

Dr. A. J. Hayes' work at the Department of Forestry and Natural Resources, Edinburgh University, on the mycology of Scots pine litter, falls in this important group of fundamental studies. This has close connections with Dr. Gifford's work (also from Edinburgh) on the micro-arthropod role in the breakdown of coniferous litter.

From the Department of Soil Science, University of Aberdeen, Dr. Tinsley and A. B. Hutchison give a further report on chemical changes in soil litter following the application of nitrogen fertilizers of several forms, with and without lime. A final report on these investigations is in preparation.

Dr. L. Leyton, Dr. E. R. C. Reynolds and Mr. F. B. Thompson of the Department of Forestry, Oxford University, report further on their studies on the water relations of trees and forests. Of special interest is the extension of the work to detailed studies of the removal of soil moisture by different parts of the root system of trees. The well-instrumented study of the interception of rainfall of various common constituents of upland flora is also noteworthy.

Dr. P. H. Thomas and Miss Margaret Law of the Joint Fire Research Organisation, Boreham Wood, contribute a further report on the basic physics of fire spread in forest fuels. Laboratory studies on standard experimental 'cribs' have been supplemented by observations on controlled lines in actual forest fuels.

Dr. W. A. Fairbairn of the Department of Forestry and Natural Resources, Edinburgh University, has continued his measurements of light intensity under various silvicultural conditions, in connection with regeneration studies.

Also from Edinburgh, Dr. Mutch reports on the important (and to us relatively new) recreational aspect of forest economy. Sampling of 'users' opinions on Forestry Commission camping sites etc. appears to indicate that facilities are inadequate for the increasing demand.

PART III

This section has a somewhat varied content of longer progress reports, especially reports on well-defined stages in long-term investigations; matters of chiefly methodological interest; and an occasional long report on a stage in a grant-aided investigation which may be more appropriately published in a Progress Report than as a finished paper elsewhere.

The longer papers carry short authors' summaries. In this issue, R. Faulkner deals with a considerable range of early experiments on flower induction in seed stands or seed orchards. D. G. Pyatt (of the Planning and Economics Division, Administration and Finance Department) gives an account of an attempt to estimate and delineate wind-throw hazard in one of the Scottish Border forests. In this field there has been close collaboration between Management Services and Research, and as the new Forestry Commission organisation comes into operation it can be expected that Research will be increasingly concerned in joint development activities with Headquarters' functional staff.

R. S. Howell and S. A. Neustein contribute a note on an approach to the estimation of exposure, an obviously complex factor which is not easily expressed by any simple general set of observations.

J. R. Aldhous has three papers on experimental work with various herbicides in the nursery and the forest. In this field, the estimation of hazards and the development of safe and profitable applications go together.

R. Lines and A. F. Mitchell deal with the special aspect of phenology in provenance studies of Sitka spruce. This is primarily important in relation to frost susceptibility, but is also of great interest in suggesting some part of the controlling mechanism behind varietal differences in growth rate.

J. T. Stoakley has some observations on the period of egg laying in the Douglas fir seed-wasp *Megastigmus spermotrophus*, the most important cause of poor seed production in this tree in home stands. An accurate knowledge of the habits of the creature is of course essential if there is to be any chance of control in valuable seed sources.

J. Farquhar gives an account of a series of experiments in the use of seedling stock for forest planting in the north. The one-year-old plantable seedling has seemed a possible target, but the weight of evidence now seems to suggest that it will not normally be attained in the more important species without control of the length of the growing season. S. A. Neustein has a short interim report on a series of semi-experimental high elevation plantations established in the North (principally in Scotland). These are mainly still too young to provide hard evidence on the economic limits of planting, but they do suggest very strongly that the planting limit will rarely be drawn by difficulties purely of *establishment*.

Dr. Myles Crooke, of the Department of Forestry, Aberdeen University has an interim report on a grant-aided study on the relationship between the populations of tits and the important defoliator of pines, the Pine Looper moth, *Bupalus piniarus*. This work continues, and it will be of much interest to have hard experimental evidence on the role of birds and the status of an important insect pest.

J. N. R. Jeffers' paper on the relationship between staff and work-load is an example of the mathematical techniques available to management which have been made practicable by the modern computer. The number of such special studies called for by Headquarters is increasing, and it seems likely that the new functional organisation will be better adapted to make use of these techniques.

PART I

Reports of Work carried out by Forestry Commission Research and Development Staff

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FOREST TREE SEED

By G. M. BUSZEWICZ

Service work on seed procurement, extraction, processing, storage, testing and supply continued as the main function of the seed section and, as in previous years, research on seed problems took second place to this work.

Service

Seed Procurement

As much as possible of the seed required is collected from home sources, that is from the Commission's own woods and plantations and, by arrangement with owners, from private woodlands. The amount of seed available from these sources varies greatly from year to year, but it is usually possible to meet our own requirement for most of the broadleaved species, although in recent years the crop of acorns and beechnuts has not been sufficient.

As regards conifers, with the exception of Scots pine and Corsican pine, there are still insufficient stands of seed-bearing age to make anything but a small contribution to our needs, it is therefore necessary to import our main requirements from overseas sources. The quantities of home-collected and imported seed are given in Table 1.

Cone crops continued to be poor. Despite great efforts only 417 lbs. of Scots pine and 34 lbs. of Hybrid larch seed were collected. Some success was obtained with Lodgepole pine seed, of which 114 lbs. were collected. No attempt was made to obtain Corsican pine seed because the stock held was sufficient for the next three years.

Altogether only 886·8 lbs. of conifer seed were collected at home and therefore the main bulk was imported; this amounted to 8,454 lbs.

The quantity of hardwood seed collected totalled 11,261 lbs. compared with 387 lbs. last year. Acorns made up the buk of this collection and amounted to 10,845 lbs. The acorn crop (with the exception of Red oak) was generally good in the south of England. To offset the shortages 15,255 lbs. were purchased from abroad.

Seed Supply

The quantities of seed distributed and stocks available are summarised in Table 2. The declining trend in conifer seed usage continues, and for the first time consumption has dropped below 10,000 lbs., which is just half of the amount used nine years ago, although the area of forest planted annually has not

Table 1

SEED PROCURED IN FOREST YEAR 1965

lbs.

Species (Conifer)	Home collected	Imported	Species (Hardwood)	Home collected	Imported
Scots pine	417·5	6·7	Red oak	—	1,000·0
Corsican pine	—	—	Pedunculate oak	2,912·0	9,559·0
Lodgepole pine	114·4	1,012·7	Sessile oak	7,933·0	2,758·0
Norway spruce	·3	205·0	Beech	31·0	1,936·0
Sitka spruce	66·9	506·0	Sycamore	50·0	—
Douglas fir	—	7·5	Maple	11·0	—
European larch	1·9	15·0	Ash	2·0	—
Japanese larch	13·8	2,854·0	Birch	8·0	2·2
Hybrid larch	34·3	—	Sweet chestnut	280·0	—
Western hemlock	11·6	223·0	Other	34·0	—
Western red cedar	·4	—			
Noble fir	99·6	1,069·0			
Grand fir	—	2,306·0			
Silver fir (*Abies alba*)	72·0	220·0			
Lawson cypress	12·7	—			
Other	41·4	29·1			
Total	886·8	8,454·0		11,261·0	15,255·2
Grand Total	9,340·8			26,516·2	

declined. Private forestry, though planting a lesser area, requires almost as much seed as the Forestry Commission, and it is interesting to note that it actually requires *greater* quantities of Scots pine, Norway spruce, Douglas fir, European larch, Japanese larch, Western hemlock and Lawson cypress.

As regards hardwood seed, Table 2 shows only those amounts distributed from imports, and the amounts collected at home (Table 1) should be added to give a total usage by the Forestry Commission of 20,308 lbs.

Seed Extraction

The year under review was the first operational season for the new plant at Alice Holt, and the work was concentrated on checking the efficiency and safety of the machinery, also on working out schedules for processing different batches of cones.

Altogether 394 bushels of cones were processed, yielding 249 lbs. of seed. The total amount of cones processed in all extractories was 1,566 bushels, made up as follows:—

Alice Holt	394 bushels	(England and Wales)
Tulliallan	296 bushels	(Scotland)
Speymouth	580 bushels	(Scotland)
Millbuie	296 bushels	(Scotland)

TABLE 2

SEED DESPATCHED AND STOCK IN HAND

lbs.

Species	Amounts supplied to: Forestry commission	Private forestry	Export, research, exchanges, etc.	Total	Stock in hand
Conifers					
Scots pine	427	495	19	941	706
Corsican pine	761	371	5	1,137	2,319
Lodgepole pine (Coastal)	393	176	4	573	733
Lodgepole pine (Inland)	117	51	—	168	155
Norway spruce	259	711	11	981	2,020
Sitka spruce	1,307	422	38	1,767	2,118
Douglas fir	479	530	3	1,012	1,974
European larch	115	374	44	533	632
Japanese larch	365	471	145	981	2,364
Hybrid larch	130	13	2	145	66
Western hemlock	79	109	3	191	819
Western red cedar	61	69	2	132	259
Noble fir	258	71	14	343	1,503
Grand fir	327	132	8	467	2,401
Lawson cypress	32	56	3	91	17
Others	312	44	15	371	522
Total, Conifer	5,422	4,095	316	9,833	18,608
Hardwoods					
Sessile oak	200	1,989	—	2,186	516
Pedunculate oak	1,722	2,034	135	3,891	5,629
Red oak	1,054	—	12	1,066	—
Beech	660	1,233	—	1,893	—
Others	7	1	4	12	—
Total, Broadleaved	3,643	5,253	151	9,048	6,145
Grand total, Conifer and Broadleaved	9,065	9,348	467	18,881	24,753

Seed Storage

The total seed stock held in our refrigerated Central Seed Store was 18,608 lbs. (Table 2) which is just sufficient for two years' requirement. The stock varies however for individual species and there is a shortage of Scots pine and Hybrid larch seed. For the first time acorns (6,100 lbs.) are being stored as a routine procedure, following the favourable results of experimental work.

Seed Testing

The essence of good seed testing lies in the application of reliable standard methods of examination to ensure that uniform and reproducible results are obtained. The United Kingdom, like most countries, has seed laws which serve to control the quality of seed on the market. One of the requirements of these laws is the provision of a certificate of seed quality, based on tests carried out on samples at an officially approved seed testing station.

The Forestry Commission has a private seed testing station which is licensed by the Ministry of Agriculture, Fisheries and Food. This station is attached to the Seed section and performs all service and research tests. During the year under review, 1,099 seed samples were tested on which the following analyses were completed:—

Purity	352
Seed size determination	452
Germination	1,298
Tetrazolium	64
Moisture content	448
Others	84

Of these tests about 20 per cent were carried out as part of the experimental programme, and the total also includes several tests performed for private forest owners.

Research

The weight of service work has necessitated a reduction in the number of research projects actively pursued. Improvement of techniques for greater uniformity of results of seed tests continued to be the major subject of investigations. In particular, the revision of the International Seed Testing Association rules involved a large programme of work. The final report on the Committee's work, which includes proposals for substantial changes in the present rules relating to tree species, will be discussed at the meeting of the Association in Munich in 1965, and the results of this will have important applications in our domestic seed testing work.

In addition, a series of germination, excised embryo, and tetrazolium tests on a number of dormant tree seed species were completed as a part of the programme of the Forest Seeds and the Biochemical Committees of the International Seed Testing Association.

Amongst current investigations, it is worth reporting on the work on the long-term storage of *Abies procera* seed, which started in 1959, and is planned to run for ten years. The object is to examine the influence on seed viability of length of storage; atmosphere; hermetic seal (vacuum and CO_2 gas seal); seed moisture content (4—16 per cent) and storage temperature (-30°C to $+20$°C).

Three different origins of *Abies procera* seed are being used, and the moisture content of each was fixed at four levels before the seed was packed in small hermetically-sealed tins containing enough seed for periodic check of germination and moisture content. The tins are stored at four levels of temperature, -30°C; -5°C; $+2$°C; and $+20$°C (room temperature). At $+20$°C two additional treatments are included:—

1. In vacuum—the air being exhausted from the tins.
2. In CO_2 gas, pumped into the tins.

The periodic checks of seed quality took place after 1, 2, 3 and 5 years of storage.

The next and final check is planned to take place after 10 years, i.e. in 1969. At each check two germination tests on filter paper substrates were performed:—

1. Jacobsen apparatus (JA) at alternative temperatures; 16 hours at 20°C and 8 hours at 30°C for 28 days with fluorescent light of 125 candles at higher temperature period. Four replications of 50 seeds each were tested.
2. Jacobsen apparatus (as above) for 21 days, but preceded by chilling for 21 days at 3°C (naked stratification).

Assessments of germination were carried out at weekly intervals, and at the end of the test the ungerminated seeds were examined by the tetrazolium biochemical method as a test of viability. The viable seeds detected by tetrazolium test were added to the germinated seeds. The moisture content tests were carried out on three replications of 5 grams using a standard air-drying oven where the seeds were exposed to a constant temperature of 105°C as long as they were losing weight. The moisture content percentage was calculated on the fresh weight basis. Table 3 gives the results of the 5th year tests as compared with the initial seed quality when put into storage in 1959.

Table 3

QUALITY OF ABIES PROCERA SEED AFTER 5 YEARS STORAGE

Seed lot	Seed moisture content %	Initial germination % in 1959	Germination capacity % (average for 2 tests) after 5 years storage at temperatures of					
			+21°C	+2°C	+2°C vacuum	+2°C CO_2	−5°C	−30°C
A	6·0	33	26	30	24	28	30	30
	7·7		23	24	27	23	32	33
	9·5		23	30	24	25	22	32
	17·2		0	0	0	0	14	2
B	4·9	40	11	16	14	16	12	8
	6·5		16	30	21	21	24	14
	9·4		8	22	17	23	23	17
	16·5		0	0	0	0	6	1
C	4·9	46	32	42	30	40	35	20
	5·9		38	46	36	46	40	37
	8·5		27	42	46	46	46	42
	17·2		0	0	0	0	6	0

The main points emerging from these comparisons are:

1. Generally, lots A and C are storing better than lot B which may have been damaged during the initial drying.
2. Moisture content at the level of 16—17 per cent is unsuitable for long storage at any temperature.
3. The temperature of −5°C seems to be the best of the range represented, and it is the only treatment where seed has remained viable at 16—17 per cent moisture level.
4. At +2°C temperature, there appears no advantage in using vacuum or CO_2 gas seal.

A full report of this experiment will be published in due course after completion of the final series of tests.

NURSERY INVESTIGATIONS

By J. R. ALDHOUS and J. ATTERSON

The collaborative research programme with Rothamsted Experimental Station continues, and reports on various aspects of the work will be found in Part II. Since the period under report, Forestry Commission Bulletin No. 37, *Experiments on Nutrition Problems in Forest Nurseries*, by Miss B. Benzian, has been published. This is a full account of the work conducted jointly by Rothamsted and the Forestry Commission between 1945 and 1962.

The great weight of nursery nutritional work remains in the above programme. The Forestry Commission's own experimental work (mainly on subjects other than nutrition) is reported below.

Factors Influencing the Yield of Seedlings

Date of Sowing

Seed of three small-seeded species, namely Lawson cypress, Western red cedar and Western hemlock, together with Douglas fir seed, was sown in the late autumn of 1963, and in February, March or April, 1964. Seed lots sown in February, March or April were divided into: (i) dry and (ii) stratified for six weeks before sowing. Four sites were used, namely the research nurseries at Kennington, Wareham and Alice Holt (Headley) and in Elms nursery, a small unit in Thetford Forest. The last nursery was selected because of the local interest in autumn and late-winter sowing in consequence of the low annual rainfall (20—25 inches) and the prevalent spring droughts experienced there.

Species responded similarly at all four nurseries, best results coming from seed stratified and sown in February. There was very little difference, however, between this treatment and seed sown dry in November and February, or stratified and sown in March. Seed sown dry in March and April produced smaller seedlings and lower yields than seed sown earlier or stratified.

The experiment, which was started in 1961 with three seed lots each of Sitka spruce, Japanese larch and Western hemlock of different ages or origins, was sown for the fourth and final year at Kennington, Wareham and Alice Holt. Seed was sown on six dates, regularly spaced between the end of February and mid-May, and at Kennington, irrigation was prescribed.

Differences in growth and yield of seedlings were less pronounced than usual, probably on account of the good germinating and growing weather in May and June. The yield from seed sown in March was not as good as usual. There were no differences attributable to age or origin of seed.

J. R. ALDHOUS

Irrigation

The large scale irrigation trial at Bareagle Nursery in Wigtownshire has been discontinued, as no responses have been obtained to irrigation treatments since the trial began in 1960.

Watering after Sowing

In 1963 a marked response in yield of seedlings to the watering of seed beds immediately after sowing was obtained in a preliminary trial at Inchnacardoch

Nursery, and in 1964 larger scale trials were laid down in six nurseries throughout Scotland. Three sowing dates at weekly intervals were included to observe the relationship of weather and watering treatments. Although in some cases marked differences were obtained in the number of seeds germinating due to date of sowing, no differences were found attributable to watering at any date.

Seed Pre-treatment

Following encouraging results in hastening the rate of germination of Lodgepole pine seed from pre-sowing treatments with hydrogen peroxide solution in a preliminary trial in 1963, larger trials were conducted at six nurseries during 1964, all with negative results. The reason for this lack of response is not known but the Seed Laboratory will be continuing work on such pre-sowing treatments.

J. ATTERSON

Nutrition

Long-term Fertility Trials

Trials in northern nurseries continue to show the superiority of seedlings grown with organic *plus* inorganic manures, over those with inorganic *or* organic manure *only*. This difference may be due to the increased retention of moisture and nutrients, especially on the lighter soils such as at Teindland. New experiments comparing organic régimes with recently introduced, slow-acting, inorganic fertilizers, such as magnesium ammonium phosphate, are proposed.

Slow-acting Inorganic Fertilizers

Two series of experiments were carried out in 1964 to test new slow-acting fertilizers. Following the success of magnesium ammonium phosphate as a nitrogen and magnesium source, experiments were laid down comparing different granular sizes and shapes of this fertilizer. From these experiments it appears that the granule size is not critical, although the method of manufacture of the granule appears to influence seedling size and colour. As in previous years, the magnesium ammonium phosphate produced seedlings taller than the standard fertilizer régime of basal potassic superphosphate *plus* nitrogen top-dressings. In spite of the absence of top-dressings on the magnesium ammonium phosphate plots, seedlings given this fertilizer were often a better colour than those given nitrogen only as top-dressings. Field scale trials of this material are proposed for 1965.

The other series of experiments compared heavily coated (25 per cent weight for weight) ammonium sulphate applied with the basal fertilizer dressings, against uncoated ammonium sulphate applied as top-dressings. The coatings used were sulphur and stearic acid. No worthwhile results were obtained by using these materials, as no improvement in seedling numbers or height resulted; the seedlings given nitrogen before sowing were yellower at the end of the growing season than those given nitrogen as top-dressings, indicating that the coatings did not slow down the release of nitrogen sufficiently. This line of experiment has now been abandoned.

J. ATTERSON

Fertilizer Scorch on Transplants

At Kennington, Wareham and Alice Holt, six species were lined out on plots without potassic superphosphate; given potassic superphosphate (PK) at standard rate; and at double the standard rate (2PK). The species were Corsican pine, Norway spruce, Sitka spruce, Noble fir, Douglas fir and Western hemlock; some were lined out in mid-March and some at two later dates. This enquiry arose out of previous observations that Norway spruce and Noble fir were sensitive to potassic superphosphate when lined out late in the season, and when dry weather followed lining out.

In this year, few symptoms of fertilizer scorch were observed, probably due to the wet weather in May and June. The only species to show any damage was Noble fir. Transplants of this species developed a scorch on the tips of young needles on 2PK plots. Plants on plots without any potassic superphosphate developed strong symptoms of potassium deficiency.

J. R. ALDHOUS

Weed Control in the Nursery

Weed Control in Seedbeds

Progress in experimentation with paraquat as a pre-emergence spray on conifer seedbeds is reviewed in Part III (pages 133–149) of this report.

At Wareham and Alice Holt, Neburon was applied as a post-emergence treatment to 4 inch band-sowings of four species in each nursery. The dates of application were: (*a*) shortly after seedlings have started to emerge, (*b*) and (*c*) three and six weeks respectively after (*a*). Neburon was formulated as a 50 per cent wettable powder, and was applied at 1, 2, 3 and 4 lbs. active ingredient in 40 gallons of water per acre.

At Alice Holt, the yield of European larch and Norway spruce seedlings, and at Wareham the yield of Western hemlock seedlings, were very significantly reduced following the first date of spraying, whatever the rate of application. The yield of Western hemlock and Norway spruce seedlings was also reduced following the higher rates of application at the later dates. The yield of Sitka spruce and Lodgepole pine at Alice Holt was reduced slightly by Neburon applied at the second date but not by Neburon applied at the first date. There is no obvious reason for this anomalous result.

At Wareham, Douglas fir, Japanese larch and Sitka spruce seedlings were not significantly affected by spraying. Control of weeds by Neburon was little better than on plots sprayed with white spirit and not as good as in 1963.

J. R. ALDHOUS

Transplants

Spacing in Transplant Lines

Three experiments were started, using Scots pine at Alice Holt, Sitka spruce at Kennington and European larch at Wareham. The primary object was to try out one of the 'Nelder' designs for testing spacing (Nelder, 1962) and to see whether forest trees responded to rectangular spacing in the manner of some market garden crops. The design chosen was one with parallel, rather than radial, rows with the distance between consecutive plants in each row increasing from one inch to twelve inches by one inch steps. At the same time, conventional uniformly spaced plots were put down. In these, plants were given 12, 16–18, or 24 square inches of soil surface as growing area. This area was always rectangular, but the shape of the rectangle ranged from long and thin to square; e.g. plants with 12 square inches growing area were spaced at 1 in. × 12 in., 1½ in. × 8 in., 2 in. × 6 in., and 3½ in. × 3½ in.

No results of these experiments are yet available but, by appearance, plants at the very crowded corner of the variable spacing plots are more spindly than those given more growing space. There are no obvious differences between plants in the conventionally-arranged plots.

The European larch at Wareham were planted at uniform spacing at Lulworth in Wareham Forest in March 1964. The Scots pine and Sitka spruce will remain in the nursery for another year.

J. R. ALDHOUS

Storage and Handling of Nursery Plants

Cold Storage of Seedlings

Two experiments were laid down to extend knowledge both of the effect of early lifting, and the suitability for cold storage, of species inadequately covered in previous experiments. At Alice Holt, Scots and Corsican pine were stored for varying periods, plants being lifted and stored at intervals of six weeks, starting in October and ending in April, and being lined out between February and mid-May. At Kennington, Norway spruce, Corsican pine, Douglas fir, Western hemlock and Western red cedar were lifted for storage and lined out at much the same time as at Alice Holt, but in addition some plants were kept for lining out in July and November as well.

Plants from both experiments were stored in the refrigerated cold chambers of the seed store at Alice Holt. Some were kept at +2°C and some at −5°C. Species lifted in October withstand cold storage as well as when lifted in December, January or February. All species withstood storage at +2°C better than at −5°C. An examination was made of roots of plants lined out in March and in May after varying periods of storage.

Table 4 shows the number of active roots recorded eight weeks after transplanting. To facilitate root examination, three plants of each species from each storage period were potted up in coarse sand in March and in May when other plants from the same treatments were being transplanted and were kept watered with dilute nutrient solution. At the time of examination, pots were immersed in water and the sand carefully washed away. Ten root tips on the three longest roots were then classified as (*a*) inactive, (*b*) new growth less than 2 mm. long, (*c*) new growth more than 2 mm. long. In Table 4, 'Growing' includes root-tips in classes (*b*) and (*c*). 'Over 2 mm.' refers to class (*c*) only.

Roots of Norway spruce seedlings which had been lifted and lined out *immediately*, appeared to have made less growth than those kept in cold store. Roots of Douglas fir appear to have responded in the opposite way, those on plants which were lifted immediately before transplanting being slightly ahead of those on stored plants. Corsican pine roots were slow to develop compared with the other species. Western hemlock roots developed quicker after lining out in mid-March while Douglas fir roots developed more quickly after lining out in mid-May.

J. R. ALDHOUS

Miscellaneous

Nursery Stocktaking

The new stocktaking procedure mentioned in the 1964 *Annual Research Report* was tried out in all Scottish nurseries and in some English and Welsh nurseries at the end of 1964—with varying degrees of acceptance. As a result of this large

Table 4

NUMBER OF ACTIVE ROOT TIPS OUT OF 30 ASSESSED (10 PER PLANT). ASSESSMENT 8 WEEKS AFTER LINING OUT: COLD STORAGE EXPERIMENT AT KENNINGTON NURSERY

Species	Lined out 25th March 1964					Lined out 27th May 1964				
	Period of Cold Storage (+ 2°C)					Period of Cold Storage (+ 2°C)				
	9 Oct.–25 Mar.	3 Dec.–25 Mar.	3 Jan.–25 Mar.	10 Feb.–25 Mar.	Lifted and lined out immediately	9 Oct.–27 May	3 Dec.–27 May	3 Jan.–27 May	10 Feb.–27 May	Lifted and lined out immediately
Norway spruce: Growing	7	24	25	30	22	20*	30	30	30	24
Over 2 mm.	6	18	16	22	9	10*	20	24	23	14
Corsican pine: Growing	X	2	1	2	5	X	21	17	20	10*
Over 2 mm.	X	0	0	1	4	X	10	12	12	5*
Douglas fir: Growing	X	3	8	17	15	X	30	25	25	24
Over 2 mm.	X	2	4	3	6	X	14	17	19	24
Western hemlock: Growing	X	25	19	26	29	X	3‡	16	23	18
Over 2 mm.	X	19	17	23	23	X	1‡	5	14	16
Western red cedar: Growing	X	27	26	20	23	X	30	30	30	20
Over 2 mm.	X	21	23	20	20	X	30	30	30	20

X = all plants dead.
* = one plant dead—only 20 root tips assessed.
‡ = two plants dead—only 10 root tips assessed.

scale 'try-out', the sampling procedure will be slightly modified for use in 1965 after which it is hoped that this new procedure will come into general use.

Nursery Demonstrations

Demonstrations of *p*H, nutrient deficiencies, seed-bed sterilisation, etc., were continued at Newton and Bush Nurseries (near Elgin and Edinburgh respectively) for the benefit of visitors.

J. ATTERSON

REFERENCE

NELDER, J. A. New kinds of systematic design for spacing experiments. *Biometrics*, 1962, 18, 283–307.

SILVICULTURAL INVESTIGATIONS

By R. M. G. SEMPLE, R. LINES, W. O. BINNS and STAFF

Afforestation of Difficult Sites

Plantations at High Elevation in the North

Three phases of research in this field may be recognised. Firstly, a few trial plantations were established prior to 1940 and (although these have some special value attributable to their age), their siting, layout and obsolete establishment methods severely limit their usefulness. In the early 1950's a series of trial plantations were established by the Research Branch to endeavour to extend the planting limit, using standard techniques; these plantations have already provided valuable evidence which, particularly in the North of Scotland, has led to a new criterion of plantability. Several of these plots were surrounded by Conservancy plantings within a few years, and further extensions of this type were subsequently planted by the Conservancies, with Research Branch in an advisory capacity. Only one new Research trial plantation has been established this year, namely at Carrick Forest, to test hardier provenances of Lodgepole pine than those used previously on this site.

A separate paper in Part III of this *Report* (page 169) summarises the success of the oldest of the post-war trial plantations.

A new series of Research plantations is now planned to test Lodgepole pine and Sitka spruce with *above standard* rates of fertiliser to test the assumption that well nourished plants may better withstand the debilitating effects of exposure.

S. A. Neustein

Plantations at High Elevations in Wales

Five out of the eight plantations established at high elevations are regarded as satisfactory. The remaining three are either badly laid out or are not representative of extreme conditions. Exposure flags have been installed in all the plots in these five sites, in order to obtain some measure of the variation in exposure both 'within sites' and 'between sites'. Twenty-two flags in all have been erected.

The first winter of study has shown that Welsh sites are subjected to climatic conditions which are apparently not experienced in environments where flags have been used in Scotland and northern England. Severe icing of the flag during the months of December, January and February has resulted in the flags tearing apart, and thus giving anomalous results. In the earlier months however, when icing did not occur, rates of tatter were still greater than the maximum reported by Lines and Howell (1963). These effects may be due to the greater elevation of the Welsh sites which vary from 1,750–2,400 ft., and their more continental climate during periods of easterly wind. In Scotland easterly winds will have been slightly warmed by passing over the North Sea, and rime and freezing fog are more commonly encountered further south.

A preliminary trial, in Hafren Forest, with a shelter fence of laths, has suggested that these may be useful for creating snowdrifts to cover the young plants during periods of cold windy weather in the early spring.

Apart from these general observations, the high-elevation Welsh trials are still too young to indicate whether acceptable crops of trees can be obtained on such exposed areas, but certainly it is possible to establish Sitka spruce. Time alone will show whether it will grow satisfactorily.

REFERENCE

R. LINES and R. S. HOWELL, 1963. *The Use of Flags to Estimate the Relative Exposure of Trial Plantations.* Forest Record No. 51. For. Comm. London.

A. I. FRASER

The Northern and Western Isles of Scotland

Advisory work to crofters and others continues. A detailed description of the first ten years of the Forestry Commission trial plantations in Shetland has been published. (*Scottish Forestry.* Vol. 18 No. 3 1964). A tour of the Island of Lewis has been completed, in company with field officers, and it is probable that at least some new trial plantations will be undertaken there.

S. A. NEUSTEIN

'Hard Heaths' at Millbuie Forest

Experimental work on the cultivation of compacted drift soils in N.E. Scotland (see *Rep. For. Res.* 1964, page 20) has in the past been held up for lack of equipment of sufficient power and robustness to disrupt the indurated horizons. This has recently been achieved using a Blaw-Knox Ripper tine and a deep-drainer plough-body mounted in tandem in a Cuthbertson carriage, the whole being headed by three Fiat crawler tractors. This trial opens the way to new controlled experimentation in the afforestation of such sites; cultivation will be combined with drainage, fertilisation and trial of species.

D. W. HENMAN

Amelioration of Forest Sites

(1) Nutrition

(*For convenience, forest nutritional work conducted by the Soils Section is included here*

(*a*) Forest Nutrition in Scotland and Northern England

Manuring of Young Crops

As mentioned in last year's *Research Report*, the main objective for nutrition research on young crops growing on deep, acid peat will be to determine the most economical form and method of application of potash fertilizer (and repeat dressings of phosphate).

Two experiments were established last year, one on Sitka spruce in the Dalchork Section of Shin Forest in Sutherland, and the other on Lodgepole pine in the Racks Moss Section of Mabie Forest in Dumfriesshire. These experiments will test the times of application of potassic superphosphate on plots large enough to enable growth measurements to continue into the pole-stage, if necessary. Naturally, no results will be available from these experiments for some years.

An experiment on a very poor Lodgepole pine/Sitka spruce mixture on very deep, acid peat at Arecleoch Forest in Ayrshire was laid out last year to compare three forms of potash salts, viz. sulphate, chloride and carbonate. The latter salt was included because previous work (Hinson and Reynolds 1958) has shown that the salts of weak acids are retained better in humus layers than salts of strong acids. The carbonate used was a fine crystalline powder and, being deliquescent, some of it stuck to the tree needles and caused some scorch. The trees have since recovered.

At the end of the first year, the foliage from this experiment was analysed for N, P and K, and this analysis has shown that the application of K has increased the percentage K in the needles from 0·5 per cent to 1 per cent for the Sitka spruce, and to 0·67 per cent for Lodgepole pine, irrespective of the type of K applied. Rates of K up to 250 lbs. per acre were applied, and surprisingly no signs of damage have appeared on the trees given the highest rate. No growth response has been observed yet, as fertilizers normally do not produce a height response in the year in which they are applied.

Another experiment established last year, alongside the previous one, compared potassic superphosphate and potassium metaphosphate, at three rates of application; again, although no growth responses are to be observed as yet, the foliage analysis from this experiment is most interesting. It indicates that the

Table 5

FOLIAGE ANALYSIS OF ARECLEOCH EXPERIMENT NO. 3/64

Treatment	Nutrients applied (lbs. per acre)		Needle weight (mg.)	Analysis of needles (% oven-dry weight)		
	P	K		N	P	K
Sitka spruce						
Potassium metaphosphate	69	84	3·0	1·00	·315	·917
Potassic superphosphate (+ some G.M.P.)	69	84	3·0	1·61	·400	·960
G.M.P. (control: no K)	69	—	3·0	1·62	·382	·777
Rate (1) Mean of Pot. *meta.*, and pot. *super.*	34·5	42	3·1	1·18	·293	·893
Rate (2) Mean of Pot. *meta.*, and pot. *super.*	69	84	3·0	1·30	·357	·938
Rate (3) Mean of Pot. *meta.*, and pot. *super.*	138	168	3·0	1·36	·420	1·017
Lodgepole pine						
Potassium metaphosphate	69	84	10·2	1·22	·165	·620
Potassic superphosphate (+ some G.M.P.)	69	84	12·2	1·56	·223	·717
G.M.P. (control: no K)	69	—	11·3	1·57	·202	·647
Rate (1) Mean of Pot. *meta.*, and pot. *super.*	34·5	42	10·0	1·22	·175	·615
Rate (2) Mean of Pot. *meta.*, and pot. *super.*	69	84	11·2	1·39	·194	·668
Rate (3) Mean of Pot. *meta.*, and pot. *super.*	138	168	11·5	1·49	·223	·703

Note. G.M.P. = ground mineral phosphate.

less soluble metaphosphate has been taken up in lesser quantity by the trees than the superphosphate (see Table 5). There is a chance, therefore, that the metaphosphate will 'last' longer than the superphosphate, which is the result that was hoped for.

As well as increasing the P and K concentrations in the needles of both species, these PK fertilizers have also increased the N concentration and, as this has also happened in the ground mineral phosphate control plots, this indicates that this is a site where the addition of phosphate renders nitrogen more available to the trees (see Table 5).

Also at Arecleoch, the large experiment comparing hand and tractor-mounted methods of applying ground mineral phosphate has shown no difference in growth or survival to date between these two methods of phosphate application. Previous smaller trials have yielded similar results.

Using conventional establishment techniques, i.e. ploughing + PK fertilizer, the choice of species for the afforestation of deep, acid peats has resolved itself into: 'Lodgepole pine or nothing.'

It is fairly certain that Sitka spruce can be grown on almost all such sites provided heather (*Calluna*) competition is removed (see Weed Control Section of this *Report* page 43), and also provided additional nitrogen is supplied. Without these abnormal measures it is a failure. Responses to nitrogen are usually quite temporary, and hence its use on relatively low-yielding stands appears uneconomic. It is possible, however, that if Sitka spruce were given a few nitrogen top-dressings, sufficient nitrogen would be 'injected' into the nutrient cycle to keep the trees growing, especially if the Sitka spruce could by this time utilise the nitrogen reserves of the peat through increased microbiological action. To test this idea an experiment has been established at Strathy Forest in Sutherland.

Nitrogen can also be supplied by the litter-fall from larch, as has been demonstrated on the Lon Mor experimental area in Inverness-shire, and a Sitka spruce/Japanese larch mixture experiment has been established in Inchnacardoch Forest. Western hemlock and Serbian spruce (*Picea omorika*), the only other promising species for deep, acid peat, have also been included in this experiment.

REFERENCE

HINSON, W. H., and REYNOLDS, E. R. C. Cation Adsorption and Forest Fertilization, *Chemistry and Industry* 1958, 194-6.

Pole-Stage Manuring

In an attempt, albeit a hit-or-miss one, to see if economic responses in volume are possible with fertilizer applications to pole-stage stands on a variety of sites, two experiments were established in 1964 at Speymouth Forest in Morayshire and Inchnacardoch Forest in Inverness-shire. Both these experiments are in pole-stage Scots pine. Two further experiments in this series will be established in 1965 at Devilla Forest in Clackmannan, again on pole-stage Scots pine, and at Glenbranter Forest in Argyll on Sitka spruce. An N P K granular compound fertilizer is being used in this experiment at two rates, the higher rate being twice the lower, which supplies 120 lbs. N, 50 lbs. P and 100 lbs. K per acre.

Although no growth responses are observable as yet, increases in needle weight and in the N, P and K concentrations of the needles have been obtained at both sites. It is likely, therefore, that growth responses will be obtained in the next few years.

At Culbin Forest in Morayshire four Sample Plots of Corsican pine, each thinned to a different grade, were treated with nitrogen at 150 lbs. per acre (as 'Nitrochalk' 21 per cent N) in May 1963. Table 6 gives the volume increment for each plot from 1962 to 1964. The present rate of growth is equal to Yield Class 100 (Quality Class IV), whereas before the nitrogen was applied the rate of growth was equivalent to Yield Class 40 (well below Quality Class tables). A distinct colour improvement in the needles of these trees was noticed in the first year after application, and it is interesting to note that in the heavy thinning grades there was a corresponding slight volume increase, due to an increase in basal area and not height.

Table 6

MAINCROP VOLUME INCREMENT OF CORSICAN PINE AT CULBIN
(Age: 38 years. Top height: 34 ft.)

Thinning grade	End 1962		Volume increment per acre (in hoppus feet)		
	No. of trees per acre	Volume per acre (h. ft.)	1962*	1963	1964
E	336	939	51	81	126
D	618	1,249	62	74	134
C/D	913	1,489	38	36	104
B	1,206	2,111	45	42	133

Note. * The volume increment attributed to 1962 is the periodic mean annual increment for years 1960–62.

Foliar Analysis

Approximately 500 foliage samples were collected and sent to the Macaulay Institute, Aberdeen, for chemical analysis at the end of 1964. These samples were mainly collected in nutrient experiments, although a few came from Conservancy areas where nutrient deficiencies were suspected. In addition, over 230 samples were collected by Forestry Commission staff for the Macaulay Institute. Most samples were analysed for N, P and K, and some for Ca and Mg in addition.

Last autumn ten permanent foliage sampling sites were selected throughout Scotland and North England. At each site twelve dominant trees were marked, from which foliage samples will be collected annually. The object of this venture is an attempt to determine how climate and geographical location affect the nutrient content of tree foliage. Sites were selected for coastal Lodgepole pine, and both good and partially-checked Sitka spruce of Queen Charlotte Island origin. The first year's results are summarised in Table 7.

Table 7

FOLIAGE ANALYSES FROM PERMANENT SAMPLING SITES

Species	Needle Wt. (mg.)	Nutrient concentration (% oven-dry wt.)				
		N	P	K	Ca	Mg
Sitka spruce (growing well)	*7·6* 5·0–11·4	*1·57* 1·22–1·74	*0·213* 0·150–0·280	*1·103* 0·820–1·340	*0·402* 0·160–0·540	*0·110* 0·070–0·160
Sitka spruce (in partial check)	*4·3* 3·2– 5·4	*1·06* 0·72–1·48	*0·129* 0·090–0·160	*0·762* 0·620–0·920	*0·491* 0·300–0·680	*0·090* 0·080–0·170
Lodgepole pine (South coastal)	*14·7* 8·0–17·8	*1·29* 1·00–1·54	*0·160* 0·110–0·195	*0·635* 0·440–0·810	*0·117* 0·080–0·180	*0·079* 0·060–0·110

Note. Figures in italics are the mean values obtained, and the figures below these are the ranges.

J. ATTERSON

(*b*) Forest Nutrition in South and Central England and Wales

Manuring of Pole-stage Crops

The results for the first five years from the simpler of the two series of pole-stage manuring experiments, a 2^5 factorial design (*Report on Forest Research* 1959, 1960), have been the subject of a detailed analysis during the year, and some conclusions can now be given. Seven experiments are on Sitka spruce, one is on Norway spruce, one on Douglas fir and one on Corsican pine. Contrary to the provisional findings, as reported last year, there have been some marked effects on increment in several experiments. Phosphorus (88 lb. P per acre as triple superphosphate) has produced positive effects on growth in eight experiments, though these increases were only statistically significant in four of them. Nitrogen (150 lb. N per acre as urea) produced positive effects in three experiments, significant in two. There have been no appreciable responses to potassium, calcium or magnesium fertilizers. The main effects are presented in Table 8, with the growth increases for the five years divided into a three-year and a two-year period.

The potassium, calcium and magnesium concentrations in the foliage are considered to be adequate in nearly all cases, so that even when concentrations have been increased by the fertilizers the lack of effects on growth are not surprising. In contrast, however, the phosphorus concentrations confirm the growth effects: every increase in increment is associated with an increase in phosphorus concentration (the difference at Hemsted Forest in Kent reached significance in the third and fifth seasons), though in some cases there have been increases in concentration without increases in increment.

A surprising fact is that the phosphorus concentrations for the untreated Sitka spruce at Brecon and Glasfynydd Forests in Wales were within the range we have previously associated with satisfactory growth of this species, based on information obtained in the main from experiments on newly-planted and pre-thicket crops. This suggests that nutrient relationships may differ appreciably at different stages in the development of the crop. The phosphorus concentrations in the untreated Norway spruce and Douglas fir at Halwill in Devon and Hemsted in Kent are considered to be inadequate.

Five of the experiments, all on Sitka spruce, have shown no significant increases due to the treatments. Three of these, Kerry, Tair Onen and Clocaenog Forests, all in Wales, are on ill-drained soils. The stand at Clocaenog suffered some windblow every year (and had to be abandoned after four years), so the results are less reliable than for the other experiments. At Gwydyr Forest, North Wales, the phosphorus treatment increased foliage phosphorus concentration from the second year onwards, and it seems likely that at the next assessment the total increment will be significantly greater in the treated plots. Only at Ebbw Forest in South Wales is there no clear indication of a limiting factor, but there is a possibility of summer drought on the very free draining soil; the absence of significant uptake of nitrogen or phosphorus is noteworthy.

The nitrogen concentrations in the foliage of the Sitka spruce on the four better drained sites are 1·7 per cent or more, which is considered adequate. The concentrations in the Norway spruce and Corsican pine, 1·2–1·5 per cent over three years, are probably below the optimum for these species.

The response to nitrogen at Halwill is not associated with a significant increase in foliage nitrogen concentration, though the mean of the treated plots was still a little higher in the second year. At Pembrey, on a sandy soil on the South Wales coast, the response to nitrogen is not surprising, though the magnitude and persistence of it are gratifying.

The significant reduction in increment at Glasfynydd and Gwydyr in the nitrogen plots may be due to toxic effects of urea, which have been reported from agriculture (though these have generally been confined to treatments where the urea was cultivated into the soil).

Because of the inaccurate methods used to measure height growth, no satisfactory figures can be given at this stage, and the effects of phosphorus on volume increment have likewise not been given in the table. However the increase in volume increment is the criterion by which the usefulness of treatments can best be judged, and a reasonable estimate of this can be obtained by applying the percentage basal area increases to the stand volume increments given in the table. Thus, for example, over the first five years the increase at Glasfynydd would probably be of the order of 45 hoppus feet, at Hemsted 30 hoppus feet, and at Pembrey 35 hoppus feet, all per acre per annum.

Most of these experiments will be maintained and remeasured periodically. Since the effects of phosphorus are usually persistent, the final benefit for the four experiments where it has increased increment could be considerable.

The results for the series will be looked at in co-operation with the Forestry Commission economists, and a full report covering all aspects of these experiments will be published elsewhere in due course.

W. O. Binns

A. E. Coates

Potassium Deficiencies on Peat

Following the widespread occurrence of potassium deficiency symptoms in Sitka spruce on peat in North Wales, and their confirmation by foliage analysis and fertilizer trials (*Report on Forest Research* 1964), three more experiments

Table 8

MANURING OF POLE-STAGE CROPS

Forest	Species	Quality class	Age at treatment	Estimated volume increment/acre/annum, all plots, Hoppus feet		% change in basal area increment due to:				Nutrient concentration in the needles at the end of the first year, % dry weight			
						Nitrogen		Phosphorus		Nitrogen		Phosphorus	
				1st period	2nd period	1st period	2nd period	1st period	2nd period	O	N applied	O	P applied
Brecon	S.S.	V	24	260	260	−2	4	2	10*	1·8	2·1***	0·23	0·30**
Glasfynydd	S.S.	V	30	260	190	−12**	−13*	22***	23**	1·8	2·0**	0·20	0·26*
Ebbw	S.S.	V	24	200	240	4	− 1	5	7	1·8	1·8	0·20	0·22
Gwydyr	S.S.	V	29	205	185	− 1	−10*	9	10	1·7	1·7	0·21	0·24
Clocaenog	S.S.	V	23	200†	—	− 2†	—	5†	—	1·5	1·7**	0·24	0·23
Kerry	S.S.	V	21	155	120	− 9	− 5	− 3	− 1	1·8	1·8	0·20	0·24**
Tair Onen	S.S.	V	30	150	150	1	17	3	18	1·5	1·7**	0·20	0·23
Halwill	N.S.	IV	32	95	125	19*	10	8	21**	1·4	1·6	0·14	0·17**
Hemsted	D.F.	V	28	100	75	− 6	−12	31*	54**	1·5	1·8*	0·13	0·15
Pembrey	C.P.	IV	23	115	85	37***	40*	0	0	1·5	1·9***	0·16	0·20**

† = over 4 years.
* = change significant at 5 per cent.
** = change significant at 1 per cent.
*** = change significant at 0·1 per cent.

testing the effects of potassium fertilizers have been started. The first, laid down in 1964 at Tarenig Forest, Cardiganshire, on four-year-old Sitka spruce, compared four rates of potassium and two of phosphorus, in factorial combination. The second, also at Tarenig, compared four different granule sizes of a water-insoluble fertilizer, potassium metaphosphate, on the same crop, but laid down a year later. The third, laid down at Clocaenog Forest, Denbighshire, in 1965, compared four rates of potassium metaphosphate of standard granule size with equivalent rates of soluble fertilizers on newly planted Sitka spruce. These trials are closely linked with similar trials in the North of England and Scotland.

W. O. BINNS

Intensive Manuring and Weedkillers Applied at Planting Time

The 'Deficiency Garden' at Wareham Forest, Dorset, an experiment designed to demonstrate nutrient deficiency symptoms in six species of conifers by unbalanced manuring in a virtually weed-free environment (*Report on Forest Research* 1960–62), has produced some remarkable early growth, which suggests that heavy manuring combined with effective weed control might both reduce establishment costs and appreciably shorten the rotation. Accordingly a new series of experiments has been started, testing complete annual manuring with complete periodic and standard manuring, with and without chemical weed control; the weedkillers used will depend on the weeds present. So far experiments have been laid down at Wareham (Bagshot Sands over clay), Thetford, Norfolk (Chalky Boulder Till), Alice Holt, Hampshire (a flinty clay), and Clocaenog, Denbighshire (a peaty podsol and an iron podsol), and they will be extended to cover a wide range of sites over the whole country.

W. O. BINNS
J. R. ALDHOUS

(2) Cultivation

Cultivation of Heathland—Inshriach Forest, Inverness-shire

The ploughing experiment at Inshriach Forest, described in the *Report on Forest Research* 1962 (page 25) has completed its third growing season. Survival has been excellent in Scots pine on unploughed ground, as well as on spaced-furrow and complete ploughing, but Lodgepole pine has suffered up to 20 per cent losses on unploughed ground. Lodgepole pine has grown rather faster than Scots pine, and in both species ploughing has benefited growth. Addition of phosphate shows a slight benefit to growth. Differences at this stage are small, and growth is slow.

A feature of this experiment has been the heavy attack by black game, *Tetrao tetrix*. Lodgepole pine was more severely browsed than Scots pine, and plants on unploughed ground much more severely than those on complete ploughing, which in turn were more browsed than those on spaced-furrow ploughing. The effect is to produce bushy plants with ill-defined leaders, but survival is not affected.

D. W. HENMAN

Cultivation of Heathland—Teindland Forest, Morayshire

A penetrometer was used to examine the relative 'hardness' of the soils in a variety of ploughing treatments in Teindland Experiment 81 (see *Rep. For. Res.*

1964, p. 158 for details of growth). The differences recorded were rather small and are being examined statistically; they do not appear to be commensurate with the considerable differences in height growth. More time must elapse before it can be seen whether the latter are more a result of the completeness of eradication of competing heather (*Calluna*) than of soil disturbance, and whether the growth differences will diminish as heather suppression is completed in all treatments.

D. W. HENMAN

(3) Drainage

Drainage of Deep Peat—Clocaenog Forest

An 80-acre raised bog at Clocaenog (Denbighshire) has been laid out with a number of experiments, of which the most important is drainage/cultivation.

Three types of cultivation—(i) 18-inch deep single furrow ploughing, (ii) 9-inch deep double mould-board, and (iii) 30-inch deep Glenamoy 'tunnel' ploughing —have been used in combination with 30-inch deep cross drains, at 11 and 22 yards spacing.

Both Sitka spruce and Lodgepole pine will be planted pure and given two rates of a PK fertilizer.

Additional work on this bog, which has all been drained, includes fertilizer experiments, species trials and a Lodgepole pine provenance experiment.

A. I. FRASER

Drainage of Deep Peat—Flanders Moss

The large experiment on Flanders Moss (Loch Ard Forest, Stirlingshire) has been ploughed to provide turfing treatments similar to those at Clocaenog. Drains will be ploughed during the 'dry' conditions of mid-summer to give a combination of depths—24 ins. and 48 ins., and spacings—25, 50 and 100 ft. Pure Lodgepole pine and a Lodgepole pine/Sitka spruce mixture have been planted, using a single rate of PK fertilizer. Contact is maintained with the Research Officer, Northern Ireland Forest Department, who is conducting very similar experiments.

We are grateful to the Peat Soils and Forest Soils Sections of the Macaulay Institute for undertaking the sampling and physical and chemical analysis of the peat during the initial phase of site-characterisation in this experiment. A preliminary survey shows that nutritionally this raised bog is much poorer than the blanket peats, which have comprised the bulk of past peatland plantings, though it is very similar to another raised bog, Racks Moss in Dumfriesshire, on which nutritional research is being conducted.

The ploughing of this large experiment on a very wet bog has been greatly eased by recent developments in machinery made by the Mechanical Engineers of the West Scotland Conservancy and Messrs. Clark of Parkgate, Dumfriesshire. The notable advance is in the direct mounting of ploughs onto the County Bogmaster tractor by means of the 'Ede' self-levelling linkage, thus disposing of the cumbersome transporting carriage. Single and double-mouldboard turfing ploughs, the Glenamoy 'tunnel' plough and, more recently, a deep-drainer plough, have all been mounted in this way, enabling a reduction in experiment plot surrounds and in damage to plot surfaces. (See Plates 9–10.)

D. W. HENMAN

Drainage of Peat—Inchnacardoch Forest, Inverness-shire

A joint experiment with the Macaulay Institute, in which water levels are being maintained at fixed depths at and below the surface, has in its second year shown differences in survival, shoot growth and colour closely related to water table depths, which range from 0 to 50 cms.

D. W. HENMAN

Drainage of Heavy Clay Soils—Orlestone Forest, Kent

The Orlestone experiment, established at the end of 1964, had a very good first growing season with the very high survival rate of 98 per cent. Borehole data from the experiment are already showing the effects of deep drains, and especially the most intensive treatment with 3 ft. deep drains at 11 yards spacing.

The existing experiments in the South, with tree crops planted after drainage, now cover the full necessary range of soils and climatic zones. A programme has therefore been prepared for drainage in existing plantations, of a range of ages, and sites for these experiments will be selected in the coming year.

A. I. FRASER

Drainage of Heavy Clay Soils—Kershope Forest, Cumberland

Much of the available evidence on rooting and stability responses to drainage on clay soils in the Scottish Borders has been obtained from experimental drainage systems probably less effective than those now recommended for practice (drains shallower and not aligned near the contour—though closer than now prescribed). A site has now been chosen at Kershope Forest for a draining experiment to test spacing of 3-foot deep, near-contour drains in a thicket-stage crop of Sitka spruce on a peaty-gley soil. Uniformity assessment of the crop and site is in progress, prior to draining during 1965.

D. W. HENMAN

Drainage of Heavy Clay Soils—Rosedale, Allerston Forest, North Yorkshire

Drains were established during the summer in the cultivation × drainage experiment at Rosedale, in Allerston Forest. This unique experiment, besides testing the effects of drains, will also compare conventional ploughing methods with establishment on ' riggs and furrs,' a method which may have advantage in ease of access and extraction and in elimination of drain maintenance, as well as possible drainage benefits. Survival during the first season has been high, though plants on the outer edges of the 'riggs' are yellower than elsewhere, probably owing to low nitrogen content of the exposed subsoil.

Dr. D. Read of the Department of Botany, University of Sheffield, has undertaken to make soil moisture assessments in this experiment, and may follow up these with assessments of needle moisture.

D. W. HENMAN

Drain Erosion Studies—Kielder Forest, Northumberland

In the extensive demonstration of forest drainage practice at High Long House, Kielder Forest, the course of silting and scouring of the drains is being recorded. Heavy rainfalls (over 2 ins. within 24 hours) occurred on three occasions in December and January, and on 10th January severe erosion of parts of the main drains occurred. These drains are the original natural watercourses of the hillside, whose rates of flow have been greatly increased by the discharge from near-contour cross-drains at spacings of about two chains (i.e. 132 feet apart). They have an average fall of about 1 in 10, and erosion of this part of the system must be accepted as unavoidable during the early years of plantations on impervious soils.

D. W. HENMAN

Drain-forming Machinery

Silvicultural staff in the North co-operated with North West England Conservancy in staging a demonstration of the range of drain-forming machinery currently available. No controlled timing and costing studies were done, the demonstration being to show up the features which are of practical importance to machinery movement and to the making of open drains on stump-covered clay or peat soils and in thicket-stage plantations.

D. W. HENMAN

Natural Regeneration and Seed Supply

Seed Trapping: Douglas Fir

The seed-trapping experiment in Douglas fir which is being conducted jointly with the Entomologist, and which is referred to in the 1964 issue of this *Report*, has been continued, and no new experiments have been added.

Seed falls in the period September 1964 to March 1965 were again low, and only at Culloden and Thornthwaite Forests were any appreciable quantities of seed produced, 10,000 and 11,600 viable seeds per acre respectively.

Prospects for a good seed year are high next year following a favourable summer in 1964.

A. I. Fraser

Seed Trapping: Sitka Spruce

The small amount of time allocated to this project in the North has previously been directed to Scots pine in the relict indigenous woods. This year attention has been turned to Sitka spruce, and a seed-trapping study has been established in a 38-year-old crop at Glenbranter Forest, Argyll. The first season's work shows that seed was already being released at the beginning of October and continued to fall up to the end of March, giving a total fall of 1¼ million viable seeds per acre during this period. A notable feature was that 70 per cent of the trees in the crop bore no cones at all.

These results will be of general value to those supervising home seed collections, as well as to future silvicultural work on the natural regeneration of the species.

D. W. HENMAN

Artificial Regeneration

Underplanting of Japanese Larch

No new experiments have been established in the South, but survival and early growth of the underplanted species in the two experiments at Radnor and Michaelston (Coed Morgannwg Forest, Glamorgan) have been very good.

Wind damage at Radnor has been fairly serious in one block, but it is of interest that the plots which have suffered worst have been those next to the clear-felled plots, and not necessarily those most heavily thinned.

In Blocks II and III, where the clear-felled plot happened to be at the windward end of the block, the number of trees blown over in each plot, down wind, as a percentage of the original number are: Block III (most windward) 33 per cent, 12 per cent, 7 per cent, 2·5 per cent; Block II 25 per cent, 8 per cent, 0·5 per cent, nil.

No new experiments have been established in the North. Survival and early growth of the underplanted species in the experiment at Drumtochty (Kincardine) has been very good. Wind damage has been serious in one block, with a maximum of 13 per cent of the over-wood windthrown in one thinning treatment. However, there was no obvious correlation between damage and intensity of thinning, nor between the location of the damaged plots and those which had been clear-felled (unlike Radnor). Wind direction and topography appear to have been the over-riding factors.

Measurements of light intensity have been repeated in this experiment and in six other underplanted crops, including Conservancy areas. An interesting relationship between light intensity and condition of underplanted crop is emerging. (See Plates 6–8.)

A. I. FRASER
S. A. NEUSTEIN

Cultivation of Felled Pine Areas in Scotland

The choice of whether to plough, or *not* to plough, prior to replanting is a particularly difficult one, and will require investigation by orthodox experimentation on a wide range of soil types. It is certainly more costly to plough stump-covered ground, and probably less effective than to plough bare ground, quite apart from the added cost of the fairly complete slash disposal which is necessary. A fact-finding tour was completed, visiting all sites in North and East Scotland where chance comparisons of ploughed and unploughed replanted areas occurred. The following factors appear to be relevant—soil; interval between clear-felling and replanting; and size, vigour and stocking of the previous crop (itself a reflection of other factors). This preliminary investigation suggested that if regeneration follows clear-felling sufficiently closely to avoid vegetation establishment, ploughing may not be worthwhile as an aid to establishment on the better pine sites, i.e. Quality Class III and above.

S. A. NEUSTEIN

Brash Disposal

The most economical means of coping with lop and top following clear-felling of Scots pine was investigated at Balblair Forest, Ross and Cromarty. Four treatments were compared as to their costs and their effect on tree growth. The practicality and costs of subsequent treatments, e.g. planting, beating-up, are also being assessed. The main preliminary result is that replanting through untouched lop and top took less than 50 per cent *additional* time per 100 plants, compared with replanting cleared (and ploughed) ground. In spite of the experimental errors inherent in this type of experiment, this result was a surprise to all concerned in the trial. The Wilder Rainthorpe chopper was not able to function, due to boulders and the very heavy branch wood. Assessments of survival and beating-up times are continuing.

S. A. NEUSTEIN

Regeneration of Scots Pine at Thetford Chase

No new work has been undertaken during the year. The establishment of the large species trial under light pine cover was successful, though losses in one or two species, notably *Cedrus atlantica*, were high.

The temperature studies are being continued, and demonstrate clearly the benefits of some overhead cover during the growing season, for frost protection. In the clear-felled areas, temperatures fell below freezing on four occasions during the growing season (−3°C 14th May; −2·2°C 10th July; −2°C 21 and 28th August); but under cover, freezing point was never reached between 24th April and 4th September.

These frosts were evidently not severe enough to cause much damage, but the temperature difference of 4—5°C may be sufficient, in colder seasons, to prevent or reduce damage.

(See also 'Ecology'—report on page 52.)

A. I. FRASER

Spruce in the Borders—Size of Felling Area

Windthrow consequent on felling areas of different size is to be the main subject of an experiment at Redesdale Forest (Northumberland). This will be similar to the experiment described in the 1964 *Research Report.* The preliminary survey of soil and crop height has been carried out, and the plots have been prepared for clear-felling. Treatment of lop and top will form a subsidiary investigation.

S. A. NEUSTEIN

Direct Sowing of Sitka Spruce

Trials of direct sowing of Sitka spruce seed were established at three forests under typical regeneration conditions, with a complete absence of vegetation. A known number of seeds were sown in untouched, and in raked-over, patches, with and without ground mineral phosphate. Germination and survival at the end of the first growing season varied considerably, with some indication that raking conferred advantages. Phosphate did not help, nor did a protective layer of dead branches. Protection of thiram-treated seed with small gauge netting against mice and birds also showed no benefit. The trials are continuing.

S. A. NEUSTEIN

Species Trials

(*a*) Trials in Scotland and Northern England

Western Hemlock

One large block of this species has been established (under heavily thinned Scots pine) on a heath site at Allerston (Yorks.) in order to provide long-term evidence of volume yield. Hemlock has shown much promise as a successor species under such conditions in small-scale Research plots but it has not been planted extensively.

Picea x lutzii

On purely theoretical grounds it has been suggested that this hybrid of Sitka and White spruce might be able to withstand moisture stress better than Sitka spruce, and so find a place in Eastern Britain. However, its reported performance in Denmark does not augur very well. The first of a small series of plots comparing it with Sitka spruce was planted.

Sycamore

A simple comparison of standard and 'luxury' planting methods was established at three forests in 1963, in order to determine whether the post-planting check so common with this species could be overcome (see 1964 *Research Report*). A dramatic response to treatment was achieved at one forest, every treated tree in each replication having put on 9 ins. to 15 ins. of shoot growth in its second year, while none of the controls grew more than 1 or 2 ins. Because this result was not achieved at the other two forests, further trials have been planted this year with strict attention to the source of nursery stock.

Nothofagus

Several plots of Chilean beech, *N. obliqua* and *N. procera*, which had been planted in 1955, received their tenth-year assessments this winter. Their growth is consistently much faster than that of any other broadleaved species—poplars and eucalypts excluded. *N. procera* is generally superior in growth and form, but good growth has been shown by *N. obliqua* from seed collected at Bedgebury (Kent), and Tortworth (Glos.). An outstanding plot is that at Garadhban Forest (Stirlingshire) on a fertile soil at low elevation, where *N. procera* (Chilean imported seed) has a top height at ten years of 28½ ft. and a standing basal area of 77 sq. ft. quarter girth. The adjacent plot of *N. obliqua* (also Chilean seed), has a top height of 23 ft. and basal area of 50 sq. ft. These growth rates compare quite favourably with those of spruces in the higher quality classes.

Eucalyptus

In a new experimental area reserved for the planting of Eucalypts at Glenbranter Forest in mid-Argyll, a plot of *Eucalyptus urnigera* (seed origin Crarae (Argyll)) planted in 1964, has been almost completely killed between January 1965 and April 1965 by low temperatures. This plot was on a steep grassy, south-east-facing slope where no pooling of air, with consequent low temperatures, would occur. However, the south-east aspect i.e., facing the rising sun, would subject the young trees to severe temperature fluctuations, and this may be the reason for the failure of this plot. This species has grown very well at Kilmun, Benmore Forest and Crarae near Minard, both of which are also in Argyll, but on the edge of sea lochs. This result is a further indication that the *Eucalyptus* genus is not one which should be planted on any scale in this country until much more is known about its susceptibility to winter cold.

R. LINES
S. A. NEUSTEIN
D. W. HENMAN
J. ATTERSON

(*b*) Trials in Southern England and Wales

The nine species of *Abies* and *Picea* planted out last year in Devon, New Forest and North Wales survived quite well, and such losses as there were seem to be associated with the quality of the plants: the losses of *Abies procera*—a very poor lot of plants—were by far the most severe. The new growth showed a variety of colours on several species at Plym Forest in Devon, with yellows and bronze predominating. This can hardly be due to deficiences on the Plym site so must be connected with severely checked growth. If so, the growth this year should be normal.

This year two species have been planted in small plots at Plym. *Abies religiosa* is probably hardier than is often thought, since one reached a considerable size on the Isle of Wight by 1931, but this species has rarely been available.

Pinus taeda is ill-represented in Britain. Half-a-dozen trees are known in Hampshire and Sussex, of considerable vigour and with good stems. Provenance may be important in this species. The plants for this plot are of Georgian (U.S.A.) origin. Smaller numbers have been planted in collections elsewhere, so that the relative hardiness of this origin may be found, but there are no other *Pinus taeda* available for comparison.

Eucalyptus species are being planted as potted-on seedlings in June, a system which obviates any check in the root-growth. To test the theory that hardiness is greatly improved by poor soil of good drainage, and full exposure to maximum sunlight, a number of species of promise are being planted on a sandy site at Thetford. The same provenances and species are being added to the established *Eucalyptus* collection at St. Clement, Lands End Forest near Truro in Cornwall.

Seed of 19 coniferous species native to Mexico has been received through the good offices of the Mexican Forest Authorities and Dr. F. C. Hummel (F.A.O.). Two are *Abies*, two *Pseudotsuga*, one *Cupressus* and 14 are *Pinus*. Of these species, eight are probably new to Britain and only three of the rest are seen outside special collections.

A. F. MITCHELL

Long-term Mixtures

Gisburn Forest: Conifer/Hardwood

The experiment established jointly with the Nature Conservancy at Gisburn Forest, Yorkshire, in 1955, is beginning to show some interesting mixture effects. The species concerned are Scots pine, Norway spruce, Sessile oak and Common alder, each pure and in mixture with the other species, in plots of half an acre. Unplanted plots, grazed and un-grazed by sheep, are also included, but assessments in these plots are not done by the Forestry Commission.

Height growth after ten years was best in Scots pine and poorest in Norway spruce. The site is at an elevation of about 900 feet with little higher ground to give topographic shelter. An exposure flag showed a tatter rate of 1·2 square inches per day, which is higher than that in many of the trial plantations in Caithness and Orkney. The poor growth of the Norway spruce is almost certainly due to these blasting winds, which caused considerable crown die-back during the severe winter of 1962/63. An assessment had been made three years before, and comparing the two it was clear that Norway spruce made a smaller height increase than any other species. The plantations which surround the experiment are largely Sitka spruce, as the local Forestry Commission staff believed the area too exposed for Norway spruce, which was included in the experiment at the express wish of the late Professor Pearsall, a former member of the Advisory Committee on Forest Research.

The main point of interest at present is the demonstration of the effectiveness of Scots pine as a nurse crop. As will be seen from Table 9, all three species have grown best when in mixture with Scots pine. As this species was three to five feet taller than the others (and evergreen) it provided a fair measure of shelter. This is shown most clearly with Norway spruce, where the plots in mixture with Scots pine averaged 7·1 feet whereas when in mixture with the deciduous oak it was only 4·9 feet tall. On the other hand, Scots pine would find least competition when in mixture with oak and most competition when competing with itself (i.e. pure) and this is also reflected in the data of Table 9.

The experiment is not due to be assessed again for height until it is fifteen years old, and by this time it may have reached the stage when the Scots pine will begin to depress the growth of the species with which it is in mixture by over-shading them. The mixtures are arranged in groups of three plants by six plants, so as to delay this effect, or eventually allow the slower growing trees to be helped by removing competitors by thinning.

Stocking is now adequate for all species, except for some unfortunate gaps in the Norway spruce caused by frost and blasting winds. The numbers of plants used for beating-up gives an indication of the difficulty of establishing the broad-leaved species relative to the conifers. The numbers used in beating-up, expressed as a percentage of those planted in 1955, are 31 per cent for Norway spruce, 19 per cent for Scots pine, 46 per cent for oak and 183 per cent for alder. The figures for oak would have been even higher except for a decision to replace only those failures which would leave an appreciable gap. Beating-up extended over nine years, which is quite exceptional, and only justified because of the long-term nature of this experiment. Attack by voles was worst on the broad-leaved species.

Table 9

MEAN HEIGHT AT 10 YEARS FOR VARIOUS SPECIES IN PURE AND MIXED CROPS (FEET)

	Scots pine	Norway spruce	Common alder	Sessile oak
Mixed with:—				
Scots pine	10·6	7·1	8·4	8·2
Norway spruce	11·4	6·0	7·4	5·6
Common alder	11·0	5·6	8·0	6·1
Sessile oak	11·7	4·9	7·6	6·6

Douglas Fir/Western Hemlock

Five experiments were planted in 1957 with pure and mixed plots; half an acre in size with three replications at each site. These were Yair Hill, Selkirk; Hamsterley, Durham; Mortimer, Hereford; Wentwood, Monmouth; and Haldon, Devon.

At the two northern sites, the initial survival of Western hemlock was poorer (70 per cent to 80 per cent) than that of Douglas fir (90 per cent to 95 per cent), but thereafter the experiments took diverging courses. At Yair Hill, which is on a valley side exposed to strong south-westerly winds, and has an annual rainfall of 45 inches, the hemlock suffered every winter from the blasting winds, which defoliated them to a greater or lesser degree. The Douglas fir, although growing with markedly one-sided crowns, were not reduced appreciably in vigour and had leading shoots up to 24 inches. After six growing seasons they averaged 6·9 feet in height, while the hemlock were 4·5 feet. At Hamsterley (where the site would accommodate only two replications) the elevation is similar, but it is much less exposed. The mean annual rainfall is only 30 inches and, as the soil is free draining, seasonal droughts are likely. It is a site which carried poor quality hardwoods, now felled, and was colonised by bracken and heather. Here the Douglas fir was always the poorer species, whereas the Western hemlock grew fast from the start. *Adelges* insects made heavy attacks on the Douglas fir, but the prime cause of the trees' poor growth is not clear, as there are good crops of this species nearby. The mean heights at six years were 4·6 feet for Douglas fir and 8·1 feet for Western hemlock. It is too early to look for much sign of interaction between species in the mixed plots, but it is of interest that except for one replication at Yair Hill, all the other plots show better growth of each species when planted pure than when mixed with the other.

At the three southern sites, initial survival rates averaged 86 per cent for Douglas fir but only 69 per cent for Western hemlock, but after beating-up there is now satisfactory stocking in all plots.

Mortimer proved to be the most difficult site, due to a combination of frost damage and uneven drainage and here the initial survival rate was lowest for both species (75 per cent for Douglas fir and 45 per cent for Western hemlock).

Wentwood, on the other hand, though more exposed than Mortimer, gave much better initial survival rates (92 per cent for Douglas fir, 76 per cent for Western hemlock) as well as good height growth.

Table 10 following gives the mean height growth in feet after six years at the three southern sites:

Table 10

DOUGLAS FIR/WESTERN HEMLOCK MIXTURE, HEIGHT GROWTH AT SIXTH YEAR

Forest	Douglas fir		Western hemlock	
	Pure	Mixed	Pure	Mixed
Mortimer	4·9	5·4	4·5	4·4
Haldon	5·1	5·0	4·9	4·5
Wentwood	5·0	5·2	7·1	7·0

Of the three sites, Mortimer is the only one where the Douglas fir suffered from *Adelges* insects to any extent. At present there is little to choose between the mixed and the pure plots of either species, but nursing effects are usually delayed till canopy is beginning to close.

Sitka Spruce/Western Hemlock Mixtures

This series of experiments was laid down in 1955. There were four Southern sites all in Wales, namely: Carno, Draethen, Gwydyr and Coed Morgannwg. A Scottish experiment was written off, and subsequently replaced by experiments on two Northern sites in 1963 and 1964. As the southern group forms a self-contained series and has now received its tenth year assessment, a brief note on results to date on the four sites is appropriate at this stage.

All sites were exposed and ranged in elevation from 700 to 1,350 feet. Initial survival rates of the Sitka spruce were excellent (over 98 per cent on all sites), but less good for the Western hemlock (66–85 per cent—average 79 per cent).

Table 11 following gives the results of height and survival assessments at the end of the first ten years.

Table 11

SITKA SPRUCE/WESTERN HEMLOCK MIXTURES HEIGHT AND SURVIVAL RATES AT THE TENTH YEAR

Forest	Sitka spruce				Western hemlock			
	Pure		Mixed		Pure		Mixed	
	Height (ft.)	Survival %	Height (ft.)	Survival %	Height (ft.)	Survival %	Height (ft.)	Survival %
Carno	11·2	99	11·3	99	3·9	65	6·6	85
Dracthen	9·0	100	9·1	100	3·2	70	4·5	79
Gwydyr	10·5	100	10·5	99	7·4	83	7·8	89
Coed Morgannwg	7·1	96	6·9	99	2·6	64	3·3	77
Overall means	9·4	99	9·4	99	4·3	70	5·5	82

Thus at all four sites, but particularly at Carno, Western hemlock has benefited from the shelter of the Sitka spruce in both height growth and survival rates. The Margam site is both dry and exposed and even the Sitka spruce has made relatively poor growth in the first ten years. Western hemlock suffered badly in the severe winter of 1962/63 and stocking in the pure plots is still quite low despite beating-up.

R. LINES
M. NIMMO

Provenance

Scots Pine

In the *Report on Forest Research* for 1963, p. 131, an account was given of the early growth of eleven provenances of Scots pine from east Scotland, and the question of whether their height growth up to six years of age was determined chiefly by their seed weight, or by other factors, was left unanswered. These three experiments have now been assessed again at ten years of age, and the results show little change in the relative performance of the provenances, although the trees at the best site are now nearly in the pole-stage, while at Glen Isla, Angus, on an unploughed site, they have not yet closed canopy. Unlike many experiments, which in the first few years show highly significant differences between provenances, such differences diminishing as they grow older, at all three sites the differences in height between provenances were statistically of higher significance at ten years than at six years. The Drummond Hill provenance, which was tallest at Laiken and at Glen Isla at six years, but only sixth in rank at Glenlivet at the same age, had moved up to second place there after ten years.

The experiment planted in 1951 at Glentrool, which suffered severe needle browning following the hard winter of 1962/63, was assessed for height at fifteen years of age. In May 1964 it was found to be even worse affected by needle browning than it had been the year before. This time even the West Coast provenances (Shieldaig and Rhunoa) had more than 90 per cent of their needles browned, except in one or two plots, and on the remaining provenances not a green needle remained. Adjacent Sitka spruce was completely unharmed.

The particular climatic conditions which cause needle death on this site are not known; the winter of 1963/64 was as mild as the winter of 1962/63 was severe. Very low humidities occurred in the latter, whereas the humidity was above normal in the former.

The tallest provenance at fifteen years was that from Pitgaveny Estate, Morayshire, which continued to show inherent vigour despite repeated browning. It was grown from specially selected large seed, but it seems very unlikely that this advantage could still persist eighteen years after sowing. The other provenances show the same variation as at ten years, with the West Coast provenances generally superior to those from the Central or Eastern Highlands. Because of repeated foliage browning, the future of this experiment is still in doubt.

Pinus nigra

The wide range of provenances, mainly from areas of calcareous rock, from Bulgaria and Poland to France, have been planted on four sites in England. These are Thetford, Brighstone (Isle of Wight), Colesbourne (near Cheltenham in Cotswold Forest, Glos.) and Wareham (Dorset). The first three sites are underlain by chalk or limestone; the Wareham site is a poor, acid, shallow peat on sand and gravel. This was included to show the interaction of provenance with soil pH. As this is a long-term experiment, the plot size is fairly large (11 × 11), being restricted by the availability of plants and areas of suitable soil type. Twenty provenances are used in the large plots, in a 5 × 4 rectangular lattice, replicated three times at each site. Three more provenances are included with these in smaller plots (8 × 8), for short-term studies, and every provenance has also been planted in widely-spaced lines of ten trees each, for studies of branching and stability.

The experiments planted at Haslingden in 1962 on the Lancashire side of the Pennines (in an area known to be subject to a fairly high level of atmospheric pollution), and at South Yorks Forest (Haw Park) in 1961 (on a site with lower pollution) have been assessed for height and survival at the end of their third growing season. They contain a similar set of provenances, which show little differences in relative growth between the two sites; the Belgian provenance from the Forêt de Koekelare was tallest at Haslingden and second tallest at Haw Park. Other fast-growing provenances were also ones which had grown for one or more generations outside the natural range of the species, so that some selection of individuals better adapted to growth in Northern Europe had probably taken place. Characteristically, the provenance direct from Corsica has made a slow start, but it is expected to show a better rate of height growth between the third and sixth years than some of the other provenances, such as that from Austria. The most vigorous provenances had the best survival rates at Haslingden, showing that they were able to withstand both severe winter cold and atmospheric pollution, at least in the young stage.

Lodgepole Pine

A major step forward has been taken towards getting seed of the desirable provenances, by the decision to send a Research Officer to the North West of America to study availability of seed sources. As part of his duties, he will arrange small collections from sources where seed supplies are difficult on a commercial scale. It will be possible to carry out new provenance experiments designed to obtain the maximum information from these valuable collections.

Alaskan provenances are chiefly of interest for poor and exposed sites in the north of Scotland. One from Hollis, Prince of Wales Island, has grown well on several such sites and compares very favourably with the Lulu Island, British Columbia, provenance which forms the matrix of these plots. It was also planted in 1954 at two forests (Watten, Caithness; and Kielder, Northumberland) where it can be compared in replicated experiments together with another Alaskan provenance (Haines, near Skagway), with Lulu Island, and with a home-collected lot originally from the coast of Washington. At both sites the Alaskan provenances were significantly inferior in height, at ten years, to the more southerly provenances, which did not differ greatly. Neither experiment was given phosphate at planting, as it was feared that that would encourage basal bowing; as a result, both lots checked severely and only commenced rapid growth after phosphate was applied. It may be noted that basal bowing was largely prevented, but the vigorous Washington coast provenance does have some leaning stems, whereas the shorter and sturdier Hollis trees are perfectly straight. As Haines was least vigorous and lacked the strong bushy appearance of 'Hollis', it is hoped that the recent large seed lot from Skagway (near Haines) will grow more rapidly. At Carrick, Ayrshire, under conditions of the worst exposure (as reflected in flag tatter), the Hollis provenance has failed, while an adjacent provenance of unknown origin, but of 'U.S. Coastal type', has nearly closed canopy and will make a crop of sorts. The choice on the poorer and most exposed sites appears to be between a reasonably certain crop, of poor stem form, with the Washington coast provenance, and a somewhat less certain crop of good stem form, though with only two-thirds the rate of growth, with the Alaskan coast provenances. Perhaps the answer lies in a hybrid between the two!

A preliminary cone collection study was carried out on six provenances of Lodgepole pine to see how early viable seed could be obtained and whether some provenances lost appreciable amounts of seed by the cones opening before the traditional date for cone harvesting with pines (January). All six provenances had normal numbers of viable seeds per cone on 1st September 1964, and although partial cone opening was observed on some provenances, the number of viable seeds per cone fell appreciably only in the Queen Charlotte Islands provenance, during six collections between September and the middle of January. Three lots from the interior of British Columbia averaged 8·6 viable seeds per cone, whereas coastal provenances from Washington, from the mouth of the Fraser River and from Queen Charlotte Islands, had 24 viable seeds per cone. The inland trees, however, had far more cones on them than the coastal ones.

A small provenance trial has been planted on three sites, representing the most difficult land typically planted with this species in south-west England and Wales. The sites are at over 1,000 feet above sea level at Brendon (Somerset), Tarenig (mid-Wales) and Clocaenog (North Wales). The trial is to test the Skeena River provenance which is being used to establish seed-plantations, and two other northern coastal provenances not before represented in southern trials, against the typical Southern coastal lots, Long Beach and Reedsport, about which more is known. Another provenance, from Concrete, Washington, is included as this may show some characteristics intermediate between coastal and inland, as do Skeena River trees.

Pinus banksiana

Two experiments, each with twenty provenances, covering a wide part of the natural range of this species, were planted in 1961 at Inshriach, Inverness-shire, and Broxa, Allerston Forest, Yorkshire, together with one inland provenance of Lodgepole pine. Both are basically heathland sites with dominant *Calluna* before ploughing at Inshriach; at Broxa the site was an abandoned heathland nursery. Early losses were negligible, but the winter of 1962/63 caused severe browning and shoot die-back at both Inshriach and Broxa. This winter damage affected different provenances at the two sites, yet at each site the provenance differences were statistically significant. On further examination, it was found that microsite differences at the topographically irregular Inshriach site could explain nearly all the differences in foliage browning. After adjusting the browning scores on the basis of the exposure of each individual plot, there was little remaining variation. At Broxa there were true and highly significant differences in winter damage.

The heights after three growing seasons showed a fair degree of agreement between the two sites, but with some anomalies, perhaps due to the winter damage. The best provenance (average of both sites) was from Douglas, Ontario, with others from Oconto, Wisconsin; Upper Jay, New York; and Winter Harbor, Maine, not far behind. There was no obvious relationship between height growth and either latitude or longitude, though some correlation with length of growing season at the point of origin. Two provenances with poor height growth from sites with a relatively long growing season, St. Louis de France, and Chapeau, Quebec, were amongst those worst damaged by the winter at both experiments.

The Lodgepole pine provenance tested (Fort Fraser, British Columbia) was near the mean for the whole experiment at Broxa, but little taller than the poorest provenance of *P. banksiana* at Inshriach. It was more resistant to winter die-back than most of the P. *banksiana.*

These experiments form part of an international series, the key experiments being in Canada and the U.S.A., and containing up to 100 provenances, covering the entire range of the species. European experiments with the same provenances have been planted in Denmark, Finland and Czechoslovakia.

Douglas Fir

Seed has been acquired for sowing, in 1965, from a promising region so far not represented in our trials. This is the Oregon coast and part of southern Washington, and these provenances will be compared with others from certified seed stands further north and inland.

Sitka Spruce (See Plate 12.)

In the series of experiments planted in 1960/61 it was noted in last year's *Report* that differences in survival rates up to the third year were small. Most provenances at all sites had a survival rate exceeding 95 per cent, the exceptions being the most northerly provenances (Lawing and Cordova, Alaska) which were very small at planting, and Sooke, Vancouver Island, which was significantly poorer in survival rate at Ratagan, Inverness-shire, and at the very exposed Mynydd Ddu site in Monmouthshire. At some of the Scottish sites there were highly significant decreases in survival rate and in the amount of shoot die-back following the severe 1962/63 winter. The worst damage was at

Glentrool, where survival rate in two of the southern provenances dropped from 98 per cent to 30 per cent or less, and even the Alaskan ones had survival rates reduced by 20 per cent to 30 per cent. It is proposed to publish detailed results later.

As a result of the winter die-back and breakage of leading shoots during the period of shoot extension, the early differences in height growth must be viewed with caution, but vigour does increase generally with decrease in latitude. The Alaskan provenances from south of the 60th parallel were distinctly more vigorous than those from north of it. There is a tendency for the off-shore island provenances to be markedly more vigorous than their latitude of origin would suggest. In the case of Sooke, Vancouver Island, it has been shown at Tarenig Forest that good height growth is partly due to greater resistance of the leading shoot to wind damage (5·7 per cent broken), than that found in other vigorous provenances from further south (8 per cent to 11 per cent broken).

The percentage of plants showing Lammas growth varied greatly between experiments, but was always significantly higher in the southern provenances; for example at Shin, Sutherland, the percentage of trees with Lammas shoots ranged between 3 per cent to 18 per cent on five Alaskan provenances, while on those south of the 49th parallel the range was 54 per cent to 87 per cent.

Norway Spruce

A trial of our 'standard' seed origins, which lie in Austria, France and Switzerland, against certain provenances found to be much superior in European trials, is being sown at Alice Holt. We are specially interested in Bulgaria (two lots) and Rumania (twelve lots). Seed from a certified source in Britain and from a good stand in the Adirondacks, New York State, is also included.

Abies alba

25 provenances of *A. alba* and two of *A. nordmanniana* were sown in 1961 at Fleet Nursery, Kirkcudbright, in a replicated experiment. A further eleven provenances, for which there was insufficient seed, were sown in unreplicated plots. A Swiss lot has the best out-turn of plants, followed by several French origins; *A. nordmanniana* and one of the Czech lots gave the poorest number of plants. There were very highly significant differences in the heights of the one-year seedlings, which varied between 0·83 inches for one from Central Italy, to 0·36 inches for a Czech one from Boubin. A regression of seedling height on the weight of 1,000 seeds was highly significant, and for provenance comparisons the heights were adjusted accordingly. This chiefly affected the Italian provenances, and on the adjusted data the Black Forest provenance was tallest, followed by French ones from the opposite side of the Rhine valley.

A small amount of frost damage occurred in May 1962. Differences in damage between provenances were highly significant, being worst on the Vosges, Jura and Black Forest provenances. Covariance of frost damage score on seedling height showed them to be highly significantly related.

The plants were lined out in July 1962, and were assessed for height in September 1963. By this time quite a few changes in rank had occurred, presumably as a result of the diminishing effect of seed size and the increasing expression of genetic factors. As the plants averaged only 3·4 inches, they were left for a further year and again assessed for height in September 1964. The rank order changed little during this year and the tallest provenances were from Ardèche

France; Benus, Czechoslovakia and the Black Forest. Swiss and Polish provenances also grew well; however, the French ones which had grown so well at first were little better than average.

These 36 provenances will be planted at five forests in 1965 and 1966, either beneath an overstorey, or in small clearings in an older crop.

Abies grandis

A small provenance trial has been sown at Kennington to compare two sources on Vancouver Island with one each from the north, middle and south of Washington State. This species overlaps with, and may be regarded as grading into, the form of *Abies concolor* known in Europe as '*Abies lowiana*'. The boundaries and degree of intercrossing between the species, or details of the intergrade, are not known. Some forms of *Abies lowiana* in Britain may be superior to normal *Abies grandis*. To shed some light on these questions a series of seed-lots ranging from Oregon *Abies grandis* to mid-Californian *A. concolor*, from 19 areas of greatest potential interest, has been acquired from Berkeley, California and sown at Wareham, Dorset.

Abies procera

A small trial comparing a 'standard' Oregon imported lot with seed from selected stands in Denmark and Britain has been sown at Kennington. There are two Danish sources, two Scottish and one each from England and Wales.

Sequoia sempervirens

Replicated plots of eleven provenances were planted at Plym Forest in Devon; demonstration lines of twelve provenances were also planted there and ten at Alice Holt. Seven provenances are in all three parts of the experiment. Both sites include trees from the extremes of the north-south range—Brookings (Oregon) to just north of Punta Gorda, California.

R. LINES
A. F. MITCHELL

Weed Control in the Forest

(*a*) Scotland and Northern England

An experiment comparing paraquat, applied with an 'Arbogard' (a special hooded sprayer), and 2,6-dichlorothiobenzamide, applied as a granular formulation by hand, was established at Eddleston Forest in Midlothian. The application times for each treatment were recorded, and on this particular site it took approximately ten minutes to apply the paraquat and 2,6-dichlorothiobenzamide per 100 plants, whereas one hand weeding took fifteen–thirty minutes per 100 plants. Although these timings are not highly reliable since the treatments were done only on 100-plant plots, they suggest that these materials can be applied a good deal quicker than the process of hand-weeding. The vegetation on this site was dense grass.

An experiment testing 'Dicamba' on bracken was laid out in Saltoun Forest in East Lothian last autumn. In addition to its effect on bracken, this weed-killer may prevent recolonisation of the bracken area by grass, in which case such a treatment might replace ploughing on bracken areas where cultivation is only required for vegetation control. A number of species have been planted throughout the treated area, this spring, to see if there is any residual effect of this weed-killer in the soil.

The growth of Sitka spruce is retarded on *Calluna*-covered peat largely because of *Calluna* competition for nitrogen. An experiment was laid down at Shin Forest in Sutherland to determine whether Sitka spruce can be grown on poor, acid peat without additional nitrogen but in the absence of *Calluna* competition. 2,4-D and paraquat are being compared in this experiment as *Calluna* herbicides.

In the replacement of larch crops with Sitka spruce in North and West Scotland, weeding of the replanted species may be required for one to three years. Three experiments have been established testing the effect of paraquat, applied at three rates in the winter prior to replanting, on weed-growth in the following season.

J. ATTERSON

S. A. NEUSTEIN

(*b*) Southern England and Wales

All new work on weed control in the forest in 1964 is included in papers on pages 133–153 in Part III of this *Report.*

Experiments established on a range of sites in 1961 to compare costs of hand and chemical weed control, were continued.

Attention is directed to the intensive manuring with total weed control experiments more fully described under 'Nutrition' on page 28.

J. R. ALDHOUS

Tree Stability

Records of Windthrow

The amount of damage reported in the year ended March 1965 is an increase on the 1964 figures:—220 acres approximately, as compared with 170 acres; but it still does not approach the 1,250 acres recorded in the period September 1961–March 1962. The new cards designed for the reporting of windblows appear to be serving well, and foresters find them convenient and return them promptly.

Spruces on badly drained soils continue to account for the largest proportion of the acreage damaged.

A. I. FRASER

Tree Pulling Investigations

A large programme of tree-pulling (in the study of rooting characteristics and resistance to windblow) was completed in the Border area during the year, with a total of 128 trees being pulled on twelve different sites. All but twenty-four of these were Sitka spruce, and of the remainder sixteen were Norway spruce, and eight *Abies grandis.*

The main study was at Newcastleton, where a soil survey of the forest was being made, and samples of trees were selected on each of the five major soil types mapped. The primary object of the work was to enable the soil map to be elaborated to include susceptibility to wind damage (see D. G. Pyatt, Part III, page 204).

Samples were also taken in a Sitka spruce thinning experiment at Bakethin, Kielder, in order to see whether heavy early thinning had improved the stability of the crop. The results show that the trees' resistance to being pulled over was not improved, but the effect on rooting was interesting. The most heavily thinned plot had significantly wider, but shallower roots than the lightest thinned of the plots.

Opportunity has arisen to study the rooting characteristics of Norway spruce grown under the reverse conditions, i.e. initially planted at spacings ranging from 3 ft. to 8 ft. and subsequently thinned to equalise stocking. A spacing experiment at Kershope Forest was windthrown by the gale of 13th to 14th January (90 m.p.h. gust recorded at Spadeadam ten miles away), the three 'closer spacing' plots and the surrounding plantations being completely blown while the '8 ft. spacing' plot remained standing almost to a tree. Work is continuing to investigate the comparability of the soils. At the time of windthrow the crops were about 47 ft. tall and carried 860 (initial 3 ft. spacing) to 600 (initial 8 ft. spacing) stems per acre.

The existing large series of spacing/thinning experiments covering a variety of species and site types is for the most part unavailable for destructive stability assessments, but one of these, in Sitka spruce on a peaty gley soil at Kershope Forest, is being treated under two contrasting thinning régimes to provide future material for tree pulling investigations.

Evidence is accumulating (see also this section of the *Report* to March 1964) that trees given more individual growing space develop heavier stems (presenting greater inertia), larger crowns (offering greater wind drag) and wider but shallower root systems. The resultant of these characteristics in practical terms of stability to gales is still being evaluated.

A. I. FRASER

D. W. HENMAN

Aerodynamic Studies

The forest experiment mentioned in the 1964 *Report* is now well in hand. The site chosen, at Redesdale Forest in Northumberland, is relatively flat, thus avoiding uncertain topographic influences. The crop is thirty feet tall Sitka spruce. Studies of the rooting conditions were made during the year, and showed that though there is considerable variation, the general root development is quite good. The crop is therefore likely to remain stable throughout the period of the experiment.

Bases have been prepared for tall masts, and the instruments for the experiment have been chosen, so that it is hoped to be able to start collecting data in October 1965.

Velocity profiles will be measured both over the trees and over open ground nearby, so that the effect of the forest on the wind can be studied. Individual trees will also be instrumented in order to examine their behaviour in the wind.

A. I. FRASER

Miscellaneous

Growth Fall-off in Sitka Spruce

Following discussion at a Research Branch Conference, a Project Plan has been drawn up to co-ordinate work on this difficult subject. Investigations are proceeding concurrently at fundamental, empirical and survey levels. A site has been selected for the investigation of canopy density in relation to soil and tree moisture relations.

The experiment at Forest of Ae, in which small plots of Sitka spruce are being kept free of *Neomyzaphis* by insecticidal fogging, had its first season's treatment. Aphis counts showed a 90 per cent kill from spraying with Malathion in June, and the population did not build up again during the succeeding autumn and winter. Basal area increment during the growing season was rather low and showed no significant response to the elimination of the aphids. However, the incidence of aphis attack in the control plots was low during the year.

D. W. Henman

Estimation of 'Exposure' by Abney Level

This investigation, noted briefly last year, has been brought to a provisional conclusion and is described in a separate paper in Part III, page 201, of this *Report*. It appears that on a national scale Abney level measurements of the angles between the surrounding geomorphic features and the horizontal have little advantage over conventional subjective estimates of exposure. However, on a more local level the procedure does seem to be of greater value.

S. A. Neustein

POPLARS AND ELMS

By J. JOBLING

POPLARS

Varietal Studies

Varietal Trial Plots

Assessments were carried out at most major trials and data were used in the construction of Forestry Commission Management Tables. The tables are based largely on the growth of black poplar hybrids, and for some years ahead they will be used almost exclusively to forecast the production of varieties such as *P.* 'Robusta' and *P.* 'Serotina.' Useful growth data continue to be collected for the only two balsam clones in cultivation (*P. tacamahaca* x *trichocarpa* 32 and 37); but their likely yields cannot yet be predicted since the oldest plots are still only 12 years old. Though both clones are surprisingly site-tolerant, they have been criticised for their slow radial growth even on fertile soils. But measurements recently made in a number of trial plots suggest that their rate of growth is likely to be better than average for poplar for this country, and the data in Table 12 below should be compared with those given in Forestry Commission Record No. 40, *Preliminary Yield Table for Poplar*, and not with the data for other, faster-growing balsam clones referred to in previous *Research Reports.*

Table 12

POPLAR TRIAL PLOTS

HEIGHT, GIRTH AND VOLUME OF P. TACAMAHACA x TRICHOCARPA

Clone	Location	Age of plot	No. of trees per acre	Average height (ft.)	Average breast ht. girth (ins.)	Basal area per acre (sq. ft.)	Volume per acre over bark (cu. ft.)
Clone 32	Stenton Forest, East Lothian	10	118	41·9	19·9	20·122	336
	Wynyard Forest, Durham	10	134	48·1	25·7	38·579	805
	Flaxley, Forest of Dean	11	134	47·6	17·9	18·660	378
Clone 37	Stenton Forest, East Lothian	8	134	35	20	23·630	351
	Wynyard Forest, Durham	8	134	30·8	18·0	18·815	
	Brahan Castle Estate, near Inverness	10	109	38·5	25·5	20·059	330
	Flaxley, Forest of Dean	11	134	44·0	21·3	26·468	490

The plots at Flaxley in the Forest of Dean, Gloucestershire, have a dense woody understory, and there is undoubtedly competition for moisture and nutrients in these. The other plots are on fairly typical poplar ground that might be planted commercially, though growth at Stenton Forest, East Lothian, is poorer than had been expected from a deep, alluvial soil. It is thought, however, that peeler logs will be obtained from the plots at Wynyard Forest, Co. Durham, and Brahan Castle Estate, in eastern Ross-shire, at the age of 15 years.

No plots were planted during the year, though several new clones are being propagated for early inclusion in trials, and a large number of old plots was closed. As nearly 900 plots, of 208 clones, were planted in the period 1948 to 1960, there is ample opportunity for selection, and clones that are found to be disease susceptible or otherwise unsuitable for commercial use, together with plots on marginal ground, are discarded.

Varietal Collection

A total of 92 clones were introduced during the year. Of these 58 were obtained from Austria, Belgium, France, Germany and Holland, following a recommendation by the International Poplar Commission, that clones put forward by national authorities for registration with the Food and Agricultural Organisation in Rome should be made available to other member countries in the region. The clones are of *P. deltoides*, *P. nigra* and their hybrids, and all are planted commercially in northern and central Europe. Additionally, 26 other clones were introduced from Czechoslovakia, Belgium, France, Germany and Holland for disease-testing or inclusion in the National Populetum, while a further 8 clones were obtained from Bryant and May (Forestry) Ltd. for inclusion in disease trials. The total number of clones in the collection now stands at 500, though several clones are certainly duplicated as a result of all the latest importations, and the final count is expected to be about 470 clones.

Populetum

The total number of clones represented is now 296; 5 clones were planted during the winter.

Silvicultural Experiments

Establishment Studies

A small number of experiments, on methods of weed suppression around newly planted trees, has continued to be informative, and it is hoped to publish some results shortly to supplement the recommendations already made to growers.

Spacing

Assessments were carried out in all experiments, excepting the most recent at Wentwood Forest, Monmouthshire, and growth trends observed earlier have been confirmed in most cases. Of particular interest is the experiment at Alice Holt Forest, Hampshire, in which the trees are spaced 9 feet, 12 feet and 15 feet apart; that is, at stockings of 538, 302 and 194 stems per acre. The object is to compare the production of pulp wood at different close spacings, and it is apparent after only 8 years that the growth rate of individual trees at 9 feet is now appreciably less than that of trees at two wider spacings. Figure 1 shows that the mean girth of the closest spaced trees is only 16 inches against a mean girth of about 19 inches for trees at the other spacings. Hence, while the stocking at 9 feet is nearly three times that at 15 feet, the basal area per acre at the close spacing is only twice that of the wider spacing (Figure 1(ii)). Volumes per acre

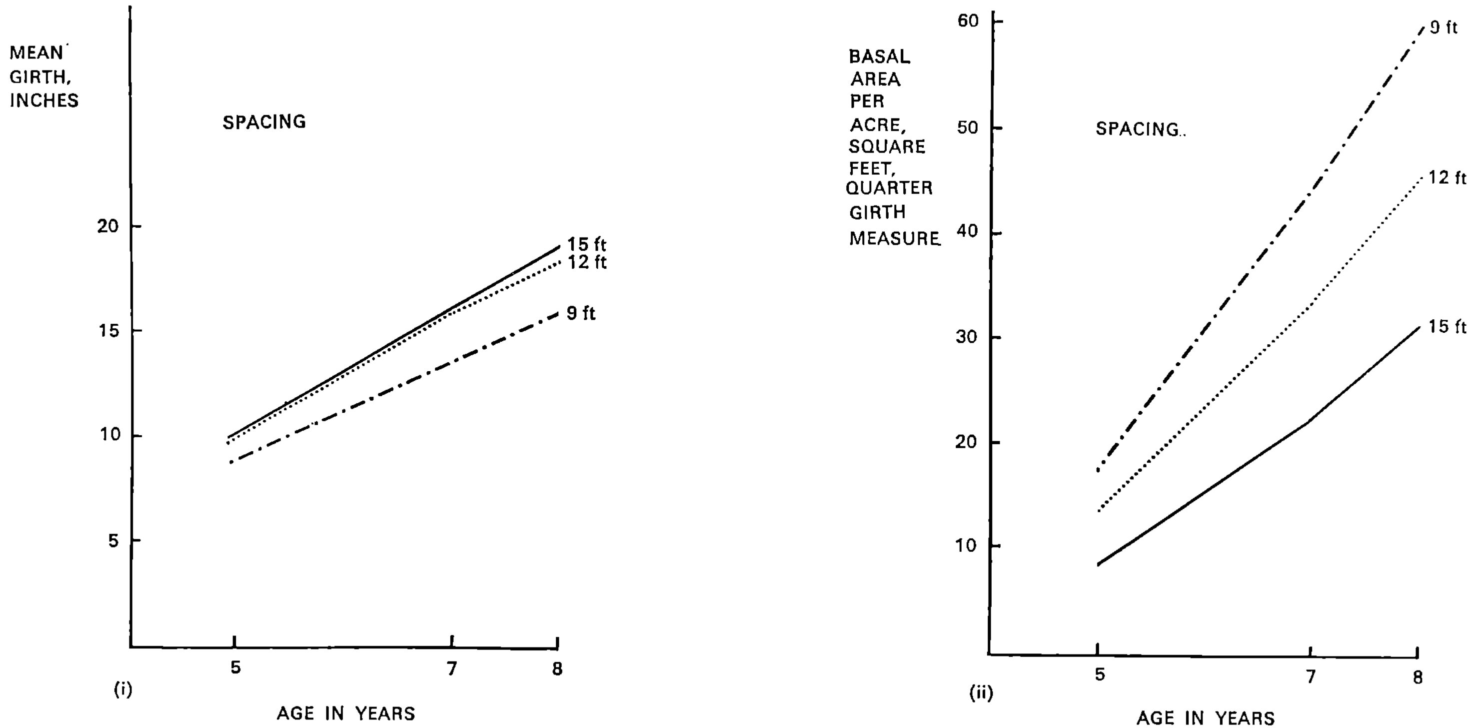

FIGURE 1. Growth of poplars at close spacing to ages of five, seven, and eight years; (i) mean girth and (ii) basal area per acre of trees at spacings of nine, twelve and fifteen feet.

at 8 years are estimated to be 370 cu. ft. (15 feet), 540 cu. ft. (12 feet) and 700 cu. ft. (9 feet). It is expected that the experiment will remain informative for a further 8 years.

Pruning

The major experiment at Cannock Chase, Staffordshire, in which the intensity and periodicity of pruning are being studied, was assessed again during the year, when further pruning was carried out on selected trees. Data collected over three seasons are being analysed, and it is hoped that preliminary results will be available for publication in the next *Research Report.* Other experiments are in progress, but they are not yet informative.

Distribution of Cuttings

Over 22,600 cuttings were distributed during the winter, mostly to private woodland owners and nurserymen in this country. *P.* 'Robusta' continued to be in demand (8,200 cuttings) though orders of *P. tacamahaca* × *trichocarpa* 32 were also substantial (7,200 cuttings). More than 600 cuttings were sent abroad, to Austria, Belgium, France, Germany, Greece, Holland, Roumania and Switzerland.

Bacterial Canker Investigations

The testing of clones for disease resistance is discussed in the chapter 'Forest Pathology', on page 62.

ELMS

Clonal Collection

Seventy clones have now been established in stool beds at Alice Holt. Of these fifty are clones selected during the past few years in different parts of Britain. Clones chosen for silvicultural study have also been planted in stool beds at Westonbirt Arboretum, Gloucestershire, and at Kennington Nursery, Oxford, so that material is readily available for large-scale propagation at these centres.

Propagation

Plants for trials are obtained by rooting softwood cuttings in mist. Efforts to improve cutting survival have not been successful, and a 'take' greater than 70 per cent is still exceptional. Experimentation carried out during the summer confirmed the advantages of early insertion (June and July); but even using selected material there were no substantial improvements in survival. Short periods of storage in a cold chamber (+ 3°C), prior to insertion had little effect on rooting, though the number of cuttings that rooted was progressively reduced if the storage period exceeded fourteen days. Records maintained over the last four years, of numbers of cuttings inserted and lifted, suggest that some elms may be better subjects for mist propagation than others. But individual clones vary in performance from one year to another, and it has been assumed that if the factors affecting rooting are not optimal, even clones that normally root well may suffer losses.

Attempts to raise plants on a large scale from hardwood cuttings have still not been successful. Various types of cutting have been tried, but none appears to do better than the others. Winter storage at low temperature (+ 3°C) has slightly improved initial rooting, but there has been no noticeable increase in the overall rate of survival following this treatment. Better rooting has been obtained in sand than in clay, and further trials are being conducted with different rooting media. But even cuttings that have rooted and survived the whole season have not grown vigorously, and unlike other subjects raised from hardwood cuttings (e.g. poplar and London plane) shoot growth of elm still tends to be slow after lining-out.

No further experimentation has been carried out on sucker growth, as it seems likely from work already undertaken that nursery treatment is a less important influence on survival and growth than the quality of the material that can be obtained in hedgerows and woodland. Weak sucker growth, particularly if taken from the parent tree with a poor root system, does not respond readily to lining-out, and only carefully selected material has given reasonable success. Cutting the shoot back after lining-out does not appear to improve survival; but a straighter plant is obtained which may be as tall at the end of the season as a plant not cut back.

Establishment Studies

Work has been confined to an examination of the early field behaviour of softwood rooted cuttings. Three types of plant are being compared, namely the one-year rooted cutting, the one-year cutting lined-out for one year, and the one-year cutting lined-out for two years. The one-year rooted cutting, because of its small size, was difficult to maintain after planting; seldom taller than 9 inches and often much less, it was easily suppressed or damaged even when local weeding was carefully undertaken. Both ages of transplanted stock survived well, but those that had been lined-out for two years were less stable in the first year after planting, and they were more liable to shoot die-back than the stock lined-out for only one year. After three years in the field, both ages of plant were the same height, although the older plants were nearly two feet taller at time of planting. The one-year rooted (softwood) cutting, lined-out for one year, has also survived well in disease trials, and no especial problems have arisen using this age and type of plant.

Disease Testing

Clones selected in this country, together with most introduced clones, are being screened in a disease trial, for resistance to Elm disease, at Alice Holt. Only one year's results are available, though more than thirty clones will be inoculated with the clausal organism (*Ceratocystis ulmi*) during the current season; any marked variability in behaviour between the different species and hybrids should be clearly discernible at the end of the summer.

FOREST ECOLOGY

By J. M. B. BROWN

Ecology of Black (Corsican) Pine, Pinus nigra

In the large East Anglian forest of Thetford Chase, Corsican pine was a principal species in the plantations created between 1920 and 1935 on the calcareous and non-calcareous glacial and inter-glacial sands of the 'breck-land'. Cutting and replanting in the older stands was initiated several years ago, with the object of improving the quality of the growing stock and forming a more even age-distribution, so that the forest might be managed efficiently as a more economic unit with sustained yield. Corsican pine is the main tree used in this artificial reforestation, in clearings of various dimensions, or (hitherto only experimentally) under a thinned canopy of Scots pine. Some aggravation of attacks by root fungi (*Fomes annosus* mainly) and some damage by roe deer were anticipated, but not the increase in damage by frost in the early growing seasons.

It appears that large scale afforestation of formerly open land with sparse woods, has altered the local climate, among other things by reducing near-ground wind speeds. Clearings made in the 40 to 50 foot tall forest tend on clear nights to become sinks for cold air, which the retarded air movement (during nights when there is some salutary turbulence on open ground) does little to disturb.

In the spring and early summer of 1964, preliminary observations on minimum temperatures at different levels within 4 feet (122 cm.) of the ground provided evidence about the influence of tree cover, size and shape of clearing, position within clearing, ground cover (grass, chopped brushwood, or bare soil) and topography on the frost risk to young *P. nigra* plants. With better instrumentation and more systematic recording, it is proposed to continue these observations for a further two or three years.

In localities where *Pinus nigra* is regarded as a suitable species for reforestation, the Corsican provenance has hitherto held an unchallenged position. As the species has a very wide distribution in southern Europe and Asia Minor, from central Spain to the Rhodope Mountains of Bulgaria, and beyond to the mountains of Anatolia in Turkey, it is logical to suppose that one or another of these alternative seed sources might be equipped, not indeed to supplant the Corsican pine in Britain but to make good some of that tree's shortcomings—particularly its susceptibility to the fungus *Brunchorstia pinea* in the cool upland climate, to root death due to *Fomes annosus* and, on highly calcareous soils, to lime-induced chlorosis. Accordingly provenance trials, established in 1965 with seed from nearly 20 *Pinus nigra* habitats, have considerable interest for the survey recently completed of Corsican pine performance in Britain. In relation to them a more detailed enquiry is being made into the geographical distribution of the species, with special reference to altitudinal limits (and relevant temperatue and rainfall statistics) and to soil properties (especially the lime content).

Sitka Spruce and the Great Spruce Bark Beetle (Dendroctonus micans Kugelaan)

In company with Mr. D. Bevan, principal Entomologist, the Ecologist visited spruce plantations in Holland, the Schleswig-Holstein province of Germany and Denmark in June, 1964, with the object of learning more about the ecology and forest importance of *Dentroctonus*. Well known, but generally innocuous, in the indigenous forests of the common spruce (*Picea abies* Karst) in central and northern Europe, this bark beetle has proved more injurious to that tree outside its natural range in western Europe: but its principal victim has been the alien Sitka spruce (*P. sitchensis* Carr.), frequently used in the afforestation of wastelands in countries bordering the North Sea. Should it become established in Britain, serious damage might be caused to plantations of our chief exotic tree. It was accordingly desired to learn more about the insect, the climatic, edaphic and silvicultural conditions associated with outbreaks during recent decades and the precautions which might be taken against admission to Britain. A report on this study is in process of publication as Forestry Commission Bulletin No. 38, *The Great Spruce Bark Beetle*.

SOIL MOISTURE, CLIMATE AND TREE GROWTH

By W. H. HINSON, R. KITCHING AND D. F. FOURT

(The Nutritional work of the Soils Section is reported under Silvicultural Investigations at page 21)

Soil Moisture Studies

The aim of these studies, stated very broadly, is to provide scientific data on the silvicultural attributes of conifers of major economic importance, and so help to make possible a more fundamental approach to the matter of the correct choice of species for particular sites, than can be derived solely from experience of their performance. Earlier work using gypsum blocks has indicated surprising differences in the water consumption of Douglas fir and Corsican pine at Bramshill Forest in Hampshire. Work has continued this year and has been extended to two new sites. One of these, at Rendlesham in Aldewood Forest (Suffolk), provides a comparison between Corsican pine and Douglas fir, and preliminary results suggest that the apparent species difference is no accident of anomalous site conditions. The other new site has been set up to compare a Sitka spruce stand with an adjoining pine crop (mixed Corsican/Scots pine). More comprehensive facilities have been provided at Bramshill, and efforts are being made to define the components of the forest water balance equation in strictly quantitative terms. The determination of soil moisture storage presents a number of difficulties under forest conditions; this year a new form of volumetric soil sampler has been developed which takes cores to a depth of 66 ins. (see below). Gravimetric data obtained, using this instrument, already indicate that the ratio of *actual* to *potential* evapotranspiration may vary with soil moisture conditions through the growing season.

The growth rate through the season does not appear to be a simple function of soil moisture or directly related to atmospheric conditions. The best hope of throwing some light on the significance of soil moisture seems to involve detailed work on soil moisture characteristics and short-term changes in storage. The acquisition of a neutron moisture meter (see below) should facilitate study of the latter and hydrological work generally. The present experimental techniques require well-stocked even stands in extensive woodland areas of even topography. The soil should be deep, freely drained and stone-free, of loam or sandy loam texture, adequate base status and without compact horizons. These conditions are more or less fulfilled at Rendlesham, Burley in the New Forest, and Bramshill.

Rendlesham, Aldewood Forest (Suffolk)

Stands of Corsican pine planted in 1920, and Douglas fir planted in 1926, have been selected in the large forested area of Rendlesham, part of Aldewood Forest, Suffolk.

The site is almost level, at an elevation of 70 ft., with a regional Potential Evaporation for the six summer months of 18·20 ins. and rainfall for the year averaging about 20 ins; it is in one of the driest parts of Britain.

The soils are somewhat leached coarse sands of low base status, but without prominent horizon development, and although lenses of small flint pebbles occur locally down to 48 ins., emplacement of instruments and sampling were possible.

Both stands were about 60 to 65 feet in height, and growing well, although the pine is more fully stocked than the Douglas fir.

The installations include girth bands, gypsum blocks, thermistors (for soil temperature measurement) and tensiometers. The tensiometers are at 66 ins. and 96 ins. to provide data on vertical movement when laboratory measurements on conductivity are complete.

The following observations on patterns of growth and soil drying seem worth recording. The dates of commencement of observable soil drying in May and June were on average a little earlier under the pine, as compared with the fir. After both plots became temporarily re-wetted later in June, the second date of drying was also earlier.The block resistances were higher in mid-July under the pine, and the drying took place to a greater depth. These observations seem to confirm the greater transpiration of pine first observed at Bramshill. At the time of writing (April 1965) the plots have not regained their usual re-wetted condition, owing to the lower than average rainfall for some months.

The growth patterns of the two species are decidedly similar, the periods of maximum or reduced growth rate showing some general correspondence. However the growth of the pine slows down before the Douglas fir at this site. This we attribute very tentatively to soil drying.

Burley (New Forest)

At Burley, in the New Forest, Hants, adjoining stands of Sitka spruce planted in 1944 and Corsican/Scots pine mixture established in 1945 were selected for study. Both were growing well on deep, near stone-free, fine sandy Brown Earths of low base status, derived from Tertiary Barton Sands.

The elevation is 210 feet with minor undulations on a south aspect. The crop heights were 30 to 35 feet, with adequate stocking, and with a surround of woodlands, including some old oak/sweet chestnut mixture, the former crop on the area. The regional Potential Evaporation for the six summer months is about 18·70 ins., and the average rainfall about 32 ins.

Differences between the soil drying patterns under Sitka spruce, compared with the adjoining pine stand, appear to be much less conspicuous than the well-marked differences between Douglas fir and Corsican pine elsewhere. The pine growth slowed down earlier in the season that at Bramshill and Rendlesham.

The Sitka spruce growth curves show a period of growth at a nearly uniform rate, extending almost to the end of the growing season.

Bramshill (Hampshire)

Further installations have been added to give more comprehensive information at this site. Additional groupings of blocks have been made in the Corsican pine area, to compare methods of emplacement of blocks (horizontal auger holes from pits or oblique holes from surface) and to examine the spatial variation of soil drying (transects running between selected trees at right angles). These indicate no difference due to emplacement, and suggest that the positions adopted for blocks at our various sites are not unrepresentative of the full range displayed by the transects. Drying is a little deeper and more intense, directly under the trees. Thermistors to register soil temperature, and also tensiometers, have been installed at a full range of depths. The tensiometers include pairs at 66 and 96 inches, and at this depth the moisture potential gradient is indicative of downward movement throughout the growing season, though the calculation of the amount must await laboratory studies.

A plot measuring 60 × 45 feet, including 16 trees, has been roofed over with tarpaulins to simulate a régime of lower rainfall. This was placed in position in May 1964. The block resistances indeed indicated more severe drying than the rest of the area; but no effect on growth compared with the rest of the area was apparent. The tarpaulins were removed during part of the winter (1964/5) and replaced after 7 ins. of rain had been recorded.

On certain occasions throughout the growing season, the growth of most of the trees was much reduced, as reported previously. This condition can occur early in the season, when the indicated general moisture tension is low.

The possibility of soil moisture conditions being limiting is nevertheless not being rejected. It is hoped that detailed quantitative study of soil moisture characteristics will elucidate this point.

As would be expected from the low rainfall in 1964, the soil drying patterns over the whole area are more severe than in previous years, and re-wetting of the profile has been delayed.

Buriton, Queen Elizabeth Forest (Sussex) and Thetford (East Anglia)

The readings at these sites (soils overlying chalk) have been maintained. Good growth was recorded for the beech crop at Buriton with no suggestion of soil moisture becoming limiting. Both sites were delayed in their return to winter moisture conditions—in the case of Thetford the profile had by no means become re-wetted at the time of writing (April, 1965).

Instrumentation and Techniques

A New Soil Sampler

A device for taking 'undisturbed' soil cores from the surface to a depth of 66 ins. has been made, and has proved to be useful in practice.

A body tube with a special tool steel cutting edge is driven into the soil, using a very heavy tubular hammer. It is withdrawn with the sample by means of a simple form of screw-jack. A split-lining tube is incorporated for easy removal of the sample core. The development is continuing with the object of reducing the weight of the equipment and the amount of manual work involved in its operation.

Potential Evapotranspiration

During the year a computer programme has been produced for calculating the potential evapotranspiration, using meteorological data after a method due to H. L. Penman. Evapotranspiration data will assume increasing importance when soil moisture storage is estimated quantitatively, using neutron and gravimetric sampling techniques.

Data Logging

Automatic logging of data is desirable in many field investigations and commercial developments in this field have been carefully watched throughout the year. A particularly promising device offered by one company consisted of a self-contained magnetic tape system in a waterproof box. This has been tested for the Silviculturist (South) but found to be unreliable. The faults have been reported to the manufacturers and it is hoped that they will overcome these difficulties.

Soil Temperatures

Thermistors have been used successfully for the measurement of soil temperatures. Commercial thermistors are usually supplied with a large tolerance, and consequently a batch will not have a common calibration curve. A technique has been evolved for bringing a batch of thermistors to a common calibration curve by modifying the characteristic with resistors. The resulting thermistor thermometers are encased in an epoxy-resin. Tests throughout the year have shown that, under typical soil temperature conditions, the drift from the initial common calibration was $<0{\cdot}4°C$.

Neutron Moisture Meter

This method makes use of the high scattering efficiency of hydrogen atoms for fast neutrons, and promises to be an accurate and convenient means of determining soil moisture. The measurement uses a relatively large 'sample', causes little soil disturbance, and can be repeated subsequently at the same point. A survey has been made of neutron-scattering moisture-measuring equipment available commercially, and at the time of writing an instrument has just been purchased. It is intended to carry out preliminary trials with the method in the next season.

Garnier Gauges

During 1964, as in previous years, records were kept of the additions and leachate volumes from the pair of similar Garnier Gauges located near the Meteorological Station at Alice Holt Lodge.

This season there was no difficulty during the winter months, as the ground was not frozen or snow-covered for any significant period. However, largely due to an excessively close shaving of the grass on and around gauges in late May, figures for June are much lower than expected. The plots took some time to recover, especially as a dry period soon set in and no further cuttings were necessary in the surround for some weeks in July. 'Oasis' effects are likely for August and September.

Table 13 shows the results for 1964 in the same form as in previous seasons.

Table 14 compares results for the last 4 seasons totals.

Table 13

GARNIER GAUGE RECORDS—ALICE HOLT, 1964

Month	Potential evaporation (ins.) (E_t)			Rainfall at Alice Holt (ins.)	Sunshine	
	Lysimeters		Calculated value*		Daily mean hours (from tables)*	Daily actual hours 1964
	A	B				
January	0·12	0·26	0·25	0·71	—	1·43
February	0·29	0·25	0·40	1·01	—	1·97
March	1·02	1·02	1·00	4·22	—	1·99
April	2·06	2·30	1·79	2·80	5·05	4·29
May	2·56	2·87	3·07	4·05	6·20	5·69
June	2·53	2·35	3·56	3·93	6·90	5·77
July	4·18	3·73	3·95	1·33	6·50	6·69
August	4·12	3·65	3·17	1·58	6·30	6·36
September	3·94	3·27	2·08	0·62	4·60	6·82
October	1·92	1·21	0·65	1·82	—	4·28
November	0·32	0·49	0·20	2·02	—	1·59
December	0·39	0·22	0·15	3·02	—	1·81
Total, 1964	23·45	21·62	20·27	27·11	—	—
Summer months	19·39	18·17	17·62	14·31	5·93*	5·94

* See Technical Bulletin No. 4, Ministry of Agriculture entitled *The Calculation of Irrigation Need* 1954.

Table 14

GARNIER GAUGE RECORDS-ANNUAL SUMMARIES 1961—1964

Year	Potential evaporation (ins.)			Rainfall at Alice Holt (ins.)	Summer sunshine Daily mean hours	
	Lysimeters		Calculated value		1954–1964 average	Season
	A	B				
1961	22·51	22·58	19·38	30·18	—	—
Summer months	20·53	20·82	16·73	12·50	5·68	5·43
1962	20·72	20·27	19·12	28·04	—	—
Summer months	17·68	17·41	16·47	13·64	5·68	5·82
1963	20·51	18·76	18·80	30·67	—	—
Summer months	17·09	16·31	16·15	15·28	5·68	5·36
1964	23·45	21·62	20·27	27·11	—	—
Summer months	19·39	18·17	17·62	14·31	5·68	5·94

FOREST GENETICS

By R. FAULKNER, R. B. HERBERT and A. M. FLETCHER

As a number of the projects in Forest Genetics are reaching the stage when it is desirable to review them at some length, it has been decided to present a less comprehensive report on each year's work, confining this to the more outstanding features. Reviews on particular projects will appear in Part III of *Research Reports* and in this issue the work carried out since 1948 on Flower Induction is described. (See page 207).

Register of Seed Sources

Work on the full revision of the Register of Seed Sources made a good start during the year. The majority of Category 'A' sources which were selected before 1960 have been revisited, checked and the records brought up to date. Each local forester has been given the necessary advice on selecting seed trees, and on the type of thinning required as a pre-requisite to full scale management. The target is to re-print and distribute the revised *Register* by mid-summer 1966. During the process of revising the *Register* it was considered desirable to add a further category to the list of four which were defined in the *Report on Forest Research* for 1964. This new Category, designated 'D', covers:

(i) Very young plantations derived from a known highly desirable original seed source, with less than fifteen per cent of replacement plants of an unknown or undesirable provenance of the same species.

(ii) Seedling seed orchards composed of plants grown from seed collected from selected provenances or parent trees, and planted with the principal object of seed production.

(iii) Native Scots pine sources.

The first two types of Category 'D' sources are intended to provide potentially valuable sources from which inexpensive seed collections can be made. They will mainly be stands of Lodgepole pine, and of mixed European and Japanese larches (or adjoining plantations of both species) whence Hybrid larch (*Larix* × *eurolepis*) seed is likely to be produced.

Seed Crops

1964 was a poor seed year for all the major species other than Sitka spruce. This species coned prolifically in western districts of south, west and north-west Scotland—one of the few areas in Britain which experienced hot and dry periods in the early summer of 1963. Advantage was taken of the unusually heavy cone crops on some of the candidate plus trees, and collections were made from forty eight of them; the numbers of cones per tree ranged from 7 to 2,050.

The Selection of Plus Trees

The total number of candidate plus trees of Sitka spruce was increased to 131 by continuing the intensive surveys in north Wales, and in south-west and north-west Scotland, which began in 1963. Measurements of the fibre length and wood density in the 21st—25th annual rings of timber samples taken at breast height were again undertaken by the Wood Anatomy Section of the Forest Products Research Laboratory at Princes Risborough. The variation between trees was similar to that reported for 1963. (See *Res. Rep., 1964*, page 54).

The increased use of Lodgepole pine as a pioneer species for planting on exposed and high elevation sites—particularly in the north-western Highlands of Scotland—has raised problems of seed supply during recent years. Attempts to secure part of our requirements of seed from Alaska, the Queen Charlotte Islands and the Skeena river area of British Columbia have been largely unsuccessful. A determined effort was made during the year to select outstanding phenotypes in a number of research pilot plots of the most successful provenances, which were principally (in the north of Scotland) established during the past fifteen years. In all thirty trees of an Alaskan provenance growing at Watten in Caithness and Morefield, Ross-shire, and twenty-six trees of Coastal Washington provenance growing at Strathy and Borgie in Sutherland, were selected. The majority of these were propagated in March, and should be ready for planting in clonal seed orchards during the spring in 1967. The plot of Alaskan Lodgepole pine at Watten is now coning heavily and yields of twelve ounces of seed per bushel of cones have been obtained.

During the year, 140 plus or candidate plus trees of all species were selected.

Seed Orchards

No new clonal seed orchards were started during the year, but sixty-two acres of Lodgepole pine seedling seed orchards were established on a variety of sites in North-east, East, South-east and South-west England. The plants used in establishing the orchards were obtained either from imported seed from Terrace on the Skeena river in British Columbia, or from collections made from selected seed trees in seed stands and other selected areas planted with Terrace, or Smithers and Hazelton (Bulkley river) British Columbian provenances growing in Scotland.

The first thinning of a number of six-year-old hybrid larch seedling seed orchards at Clanna in the Forest of Dean was completed. Many of the trees are now over twenty feet in height and have started to flower.

Vegetative Propagation

Sitka spruce has proved to be a difficult species to propagate, either from cuttings or by grafting. However, more encouraging results have been obtained in a current experiment with cuttings at Grizedale, which compares different dates of insertion and types of cutting material. Results from the August/September insertions show that sixty per cent of the cuttings taken from the twelfth internode from the top of the trees, and treated with 'Seradix' B1 powder (the mildest type of IAA rooting hormone powder) have rooted. The cuttings were rooted in a growth room under a twenty-hour photoperiod, using fluorescent tubes at a temperature of 65°F and at a humidity of approximately eighty per cent. The first batch of cuttings were assessed and potted up at the end of February 1965. (IAA = Indole acetic acid).

Glasshouse Investigations

The construction of the 60 ft. × 20 ft. glasshouse at Alice Holt was completed in January, and control equipment for heating, lighting and mist irrigation was installed in one of the four sections. Trials are being undertaken to determine the degree of control which can be obtained over conditions in the glasshouse, and on techniques of intensive raising of progenies, as a prelude to more detailed work which will begin in 1966. (See Plate 1).

FOREST PATHOLOGY

By D. H. PHILLIPS

Death and Decay caused by Fomes annosus (Fr.) Cooke

Further trials were carried out with sodium nitrite, and the results confirmed the consistently excellent performance of this material as a stump protectant against *Fomes annosus*. Results were good not only under normal conditions, but also when treatment was delayed or badly carried out, and when treated stumps were subsequently damaged during the extraction of produce. Sodium nitrite was therefore generally introduced in place of creosote in the routine treatment of conifer stumps.

In the case of pine, large-scale trials in biological control, using the competing fungus *Peniophora gigantea*, continued to give very promising results. Oidia made up in tablets as described by Rishbeth (1963) gave better results than the fresh cultures previously used, and the tablets are being given further trials in the forest. Preparations of this kind are not yet available commercially, and the practical questions involved in quality control in the laboratory, and in storage and use in the forest, require further attention before the general introduction of *P. gigantea* for all pine areas can be considered.

Work continued on the problem of the replacement of crops already infested by *F. annosus*, especially on sites where pine has been killed by the fungus. Evidence accumulating from our earlier experiments continues to show that where infection is established in a first rotation it becomes more serious in the succeeding crop. The inoculation of stumps with *Peniophora gigantea* (in the case of pine), delayed replanting, and in bad cases the removal of stumps, are all methods that show some promise, and may help to give control when clear felling.

Establishment of Corsican Pine

In the course of studies on *Fomes annosus* on sites on which clear felling had been carried out, it was sometimes found difficult to establish Corsican pine. Preliminary studies showed that low temperatures on the sites concerned might be among the factors involved, and temperature studies were therefore continued in some of these areas. Some confirmation was obtained that these areas were colder than the open ground, and that litter and chopped brash, or a heavy cover of grass, insulated the mineral soil and decreased normal heat exchange. To parallel these observations, plants have been subjected to controlled cold temperatures during the period when they are most subject to damage. These studies, and others on air drainage and ground cover, are being continued, in co-operation with members of the staff of the Agricultural Branch of the Meteorological Office.

Stem Crack in Abies grandis

Studies on stem crack in *Abies grandis* (of particular interest because it is resistant to attack by *Fomes annosus*) were continued, and a survey was carried out in which 102 sites were visited. These sites covered all Forestry Commission plantings of over one acre and over 21 years of age, and the amount of cracking, as revealed by bark scars, was recorded. Of all the trees examined, 7·7 per cent showed scars more than 3 ft. long, and a further 5·5 per cent had shorter scars than this.

A sample of trees, some with scars and some without, was converted in a commercial mill. The sample contained 58 per cent of trees with scars over 3 ft. long, a higher proportion than that found in any one stand examined anywhere during the survey. The overall loss in volume was 2·5 per cent, and that in value was 5·5 per cent. Results so far are more favourable than was expected, and during the course of the survey *A. grandis* was found to be growing very well over a wide range of conditions. A more detailed study of stem crack in this species is therefore being carried out on selected sites, in collaboration with the Forest Products Research Laboratory, Princes Risborough.

Bacterial Canker of Poplar, Caused by Aplanobacterium populi Ridé

The testing of poplar clones for resistance to bacterial canker has been carried out in this country for many years, but in some cases the results have been inconsistent and difficult to interpret. The confusing results of these tests cannot be explained, nor can the screening trials be put on a reliable foundation, until the causal bacterium and its life cycle are more fully understood. Laboratory studies on *Aplanobacterium populi* have therefore been started. A search is being made for substances that accelerate its growth in culture, and poplar tissue is also being studied to see if it contains any of these materials.

Previous inoculation trials to test for resistance to the disease have all been carried out with natural bacterial slime. *A. populi* has now been isolated from poplars here, and experiments are being set up to compare the results of inoculations with pure cultures of the bacterium and with the natural slime. It is hoped that inoculations with the pure cultures can be given at a standard concentration, and may help to give more consistent results than those obtained in the past.

Testing of new clones for susceptibility has continued at Fen Row Nursery (Rendlesham), and a more comprehensive, statistically-based screening trial continues at Blandford, Dorset. Natural slime is being used as inoculum in both these trials, but at Blandford pure cultures are also being used for comparison.

Tests to compare the results of inoculation with samples of natural slime from different parts of the country were also continued. Earlier, small-scale experiments of this kind suggested that there might be strains of the bacterium varying in pathogenicity (Jobling and Young, 1965). In the present tests no marked differences in virulence were apparent. It is too soon after inoculation to draw definite conclusions, however, and observations on the test plants will be continued. A similar trial is now being set up, using pure cultures from various parts of the country. Other experiments have been set up to examine the variations between different sites in the incidence of bacterial canker.

Observations and experiments are continuing on the relation of the Agromyzid cambial miner to bacterial canker, and on the importance of leaf scars as sites for infection.

Blue Stain of Pine

A field trial to find a chemical control for blue stain in pine was carried out in Thetford Forest. This work was done jointly with the Forest Products

Research Laboratory and with the assistance of the local staff of East England Conservancy. Although the experiment was set up at the time when it was expected that staining was most likely to occur, no blue stain appeared in either treated or control logs, and no information was gained on the comparative value of the chemicals used. This and earlier experiments emphasized the fact that more fundamental information on the biology of the various blue stain fungi is needed before field experiments (and any control measures arising from them) can be satisfactorily timed. Studies to gain some of this information will soon begin elsewhere.

Needle Blight (Didymascella thujina (Dur.) Maire, syn. Keithia thujina Dur.) of Western Red Cedar (Thuja plicata)

In recent years, excellent control of needle blight of Western red cedar has often been obtained by spraying with Actispray (a proprietary formulation of cycloheximide) at a concentration of 85 p.p.m. (Pawsey, 1962, and 1965).

Less effective control was achieved at lower concentrations, and at higher ones the plants were damaged. So far the spray has been applied at the high rate of 250 gallons per acre, and it is now being tested at lower rates.

Results have often been excellent when the crop has been sprayed only once each year, in late March, but one spray applied at this time has not always given satisfactory control. Information on the precise times of spore discharge of the fungus and of infection of *Thuja* plants is now needed to provide the basis of a forecasting scheme, so that advice can be given on the timing of protective spray applications, and a preliminary study of this matter has now begun.

General

Advisory work continued to increase, and 324 enquiries were received, 118 from Commission forests and 206 from elsewhere. About 50 visits to forests and nurseries were made as a result of these queries.

In the winter of 1963–4, mild spells tended to alternate with cold conditions, often associated with easterly winds. These fluctuations in temperature continued through March, and caused considerable damage to conifer foliage in nurseries and plantations. Much of this damage became obvious in April and early May, particularly on Scots pine, the tree most markedly affected, but also on Western red cedar, Lodgepole and Corsican pines, *Pinus radiata*, Douglas fir, and Lawson and Leyland cypresses.

The weather became warm at the end of April, and with continuing high temperatures in May, conditions in the early growing season favoured rapid, lush growth. Just following this period, from the end of May to the middle of July, an unusually large number of enquiries were received on diseases of willows. A few of these queries involved cases of willow scab (*Fusicladium saliciperdum* (Bres.) Magn., the imperfect state of *Venturia chlorospora* (Ces.) Karst.) but most concerned the willow leaf spot and branch canker disease (Anthracnose) caused by *Marssonina salicicola* (Bres.) Magn., which in every case was on Weeping willow (*Salix babylonica*). Outbreaks of this disease were scattered over the coutry south of a line from Chepstow in the west to Canterbury in the south-east.

The warm conditions in May were briefly interrupted by a cold spell in the middle of the month, when night temperatures were low, with frosts in some areas. Later, there were exceptionally cold spells in June, and frost damage occurred in some plantations and nurseries on spruces, larches, Douglas fir, Silver fir and hemlock, and was sometimes followed by Grey mould (*Botrytis cinerea* Fr.). Various forms of shoot damage to conifers, mainly Sitka spruce, occurred in situations unlikely to have been affected by frost, and in these instances it was suspected that the plants had been affected by sudden cooling, short of freezing, after unusually warm conditions. The symptoms included withering and yellowing of shaded shoots, and bending and fracture of upper ones, which appeared to have been rendered flaccid and liable to damage by gravity, wind and perching birds.

In July, a severe hailstorm caused much damage to Lodgepole pine and other species in Haslingden Forest in Lancashire.

Trees affected by the cold winter of 1962–3 continued to decline and die. Deaths were noted of cedar (*Cedrus* species), poplar, sycamore, beech and birch originally damaged at this time.

December 1963 and the first two months of 1964 were very dry, and in England and Wales it was the driest winter for more than 200 years. A good many examples of root failure of newly planted or transplanted conifers were seen later throughout the season, and in some cases the root damage may well have originated at this time, when the risk of drying of the roots during handling was unusually high. Further damage by drought occurred in the latter half of the year, which was also very dry in the east and south-east of the country.

Wet weather in March 1964 led to death of nursery plants through water-logging. Thundery rains in June caused similar damage in some nurseries in the south-east, especially to Sweet chestnut seedlings.

The 1964 growing season produced a number of disorders that were considered to be climatic in origin, but for which no precise explanation could be found. Notable among these was a widespread browning of Horse chestnut leaves.

In August *Peridermium pini* (Pers.) Lév. was recorded on Scots pine in Ardross Forest, Ross. This station is further north than any other in which this fungus has been found so far.

Also in Scotland, in late April and early May, *Crumenula sororia* Karst. was recorded on cankered pole-stage trees of Lodgepole pine (*Pinus contorta*) at Mabie Forest, Dumfries, Kirroughtree Forest, Kirkcudbright, Achnashellach Forest, Ross, and Tentsmuir Forest, Fife.

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FOREST ENTOMOLOGY

By D. BEVAN

Pine Looper Moth, Bupalus piniarius

The general level of Pine looper populations as revealed by winter counts of pupae, is low in all parts of the country. The highest compartment-mean pupal count was found at Sherwood Forest, Block V., 11.6 pupae per square yard.

Douglas Fir Seed Wasp, Megastigmus spermotrophus

The 1964 Douglas fir cone crop was very light, and this made control experiments impossible. Seed sampling from cones removed from the tree continue to show large variability in infestation rates between cone and cone, from one and the same tree, and also between collections of cones from different trees. Seed trapping is being investigated as a means of finding a more statistically reliable method of estimating seed yield and infestation rate. For practical purposes, seed sampling through cone collections continues to be a useful technique, and a comparison has, therefore, been carried out between estimates based on extracted seed and those on the quicker cone-knife test. Results will be published shortly. Investigations were also conducted into the period over which oviposition takes place in the field and the results may be found in Part III of this Report, page 185.

Control of Adelges species on Conifers

Trials of insecticides were continued against *Adelges* species on grafted stock. Successful control of *Adelges pini* on Scots pine was obtained, for the whole season, by a single application just before bud burst in May, of either of the two winter washes, D.N.C. in petroleum oil, and Thiol. These chemicals killed eggs, nymphs and adults. Four successive applications of Malathion were required to obtain results comparable to those of the two winter washes.

Biology of Adelges species in Conifers

A suction trap was used for the first time this year to sample *Adelgid* and other aphid populations, in the environs of Alice Holt, where a great variety of conifer and hardwood hosts are grown. The investigation aims, in the first place, to assess and check on occurrence and biology of the species present and, in particular, to sort out the complex on larch and spruce.

Sitka Spruce Aphis, Neomyzaphis abietina

Trials of systemic insecticides, and methods of applying them, are being carried out mainly as a research tool, in an attempt to assess increment loss resulting from *Neomyzaphis* defoliation. Materials have so far been applied as liquids in 'trunk-bands' and, in granular form, to the roots. The treatments will be extended to include trunk-painting with undiluted chemicals in polyvinyl alcohol during the next season.

In connection with the above, the development of methods of ring analysis, by radiographing thin discs, is also being investigated.

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Enquiries and Displays

There were 115 enquiries from Forestry Commission and 77 from private sources during the year.

The Entomology Section held open days for the XII International Congress of Entomology on July 14th, 1964 and for the F.A.O./I.U.F.R.O. Symposium on 'Internationally Dangerous Forest Diseases and Insects', on July 20th and 21st, 1964.

MAMMALS AND BIRDS

By JUDITH J. ROWE

Grey Squirrels

Investigations of methods of grey squirrel control are carried out jointly with the Infestation Control Laboratory (Land Pests Branch) of the Ministry of Agriculture, Fisheries and Food.

Poisoning trials with 'Warfarin-treated' wheat were continued in Scotland. Two types of hoppers of simple construction were used to provide the source of poisoned bait. These consisted of a ground hopper with a tunnel entrance, and of a can of bait tied to a leaning pole attached to a tree. Bait was taken and a satisfactory kill of squirrels achieved with both types. No evidence of other mammals or birds being poisoned was obtained, though mice and voles in the immediate vicinity of the ground hoppers were probably affected.

The bait for this and previous trials has been treated with 'Warfarin' in the laboratory to ensure that the necessary poison concentration is achieved. Trials will be made next year with a commercially available poisoned wheat. Although this is more expensive than treating the wheat with 'Warfarin' by hand, it is thought that, if successful, the manufacturers' product is more practical for non-research use.

Protection of a vulnerable crop by cage-trapping in and around it. just prior to the damage period (May to July), has now apparently been achieved for four successive years on a non-isolated woodland. The last trial consisted of three operations. A capture/mark/release trapping was carried out in March, eight weeks before the capture/kill protection trapping at the beginning of May. Approximately half of the squirrels caught in March had been marked the previous July. During the capture/kill protection trapping, eight weeks later, more unmarked squirrels were caught than in the equivalent operation last year. This was associated with more shooting by the local keeper between the two trap rounds this year. The results obtained in these two years suggest that there is little change in the population between March and May, if it is left undisturbed, but that squirrels come in rapidly as a proportion of the population is removed. The numbers of animals caught in each trap round has been very similar each year. The third trap round was carried out in July, and it was found that recolonisation had occurred; none of the animals had previously been marked. No damage was observed.

Voles and Mice

'Warfarin' on cut wheat was laid down at a density of approximately 25 bait points per acre, to test the effects on a mixed population of field-voles, *Microtus agrestis*, bank-voles, *Clethrionomys glareolus* and wood-mice, *Apodemus sylvaticus*. Eight ounces of poison bait were laid at each bait point for one month in mid-winter, December to January. Trapping was carried out within the plots for four days prior to the poison being laid, and also for the same period immediately after the remaining poison had been picked up. Too few *Clethrionomys* were taken during the trap rounds for any conclusions to be drawn, but populations of both *Apodemus* and *Microtus* were adversely affected by the poison.

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Deer

Various methods of determining the ages of individuals are being investigated: these include eye lens' weights, tooth wear and the production of dental cement layers in different age classes. A telemetric study of diurnal movements and seasonal behaviour in roe deer has also been initiated. Some aspects of red deer management are being investigated in co-operation with South Scotland Conservancy. These include the use of salt and mineral licks, and the improvement of winter feed as possible methods of reducing damage to trees in the Galloway area, where red deer are not fenced out of plantations.

Nursery: Protection of Seed from Birds

Seed dressing trials have been continued using a thiram formulation, Fernasan S, applied with a latex sticker to pine seed at a rate of approximately 15 per cent w/w. The results suggest that predation by birds is reduced by the seed dressing, but complete protection is not achieved. The most satisfactory form of protection at present is 42 inch × ½ inch-mesh wire netting.

Chemical Repellants in the Forest

Further trials of various chemical repellants have confirmed that their effectiveness in preventing damage by deer is short-lived and is partially dependent on the susceptibility to browsing of the tree species concerned, and on the availability of alternative food. Experiments of a few repellants against blackgame (*Tetrao tetrix*) and capercailzie (*Tetrao urogallus*) are being continued. Trials of a systemic repellant against deer, rabbits and hares are being made in Thetford Chase (Norfolk).

Electric Fencing

Trials of electric fencing suggest that this can only be effective where inspection can be made frequently to ensure that the fence has not been short-circuited by vegetation. Herbicidal spraying under the lowest strand is being used in an attempt to overcome this difficulty.

Other Fencing

A Swyf-tyte fence has been erected in Thetford Chase (see Plate 11) As the fence incorporates metal main-post and corner-post assemblies, with ground anchors, comparatively few wooden stakes are required. Metal droppers are used to stay four high-tensile steel strands on which, in this experiment, ordinary rabbit netting has been hung. An extension of the corner posts has been developed; this carries one strand of the high-tensile wire, and from this a three-foot width of black polythene netting is suspended to convert the rabbit fence into a deer fence. Erection was easy and rapid and in the four months since its erection no disadvantages have been noticed. The fence will remain in place for some years and will then be taken down and re-erected on another site to test how well the components stand up to repeated use as temporary fencing for young plantations during establishment.

Questionnaires

The annual questionnaire on red and grey squirrels for the year ending September 1964 showed that both species had decreased in numbers since the previous year, and that less damage had occurred. No major changes in distribution of either species within Forestry Commission plantations is apparent.

The annual questionnaire on deer is being replaced by an individual deer recording system during 1965.

PLANNING AND ECONOMICS BRANCH

By D. R. JOHNSTON

The Planning and Economics Branch comprises four sections, Working Plans, Economics, Mensuration and Census, and although not part of Research the work of these sections has a research or development content, and involves collaboration with various sections of the Research Branch. For this reason the Planning and Economics Branch contributes a brief report to the *Annual Report on Forest Research.*

D. R. JOHNSTON

Working Plans

During the year, field surveys were completed at forests having a gross area of 380,000 acres; at the end of the year work was in progress in nineteen forests having a total gross area of 180,000 acres.

Methods of collecting and presenting data on the growth of stands were modified to facilitate the use of the new Production Forecast Tables and Thinning Control Tables. All the existing forest summaries of stands, by age and quality class, were converted to the yield class classification; the planting-year classes were amended where necessary to coincide with the revised system of production forecasting.

The first of a series of conservancy field demonstrations in thinning control was held in Thetford Chase, East Anglia in the autumn of 1964.

Four-week courses in topographic survey and forest inventory were given to new members of the Working Plan Survey teams. Soil surveys, at a scale of 1:10,560, were completed for Newcastleton and Whitrope forests in Roxburghshire, for Carron Valley and Lennox forests in Stirlingshire and for Savernake Forest in Wiltshire. Reconnaissance surveys for the production of 'windthrow probability' maps were made in Kershope and Kielder forests on the Scottish Border.

A Working Plans Code was revised and issued to Commission staff during the year.

D. M. ROBERTSON

Mensuration

Three replicated thinning experiments were established during the course of the year. Two of these are in Sitka spruce, one at the Forest of Ae in South Scotland, and the other at Dovey Forest in mid-Wales. The third experiment is in Corsican pine in Sherwood Forest, Nottinghamshire, and is a straightforward comparison of four thinning intensities plus an unthinned control, replicated four times. At Dovey, the effect of three different thinning cycles is being investigated, together with the effect of three different intensities of thinning on the same cycle, plus an unthinned control, replicated three times. The Ae experiment is based on a factorial combination of three intensities of thinning with three types of thinning, namely extreme low, intermediate and extreme crown, plus an unthinned control, replicated twice. A small individual-tree thinning experiment has been sited in the same stand as the main experiment.

The first of two replicated transplant experiments has been terminated, the material measured and weighed, and the analysis begun. This was a thinning experiment in Japanese larch at Wareham Forest in Dorset. The remaining (spacing) experiment in European larch at Alice Holt Forest, Hants., will be terminated at the end of this growing season.

A non-replicated underplanting experiment was established at Micheldever Forest, Hampshire alongside an existing thinning series in pedunculate oak. In one plot the cover was completely removed from the understorey of Western hemlock planted four years previously; in the other three plots the oak overstorey was reduced to 40, 80 and 160 trees per acre. The adjacent thinning series will provide the control for the oak overstorey, one plot in this series having been reduced to 160 trees per acre.

The Management Tables comprising yield tables, thinning control tables, forecasting tables and various ancillary tables and graphs were completed for 20 coniferous and hardwood species. A publication describing the methods used in constructing the tables is in the press (Forestry Commission Booklet 16, entitled *Forest Management Tables.*) Work has been started on the construction of tabular aids for timber measurement and on the preparation of a standard measurement procedure.

R. T. BRADLEY

Census of Woodlands

A National Census of privately owned woodlands will be started in June 1965 and is expected to be finished by mid-1966.

The field work will be on a sampling basis, and the problem is to design a sampling scheme which will provide us with a sufficiently accurate estimate of woodland area, and its breakdown by forest type, species, age, etc., at minimum cost. The difficulties are essentially threefold.

First, private woodlands cover a relatively small proportion, about 5 per cent, of the land surface of the country and a fairly high intensity of sampling is therefore required to ensure that an adequate acreage of woodland is included in the sample; secondly, most marketing inquiries relate only to specific parts of the country, so that the sampling must be done in such a way that data can be produced for any combination of counties; thirdly, woodland is very unevenly distributed over the land surface of Britain, so that if a regional basis is adopted we are faced with the choice either of adopting a fixed sampling fraction, which will result in the *same proportion* of the woodland being sampled within each region, or a variable fraction, which will result in approximately the *same acreage* being sampled in each region. The latter system is statistically more efficient, but leads to computational difficulties when data from regions with differing sampling fractions are combined. Marketing regions are seldom permanent and the method of sampling must be flexible enough to permit re-adjustment of the regional boundaries when the need arises.

The scheme which will be adopted is based on a two-stage sampling system. The first-stage sample is a fixed percentage, namely 15 per cent, of the land surface of the country. This fairly high level has been adopted to ensure, when the country is subdivided into regions, that even the most lightly-wooded of them will be adequately sampled. The sampling units will be kilometre grid squares, and these will be selected at random so that they cover all types of land such as towns, agricultural crops, inland water, woodland. Many of these squares will thus contain no woodland at all, and in order to avoid unnecessary travelling local Forestry Commission staff will be asked to state which sampling units contain private woodlands, and which do not. All sampling units which contain woodland will then be visited by census field surveyors, who will record the areas occupied by each crop type. Concurrently with this assessment they will carry out the second stage of sampling, with the object of obtaining estimates of standing volume and yield class. This will consist of the measurement of small plots, varying in size from one-fortieth to one-fifth of an acre, randomly distributed throughout the woodland on each kilometre square.

The data collected will be recorded on special forms which will be scanned by an optical document reader known as Lector, and the data transferred automatically to punched tape. This will avoid the necessity for the data being transferred to tape by manual punching and verification, an expensive procedure when large quantities of data are involved.

G. M. L. LOCKE

Economics

The advisory content of work in this Section continues, as noted in the *Research Report* for 1963, to occupy more time than the research element. Nevertheless some useful developments of a research nature have been made in techniques of analysis, and these will enable the Section to contribute more successfully to planning.These developments centre on automatic data processing. The main applications have been in automating the process of forecasting future production, and in practising the use of linear programming in solving forest management problems.

Little further work has been done on generalised aids to planning such as those provided by ready reckoners for selection of acquisitions, species choice, and crop replacement timing. As new and more complex situations arise, or new problems are recognised, there is a growing need to plan comprehensively rather than piecemeal. Ready reckoners to which field officers may apply their own assumptions as to average yields, costs, etc., are limited in their application and usefulness. With improved data collection, and with a vastly increased capacity to handle original data rather than average values, the competence of planning can be greatly increased. At the same time, the disciplines and even the physical tools used, namely data processing machinery and computers, require such all-embracing planning functions to be undertaken centrally rather than at local (District) level or Conservancy. This may raise certain problems of communication but such difficulties have not shown themselves to be serious in the applications which have been made so far. The most important examples of these concern the cutting (i.e. thinning and felling) programmes for individual forests or groups of forests. Following the rather limited application to the New Forest in 1964 (see P. A. Wardle, *Report on Forest Research for 1964*, pp. 200) a much bigger linear programming analysis has been undertaken for the supply area of the new pulp and paper mill at Fort William in Inverness-shire.

A. J. GRAYSON

WORK STUDY

By L. C. TROUP

Re-organisation of Section

In 1963 it was decided that the Section should expand with the aim of achieving an eight-team set-up by 1966. The first phase of this expansion is now nearing completion and there are five teams in the field. A mechanical engineer has joined the Section, thus enabling fuller coverage to be given to field trials which we may be asked to supervise and, more generally, to make a contribution towards the mechanisation, or improved mechanisation, of a wide range of operations—particularly those concerned with timber production. An officer is now stationed at Alice Holt to supervise the activities of the East England Conservancy and New Forest teams, to maintain liaison with Research and to represent the Section on various joint study groups which are likely to be formed. A new team has been created and is based at Brecon in South Wales.

This first expansion of the Section has involved the recruitment and training of five District Officers. Mr. J. W.L. Zehetmayr on his promotion to Conservator of Forests for West Scotland, has handed over his duties as Chief Work Study Officer to the present section head. One Team Leader has been transferred out of the Section, and another is to leave shortly. A brief period of consolidation is necessary before the next phase of the expansion takes place.

In 1965 it is proposed to set up an experimental team which, based on Kielder Forest in Northumberland, will have the main tasks of undertaking field trials of machinery and conducting investigations into logging systems. The team, which will include a mechanical engineer, will initially conduct a series of investigations into clear felling systems, with special reference to modes of extraction.

Locations for the new teams remain for decision after consultation. It is clear that a very large part of the Section's work will be concerned with mechanisation, and fuller co-ordination of effort in this field is very desirable.

When the proposed expansion is completed, it will be possible to give Conservancies reasonable coverage from the regionally-based teams. At the same time, central co-ordination will ensure that efforts are not needlessly duplicated and that direction is given to activities which are of national rather than purely regional interest.

Assignments in Forest Year 1964

Great Glen Team

Work has been concentrated on studying the preparation of pulpwood for Scottish Pulp Ltd, who are operating the new pulp and paper mill at Fort William in Inverness-shire. The results have been put to statistical analysis and provisional standard time-tables will be available for the start of major operations in 1965. The data will be refined and extended by further studies during 1965. The Work Study Section's skidding arch has been further developed and numbers are now operating in Conservancies in the three countries.

Borders Team

The main project is a study of supplies of pulpwood to Thames Board Ltd. at Workington in Cumberland. The first studies revealed the price differentials between 7½ ft. lengths and 10 ft. lengths: there were two possible specifications for the mill, but the former has now been accepted and work is restricted to this specification (7½ ft. with tolerance down to 6 ft; top diameter 2½ inches). The Kershope winch was studied as a preliminary to later more detailed studies in connection with the extraction of Thames Board Mill material.

East England Team

The Thetford assignment has been wound up and the team is reconstituted at Yardley Chase in East England. From this centre it has begun to make an intensive study of weeding and cleaning. Final work at Thetford concentrated on production studies; data for power saw felling was produced, and a Cambio peeler was introduced into Brandon Depot. Mechanical adjustments to the peeler have been almost completed, and the operators are improving their performance. There is every reason to suppose that the throughput will rise to the anticipated 350–470 Hoppus feet per hour. When this stage is reached the Cambio, with its two-man crew, will be doing the work of twenty-five or more hand peelers, at about half the cost. The quality of peeling is excellent.

Studies on loading with 'Hiab' cranes and grapples have also been concluded. A paper was issued giving an account of the types (not makes) of crane available, and indicated the annual volumes necessary to justify crane loading.

New Forest Team

Standard times have been produced for the wide range of coniferous end-products prepared at the New Forest. The study revealed that prices tended to be tight in some of the smaller categories of produce, particularly chip-board material, but loose in the larger categories.

A study into clear felling of oak has led to the recommendation that cordwood should no longer be stacked. This should result in an increased timber output of 20–30 per cent.

Work has also begun on snedding by power saw, using a 'Homelite XL-12' with 16-inch guide bar, as representing the light saws now coming on to the market. An experimental approach has been adopted, the team itself doing all the necessary self-training and operational work. It can be said that, in the case of the Corsican pine studied:—

(a) a direct relationship was established between breast-height quarter girth and total branch diameter;

(b) in terms of time, the chainsaw did not become competitive with the axe until it was cutting branches whose average diameter was in excess of 0·5 inch;

(c) in terms of cost, the break-even point between axe-work and saw-work was found where branch diameters reached an average of 0·75 to 1·0 inches, this diameter being associated with breast-height quarter girths of 10¾ inches.

Further studies will seek to confirm these relationships and extend the enquiry to other species.

Mid-Wales Team

The major project is a study of supplies of pulpwood to Messrs. Bowaters paper mill at Ellesmere Port in Cheshire, from South Wales. Work Study brashing techniques have also been introduced into the Conservancy and a service has been provided to North Wales—a Conservancy which is using a wide range of Work Study data. During the course of the pulpwood studies, the Crychan double-drum winch will be investigated.

The Experimental Team

Reference has already been made to this proposed team. When formed it is intended to investigate the following:—

(a) Clear-felling techniques with special reference to modes of extraction.

(b) The effects of different methods of extraction upon roading densities.

(c) Half-tracked tractors: a comparison with three-quarters and full tracked machines.

Machinery

Fleet of Transport to Supply Pulpwood to Scottish Pulp Ltd.

On the assumption that the Forestry Commission might transport a proportion of the material, a detailed investigation into the following possibilities was carried out:—

Articulated fleet
Six-wheelers with independent loader
Six-wheelers, self-loading
Four-wheelers with independent loader

It was concluded that the articulated fleet was theoretically cheapest, followed very closely by self-loading six-wheelers. The greater flexibility of the latter system was a persuasive factor which led to its recommendation. However, the new Construction and Use Regulations which permit heavier loads than heretofore, are particularly favourable in respect of articulated vehicles; should the occasion arise we shall do some re-evaluations.

The Independent Loader

This is a County Tractor equipped with a 2-ton 'Hiab' crane and grapple. At present it is operating in the North Scotland Conservancy and its main function will be extraction of material using a self-towed trailer of 8–10 ton capacity, designed by the Work Study Engineer, Mr. R. B. Ross. This technique is promising on fairly flat terrain, and the equipment described will be compared with the Swedish 'Robur'.

Light Tracked Tractors

Almost three years' experience with three-quarter and full tracks, mounted on Ferguson tractors at Kielder and Redesdale Forests, have now been summarised. One may conclude that mechanical defects (particularly brake failures) militate against the use of these tracks for *direct haulage*, but that they may find a place as carriers for Isachsen winches. Frequently it is necessary for the Isachsen to be drawn off the hard road, and light tracks make this possible under soft ground conditions. Furthermore travelling time is reduced, since the machine can traverse rides impossible to a wheeled Ferguson. It now remains to study half-tracked tractors.

Power Saws

The Section has co-operated in a user trial of seven new saws. The trials, which were held at Thetford and in West Scotland, included examples of the new light saws.

'Piece-work' Booklet and Standard Time Tables

Standard Time Booklet

This booklet, which had a restricted circulation, has now been revised and is intended for issue to Forestry Commission staff generally. It provides managers and supervisors with a convenient account of work study matters, including the translation of standard times into incentive schemes and control methods. Part II of the booklet will consist of tables of standard times, as applicable to the particular forest or region.

Dissemination of Information

The following booklets were published during the year:—Forestry Commission Booklet 11. *Extraction of Conifer Thinnings.* H.M.S.O. 5s. 0d. Forestry Commission Booklet 12. *Double Drum Winch Technique.* H.M.S.O. 3s. 0d.

Booklets in preparation deal with (a) brashing and (b) extraction systems used at Thetford. These booklets reach a wide public and seem to be well appreciated.

The Blackbushe Forestry Exhibition, June 1964

The Section made a major contribution to the outdoor display, exhibiting a variety of extraction equipment.

The Costing of Production Operations

The Section has co-operated in the revision of the internal instruction S.M. 115 in order to provide a surer weapon for the determination of the most profitable course of action. *Inter alia* the draft provides a mechanism for estimating the likely operational surpluses to be derived from differing product mixes and/or methods. The *Timber Grower* has been provided with an article explaining the method to private woodland owners and agents.

UTILISATION DEVELOPMENT

By B. W. HOLTAM

Properties of Home-Grown Timber

The joint programme of research with the Forest Products Research Laboratory of the Ministry of Technology at Princes Risborough, Buckinghamshire, on the properties of home-grown timbers, continued. In the general programme of work, an examination of the properties of Norway spruce and Lodgepole pine was completed. Three other projects that may be of special interest are described below.

The Effect of Pruning on the Yield of Sawn Timber

A comparison of the yield of sawn timber from pruned and unpruned logs of Norway spruce and Douglas fir and European larch, which began at the Laboratory in the previous year, was completed. The logs were converted on a rack bench and the sawn lumber produced was graded in accordance with Forest Products Research Leaflet No. 49, *Grading Rules for Sawn British Softwood.* The yields expressed as a percentage of the total volume of sawn timber are given below:—

Species and Source	*Grade*	*Pruned Logs*	*Unpruned Logs*
Norway spruce (Dean)	I	23	1
	II	31	11
	III	31	79
	IV	15	9
European larch (Dean)	I	3	1
	II	31	15
	III	58	80
	IV	15	4
Douglas fir (Dean)	I	13	1
	II	34	12
	III	40	68
	IV	13	19
Douglas fir (Inverliever)	I	2	0.3
	II	67	43
	III	25	51
	IV	6	5

The results show that the pruning had the effect of increasing the proportion of Grade II timber; the yield of Grade I timber was also increased, but to a lesser extent. Although the proportion of clear wood from the pruned logs never exceeded five per cent, no clear wood was produced by the unpruned logs. A detailed account of certain aspects of this work has since been published as Forest Products Research Special Report No. 22. *The Effect of Pruning on the Value of Home-Grown Softwoods.* H.M.S.O. 1965. 3*s.* 0*d.*

Home-Grown Timber for Plywood Manufacture

Logs of Scots pine, oak and Douglas fir, which were delivered to the Forest Products Research Laboratory in the previous year, were peeled into five ft. by one tenth of an inch veneer. The veneers were then dried and bonded with a phenol-formaldehyde resin to make three ply and five ply, five-ft. square, panels. The Douglas fir proved to be the more difficult to process, largely on account of the development of splits in drying. Except in the vicinity of large knots, the oak peeled well, and the incidence of defects was not great; the plywood was of pleasing appearance, but was rather heavier than either of the softwood plywoods. Some problems associated with the glueing of the oak plywood remained to be solved.

Predrier Development Project

The simple low-cost kiln built at the Forest Products Research Laboratory, which has been designed to reduce the moisture content of green timber to 20 per cent–25 per cent of its dry weight, went into operation during the year. Trial runs have so far been made with two in. thick Scots pine, two in. thick Sitka spruce, two in. thick Norway spruce and 1¼ in. thick beech. It was found that softwoods could be dried satisfactorily in between nine and 16 days. Under the most favourable conditions for air drying, about eight weeks are required for softwood of similar thickness to dry to the same moisture content achieved during these trial runs.

Fence Post Trials

The annual assessment of the service given by round fence posts of different species of timber, some of which have been treated with wood preservatives, was made for the seventh successive year in Scotland, and the sixth successive year in England and Wales.

In Scotland only 20 per cent of the untreated birch posts, and 56 per cent of the untreated Sitka spruce posts, have remained sound, and most of the surviving untreated posts are in peat soils in areas with a high rainfall. None of the creosoted posts have failed so far.

In England and Wales, where a greater number of species have been included, there have been no failures so far in the European larch, Japanese larch and sweet chestnut posts, nor in any of the creosoted posts.

Of the untreated posts of other species, 27 per cent of the Scots pine, 23 per cent of the ash, 31 per cent of the elm, 20 per cent of the birch and 31 per cent of the sycamore remain. However, nearly all of the surviving birch were at a site with deep peat.

The experiments have now been extended to include Douglas fir and an additional water-borne preservative which is based on copper-chrome arsenate. At each of the three experimental husbandry farms (Terrington, High Mowthorpe and Rosemaund) of the National Agricultural Advisory Service, sixteen posts of each of the following types of treatment have been driven: Douglas fir treated with copper-chrome arsenate by the two-tank hot and cold process, Douglas fir treated with creosote, Douglas fir untreated (controls), Scots pine treated with the two-tank hot and cold process, and Scots pine untreated (controls). In the two-tank hot and cold method of treatment, seasoned posts were immersed in hot water (at about 90°C) for 1 to 2 hours, and were then transferred to a tank of cold preservative. The contracting air within the wood cells draws in the preservative solution. This method is particularly suitable for the copper-chrome arsenate types of preservative which are not heat-stable.

Telegraph Pole Trials with Japanese and Hybrid Larch

Following the findings of the Forest Products Research Laboratory, that the differences in timber properties between European and Japanese larches were not sufficient to merit difference in use, arrangements were made with the Post Office to have trials using Japanese and hybrid larch telegraph poles, to see whether these two species could be added to their specification which currently permits only the use of *European* larch. The poles have been selected from Brechfa Forest (Japanese larch), Forest of Dean (hybrid larch) and Tintern Forest (European larch controls). The poles are to be air-dried and creosoted under pressure and may go into service late in 1965.

DESIGN AND ANALYSIS OF EXPERIMENTS

By J. N. R. JEFFERS

The Statistics Section has continued to provide advice on the design and analysis of experiments and surveys to all Sections of the Research Branch, and to the Forestry Commission generally, and also to undertake the analysis and interpretation of numerical data. A limited programme of research into the application of statistical methods and computing techniques, to forestry problems, has also been undertaken.

In the year under review, there have been no major changes in the numbers of staff of the Section or in its equipment. The International Computers and Tabulators Sirius computer has continued to give excellent service, and the greater part of all the analytical work of the Section has been done on this machine. Courses on computer programming have been provided for members of the Research Branch. Students from the Ministry of Aviation and from other organisations have spent periods of up to six months with the Section, learning the practical application of statistical methods to a wide variety of problems. Many of these students were engaged on sandwich courses leading to the Diploma of Technology.

The Statistician attended the Summer school on Non-linear Programming of the Advanced Study Institute of the North Atlantic Treaty Organisation at Menton, France in June 1964. The subject matter of this Summer School has since proved to be of particular importance in the application of operational research techniques to forest problems.

The Statistician also visited Sweden during October 1964, in company with one of the senior executives of the Forestry Commission, for the purpose of studying the methods of automatic data-processing used by the Swedish Forestry Board.

Design of Experiments and Surveys

Advice on the design of experiments and surveys has remained an important commitment of the Section, and designs have been provided for nearly one hundred investigations throughout the year. The types of designs used have been very similar to those in previous years, but with a slight increase in the use of non-orthogonal designs, made possible by the increased facilities of analysis provided by the electronic computer.

Particular attention has been paid, in the year under review, to the problems of work study, and to the analysis of data arising from work study investigations. The major part of the time of the Assistant Statistician, stationed in Edinburgh has, in fact, been devoted to this activity. As a result, there is now considerably more co-operation between the members of the Work Study teams and those of the Statistics Section in the design and interpretation of investigations. This closer co-operation is already leading to a more flexible and more efficient system of collecting information for work study purposes.

Analysis of Experiments and Surveys

The analysis and interpretation of numerical data has been limited only by the time of the qualified staff to think about problems, and, in the past year, more than 16,500 separate analyses were completed. About one-third of these analyses were concerned with the routine analysis of the intermediate results of long-term experiments. A further third of the analyses were studies of relationships of various kinds, including regression and multivariate studies, and the remaining third of the analyses were concerned with the construction of mathematical models of various parts of the research or organisational problems of the Forestry Commission.

Particular interest has been centred in the use of measured variables in the study of taxonomic variation of both plants and animals, and the work of the Section in this field has attracted the attention of research workers from fields outside forestry, with the result that members of the Section have frequently been asked to assist with problems that are, strictly speaking, outside the scope of the activities of the Forestry Commission. As much help as possible has nevertheless been given with these problems, partly because they provide an opportunity to test the techniques on the widest possible range of organisms, and partly because the opportunity to discuss basic taxonomic problems with other research workers has proved to be invaluable.

Computer Programming and Serviceability

A considerable amount of programming has continued to be done for the Sirius computer, and the range of programmes available is now very great. The Section has also continued its co-operation with the East Malling Horticultural Research Station in Kent, in the writing of programmes of joint interest, and in providing time for the development of programmes on the computer, as well as a limited amount of production time. An index of these computer programmes has been prepared, and is available to any interested organisation on request.

The computer itself has continued to be both reliable and productive. Table 15 gives the details of the use of the machine for each month in the year under review. These details show the increased use made of the computer from November onwards, and the relatively small amount of time lost to repairs and other causes. Table 16 summarises these details, using the criteria laid down by the Treasury for computer records, and it is clear from this summary that the three criteria of 'serviceability', 'availability' and 'utilisation' have all remained at a consistently high level.

Considerable effort has been given to the investigation of the problems of data capture, and their subsequent processing by the computer. A number of methods and devices have been tested, including the English Electric Lector document reader, various portable tape recorders, the 'Metercorder', the International Business Machines 'Porta-punch', and the Addressograph card punch. Results of these tests, which have included replicated experimental designs, so far suggest that the English Electric Lector document reader and the 'Metercorder' have distinct advantages, but that there are situations in which a suitably portable tape-recorder can be particularly useful.

International Union of Forest Research Organisations

The Statistics Section has continued to take an active part in the work of this Organisation, and particularly in the Advisory Group of Forest Statisticians of Section 25.

Table 15

DETAILS OF COMPUTER OPERATIONS

Month	No. of Faults	Total time in minutes						
		Production time	Development time	Idle	Repairs	Scheduled maintenance	Supplementary maintenance	External causes
April 1964	3	7,135	2,188	324	255	1,061	0	0
May 1964	5	9,322	1,686	333	255	1,563	205	0
June 1964	1	7,574	900	154	35	1,125	150	0
July 1964	5	7,349	1,914	339	1,090	1,206	230	0
Aug. 1964	3	9,953	1,600	94	160	1,237	0	0
Sept. 1964	4	8,270	2,992	224	173	952	0	92
Oct. 1964	0	8,139	1,523	339	0	923	0	0
Nov. 1964	3	13,674	3,446	72	90	1,308	135	100
Dec. 1964	4	7,763	940	24	275	796	250	160
Jan. 1965	3	14,928	1,731	189	560	2,233	75	0
Feb. 1965	1	12,539	861	71	40	884	30	50
Mar. 1965	1	14,585	1,164	96	360	1,025	60	0
Total	33	121,231	20,945	2,259	3,293	14,313	1,135	402

Table 16

SERVICEABILITY OF COMPUTER

Month	Serviceability	Availability	Utilisation	Total time hrs.	mins.
April 1964	·974	·880	·966	182	43
May 1964	·978	·862	·971	222	44
June 1964	·996	·881	·982	165	38
July 1964	·898	·807	·965	202	8
Aug. 1964	·986	·893	·992	217	24
Sept. 1964	·985	·911	·980	211	43
Oct. 1964	1·000	·916	·966	182	4
Nov. 1964	·995	·925	·996	313	45
Dec. 1964	·969	·891	·997	170	8
Jan. 1965	·968	·858	·989	328	36
Feb. 1965	·997	·936	·995	241	15
Mar. 1965	·978	·920	·994	288	10

Key:

$$\text{Serviceability} = \frac{\text{Serviceable time}}{\text{Serviceable time} + \text{fault time}}$$

$$\text{Availability} = \frac{\text{Serviceable time}}{\text{Serviceable time} + \text{fault time} + \text{maintenance time}}$$

$$\text{Utilisation} = \frac{\text{Effective time}}{\text{Serviceable time}}$$

Statistics Section Papers

Twenty-seven Statistics Section Papers were produced in the year under review, with the titles set out below. Any enquiries concerning them should be directed to the author.

69. The effect of length and straightness specifications on the proportion of pulpwood and waste.
70. Moisture content and specific gravity of fresh-felled conifers; weighted tree means.
71. Study on the conversion of pruned and unpruned Norway spruce from Inverliever.
72. Control of wet time; an exercise in statistical management control.
73. Principal component analysis of South-east England rainfall, sunshine and temperature for the years 1922–1963.
74. District Officers survey.
75. Fused needle disease of *Pinus contorta.*
76. Test of Franz' formula.
77. Some observations on linear and non-linear programming in the Forestry Commission.
78. A multivariate analysis of the relationship between staff and work load.
79. Relationship between staff and work load in individual forest units.
80. Studies of felling and conversion of conifers in the New Forest.
81. Conversion study on Norway spruce from a pruning experiment.
82. Canonical variate analysis applied to three problems of plant and insect taxonomy.
83. Principal component analysis in taxonomic research.
84. Collection and analysis of information on forest fires.
85. Draft instructions for new fire report form.
86. Computer forecasting of future timber production.
87. Cyprus experiment; planting on gentle slopes.
88. Cyprus experiment 5/59; direct seeding in cultivated and uncultivated soil on gentle slopes.
89. Forecasting of future timber production: programmes and procedures.
90. The study of variation in taxonomic research.
91. Conservancy differences in the allocation of staff to meet prescribed work loads.
92. A short-term plan for the Statistics Section of the Forestry Commission Research Branch.
93. Preliminary report on the Forest Year 1964 trials of the new nursery stocktaking procedure.
94. A second statistical report on studies of felling and conversion of conifers in the New Forest.
95. A study of the relationship between weather conditions, soil moisture, and tree growth in *Pterocarpus* woodland.

PUBLICATIONS AND LIBRARY

By H. L. EDLIN

Publications

Mr. S. H. Sharpley succeeded Miss E. Niven as Executive Officer for publications work in October, 1964.

The usual series of publications were continued. The following 11 new issues were made through Her Majesty's Stationery Office:

Reports

Forty-fourth Annual Report of the Forestry Commissioners, 1963 (H.C. 169. Session 1963–64, 7s. 0d.).

Report on Forest Research for the year ended March 1963 (14s. 0d.).

Bulletin:

No. 14. Forestry Practice—A Summary of Methods of Establishing Forest Nurseries and Plantations, with Advice on other Forestry Questions for Owners, Agents and Foresters. 8th Edition, 1964, Edited by H. L. Edlin, (5s. 6d.)

Forest Record:

No. 52. Home Grown Roundwood, by B. W. Holtam. (3s. 0d.)

Booklets:

No. 10. The New Forests of Dartmoor, by G. D. Rouse (2s. 6d.)
No. 11. Extraction of Conifer Thinnings, by R. E. Crowther (5s. 0d.)
No. 12. Double Drum Winch Technique, by R. E. Crowther and S. Forrester (3s. 0d.)

Leaflets:

No. 48. Needle-cast of Pine, by R. G. Pawsey (1s. 3d.)
No. 49. Resin-Top Disease of Scots Pine, by R. G. Pawsey (1s. 6d.)
No. 50. Grey Mould in Forest Nurseries, by R. G. Pawsey (1s. 6d.)

Guide:

Short Guide to the Queen Elizabeth Forest Park, by R. P. Illingworth (1s. 0d.)

The following were prepared for Departmental circulation:

Journal of the Forestry Commission, No. 32: 1963, edited by H. L. Edlin.
Forest Work Series, No. 1: Brashing and Pruning, by S. J. Betterton.
Safety Series, No. 1: 'Dont Read This Book . . .', designed and drawn by D. T. Patterson.

Revisions

In addition 21 existing publications were revised and re-issued.

Exchanges and Advisory Work

Exchange arrangements with other research stations and forestry departments, mainly overseas, were maintained and, where opportunity offered, extended.

Contacts were maintained with the editors of journals on forestry and related sciences throughout the British Isles, and assistance with photographic illustrations was afforded to several publishers of textbooks.

Library

Miss C. M. Davies succeeded Mr. R. G. Harris as Assistant Librarian in September, 1964.

New Developments

Work has continued on well-established lines, and it is only necessary to comment here on some changes of emphasis. Some of these arose from a review of the library's aims and objects at a Research Branch staff conference in September 1964. The main conclusion reached was that the library was serving staff at Headquarters and in the various research and specialist sections reasonably well, but was less successful in making new knowledge available to the Commission's field staff. These people are, from the nature of the Commission's activities, widely dispersed over some 450 forests and regional offices. In one sense the problem is internal to the Commission but it no doubt arises in other Forest Services.

(a) A *Library Catalogue of Books* was prepared for distribution to all field staff down to Assistant Forester grade.

(b) The circulation of the established *Library Bulletin*, now renamed the *Library Review*, was extended from a small group of specialists to all trained field staff.

(c) A procedure was evolved for duplicating and circulating *Select Translations* to the field staff in general. It is appreciated that many translations can interest only a small group of specialised workers, but there are many that may increase the efficiency of a far wider circle of professional staff.

(d) Visiting parties of field staff were given short talks on the work of the library, with demonstrations of the services it offers.

In view of the expected publication of a microfilm version of the Card Catalogue of the Commonwealth Forestry Institute at Oxford, and of microfilm versions of many back runs of periodicals by the Oxford Forestry Microfilm Unit, it was decided to purchase a microfilm reader.

Routine Activities

Two hundred and fifty-three books were acquired during the year, most by purchase but some by gift or exchange. The National Lending Library kindly provided 165 photocopies of papers from a wide range of periodicals outside our usual sphere.

The Library made a total of 1,242 recorded loans; 1,047 of these were to members of the Commission's staff, and 165 (or 13 per cent) to members of the public. Borrowings from associated libraries totalled 246.

Forty-nine volumes of periodicals were bound, bringing our total to 1,631.

Requests for translations of papers in foreign languages increased substantially; 65 were completed, as compared with 40 in the previous year. The main demand was for information from Scandinavia, where many developments follow lines that run parallel with our own researches.

PART II

Research Undertaken for the Forestry Commission by Workers at Universities and other Institutions

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RESEARCH ON SCOTTISH FOREST AND NURSERY SOILS

By J. B. CRAIG and H. G. MILLER,

The Macaulay Institute for Soil Research, Aberdeen

The year has been one of consolidation following recent changes in staff. Investigations into physical factors of soil and, in particular, peat in relation to tree growth, have been greatly extended, whilst tree nutrition investigations are tending to be concentrated on the more fundamental physiological and ecological aspects.

Tree Nutrition

The fertilizer experiments described in last year's report (*Rep. For. Res. For. Comm. Lond. 1964*) have continued. That laid down on Corsican pine at Culbin Forest, Morayshire, in 1961 showed similar growth responses in 1964 to those already reported for 1963; but the foliage nitrogen content in the plots receiving 135 lb. nitrogen per acre per annum has now risen to over 1·3 per cent, at which level the curves for both height growth and diameter growth are showing a tendency to flatten out. The treatments with vermiculite-ammonia complex have still not produced any definite response in tree growth or foliage nitrogen content. The nitrogen experiment on Japanese larch and Sitka spruce laid down at Broxa in Allerston Forest, Yorkshire, in 1962 is to receive a blanket dressing of phosphate in the spring of 1965; this follows the indications of a secondary deficiency of phosphorus at nitrogen applications over 120 lb. per acre per annum, which were reported last year. There are now indications that a secondary deficiency of phosphorus is also occurring in the nitrogen experiment on Scots pine at Inshriach Forest in Inverness-shire, which like that at Broxa is on a *Calluna* heathland site.

Investigations into the nitrogen nutrition of Corsican pine on the sand dunes at Culbin Forest have been extended with the laying down of two new experiments, one in an 11-year-old crop and the other in a 36-year-old crop. Both experiments involve five treatments, ranging from 0 to 450 lb. of nitrogen per acre per annum, applied as sulphate of ammonia. In the two higher treatments —300 and 450 lb. of nitrogen—the fertilizer is applied in two and three applications respectively, at different times during the growing season; each application is of 150 lb. of nitrogen per acre and it is separated from the previous one by an interval of at least four weeks.

Prior to the first application of fertilizer to the experiment in the older crop, thirty trees, covering the full size-range, were harvested, and their weights determined. Samples were then taken of the roots, stumps, bark and wood in five sections up the stem, and also in live and dead branches, needle-bearing twigs and needles by age. The weights of the ground vegetation, litter and humus layers, and of the soil to a depth of 3½ feet, were also determined and samples of each were taken. The tree samples are at present being subjected to chemical analyses for macronutrients and a number of trace elements, whilst those samples from the rest of the ecosystem are being analysed for nitrogen alone.

Litter-fall has been collected monthly in this experiment, and this has shown that, during the period June 1964 to January 1965, inclusive, the nitrogen treatments have resulted in a marked increase in needle retention, the estimated needle-fall for the untreated control plots being 2,600 kg. per hectare over this period, as against 1,800 kg. per hectare for the treated plots. Needle-fall during the period returned about 10·5 kg. of nitrogen per hectare to the soil in the untreated control plots, whereas in the treated plots the figure is 8 kg. per hectare; as yet there is no significant difference between the various nitrogen treatments. Other categories of litter, such as twigs, cones, bark etc., have also been collected, but the analyses of these are not yet complete.

Physical Studies

The field experiment at the Lon Mor, Inchnacardoch Forest near Fort Augustus in Inverness-shire (*Rep. For. Res. For. Comm. Lond. 1963*) has continued. An assessment made by the Forestry Commission staff in November 1964 showed that, with increase in depth of drains, the plant height, the shoot length and the percentage survival generally all increased; while the colour of the foliage changed from yellow-green to green. Significant differences in plant height and shoot length were found between the '0 cm' and '10 cm' drainage treatments, and also between the '30 cm' and '50 cm' drainage treatments.

Experimental instruments to measure the height of the water tables have been installed in one of the plots, and if this proves successful, similar instruments will be installed in all plots and the water level telemetered by an automatic camera device. A Dine rain gauge has also been placed in the area so that water-level fluctuations can be compared with rainfall. Several tensiometers are in operation in peat at Moss Maud, Aberdeenshire, as a trial before transferring them to the Lon Mor. On the driest peat, water tensions of 10 cm of mercury have not been exceeded.

Peat Analysis

In the experiment at Flanders Moss, Loch Ard Forest, Stirlingshire, the preliminary sampling of peat (*Rep. For. Res. For. Comm. Lond. 1964*) has been followed up by more intensive sampling. In each of the 44 plots, five pits were sampled on a volume basis every 2 inches to depth of 1 foot, thereafter every 3 inches to a depth of 3 feet. The samples are in process of being analysed. Arrangements have been made to analyse peat samples from selected Forestry Commission experimental areas. A study is being made of peat samplers, two for sampling on a volume basis and four for sampling on a weight basis.

Forest Nurseries

The preparation of fertilizer prescriptions for forest nurseries, based on soil analyses carried out by the Department of Soil Fertility of the Macaulay

Institute has continued with little change. Analysis of the soil from the Long-Term Fertility Experiments in Scottish nurseries continues (*Rep. For. Res. For. Comm. Lond. 1957*) and this year samples were taken, probably for the last time, from that at Fleet Nursery, in Kirkcudbrightshire.

SUMMARY

The year has seen a considerable expansion in investigations into physical factors of soil and peat in relation to tree growth. Nutritional work commenced during the period includes more fundamental investigations of the physiological and ecological aspects of nitrogen in forest fertilization. The fertilizer experiments previously reported (*Rep. For. Res. For. Comm. Lond. 1964*) have continued, and a further two experiments to investigate the nitrogen nutrition of Corsican pine have been laid out at Culbin Forest, one in an 11-year old crop and the other in a 36-year-old crop. In the older experiment extensive sampling involving the harvesting of 30 trees and the sampling of the litter, humus and soil was carried out prior to the application of treatments. Monthly collection of litter fall in this experiment has shown that the application of nitrogen has significantly increased needle retention during the first year. The experiment at the Lon Mor, Inchnacardoch Forest (*Rep. For. Res. For. Comm. Lond. 1963*) investigating peat drainage continues; assessments have shown that significant differences in the height growth of young Lodgepole pine occur even when the level of the water is lowered to only 10 cm below the peat surface.

NUTRITION EXPERIMENTS IN FOREST NURSERIES: SLOW-RELEASE FERTILIZERS FOR CONIFER SEEDLINGS

By BLANCHE BENZIAN, J. BOLTON and G. E. G. MATTINGLY

Rothamsted Experimental Station, Harpenden, Herts.

Extract from Rothamsted Annual Report for 1964

Conifer seedlings, which make much of their growth in the late summer, are often grown on light sandy soils where soluble salts are rapidly lost by leaching. Under these conditions 'slow-release' fertilizers may have special merits, and the very wet spring and early summer of 1964, which probably aggravated leaching losses, gave a good opportunity for testing sparingly soluble sources of N, P and K. Because of the prolonged dry spell that followed, seedlings remained small.

In experiments with Sitka and Norway spruce seedlings, a PK compound fertilizer made from superphosphate and potassium chloride was compared with potassium dihydrogen phosphate and also with potassium metaphosphate; all fertilizers were applied in March before sowing. In a fourth treatment the PK compound was supplemented by potassium nitrate added in three summer top-dressings. (All plots had basal dressings of 'Nitro-Chalk' and kieserite; on the potassium nitrate plots the 'Nitro-Chalk' dressings were correspondingly decreased.)

At the end of June, plants treated with potassium metaphosphate were greenest and most vigorous; they remained best throughout the season, closely followed by plants given potassium nitrate. Seedling tops were analysed at four times between early July and November. The percentage P in plants given metaphosphate consistently exceeded the percentage P in plants given other fertilizers. Comparing the PK fertilizers only, percentage K in the plants was always least where PK compound only was given; percentage K in plants from other plots increased in the order: potassium dihydrogen phosphate, PK compound plus potassium nitrate, and potassium metaphosphate. By November plants on the potassium nitrate plots had overtaken those given potassium metaphosphate. Table 17 shows measurements made at the end of the growing season and scores for colour in September. The two species behaved similarly.

Magnesium ammonium phosphate is sparingly soluble, and so has potential use as a slowly acting source of N, P and Mg. Because it supplies three nutrients, designing experiments to compare it with other materials is difficult, while at the same time defining the shapes of nutrient response curves. Preliminary work in 1964 indicated some of the experimental problems, but suggested that this salt may be a useful fertilizer on very light soils. In a second experiment with Sitka spruce, a 'standard fertilizer', consisting of 'Nitro-Chalk', superphosphate, potassium chloride and kieserite, was compared with a compost made from bracken and hopwaste (applied at 15 lb./sq. yd.), and also with magnesium ammonium phosphate used at three rates. As much basal K as was supplied by the standard fertilizer was given with all rates of magnesium ammonium phosphate; but this fertilizer supplied more P and Mg at all the rates tested and a little more N at the largest. The plants on the plots with the two larger rates

Table 17

THE EFFECTS OF P AND K FERTILIZERS ON 1-YEAR SEEDLINGS AT WAREHAM IN 1964

Species and treatment	Rate of application (g element/ sq. yd.)		Height (ins.)	Dry matter of tops (mg./ plant)	Colour* score	P (%)	K (%)
	P	K				(in dry matter of seedlings)	
Sitka spruce							
No fertilizer	0	0	0·8	53	3	0·11	0·43
Superphosphate only	9	0	1·0	78	4	0·18	0·28
PK compound (from super + KCl)	9	9	1·0	71	2	0·14	0·36
Potassium dihydrogen phosphate	9	12	1·0	81	1	0·15	0·58
PK compound + KNO_3	9	15	1·3	120	0	0·18	1·05
Potassium metaphosphate	9	12	1·5	136	0	0·23	0·86
Norway spruce							
No fertilizer	0	0	0·9	68	4	0·10	0·30
Superphosphate only	9	0	1·2	96	4	0·16	0·24
PK compound (from super + KCl)	9	9	1·2	100	3	0·16	0·30
Potassium dihydrogen phosphate	9	12	1·4	122	1	0·12	0·41
PK compound + KNO_3	9	15	1·6	144	0	0·14	0·83
Potassium metaphosphate	9	12	1·7	151	0	0·24	0·70

* For the purple and yellow discoloration typical of K-deficiency (0 = no discoloration).

of magnesium ammonium phosphate grew faster throughout the season than those on 'standard fertilizer' or compost plots, but showed signs of severe potassium deficiency, reflecting the early loss of K by leaching. In height and dry matter the plants with compost were roughly midway between those with standard fertilizer, and those with magnesium ammonium phosphate, though much better in colour than either. Plants given compost and standard fertilizer had much smaller percentage P (at the last sampling date) than plants given magnesium ammonium phosphate. Plants given compost had much larger percentage K than those given any other treatment.

DISTRIBUTION OF FERTILIZER RESIDUES IN A FOREST NURSERY MANURING EXPERIMENT ON A SANDY PODSOL AT WAREHAM, DORSET

By J. BOLTON and J. K. COULTER

Rothamsted Experimental Station, Harpenden, Herts.

Experiments made on sandy podsols used as forest nurseries (Benzian 1965) showed that potassium chloride applied to the seedbed was not fully effective because potassium was rapidly leached from the rooting zone. Mattingly (1966) showed that soluble phosphates also are easily leached from the surface horizon (A_1) of these soils but that insoluble phosphates, namely rock phosphate and basic slag, accumulated mainly in the sand and silt. We have determined the distribution of fertilizer residues in the four major soil horizons in the top 20-inch layer of soil of plots given different forms of nitrogen and phosphate, as well as potassium and magnesium fertilizers, annually since 1949. (W 41, the same experiment as used by Mattingly.)

Soil samples from each horizon of all plots were taken in early Spring 1964. The soil is an acid podsol which has developed under *Calluna* heath on a sandy phase of the Bagshot beds. Descriptions, mechanical analyses and average depths of the horizons are in Table 18, together with measurements of the organic carbon from one plot. Exchangeable cations (Ca, Mg, K, Na), total phosphate and pH in water were measured on all samples.

Table 18

MECHANICAL ANALYSES, DEPTH AND ORGANIC CARBON CONTENT OF THE 4 MAJOR SOIL HORIZONS

Horizons	Description	Average depth ins.	Coarse sand %	Fine sand %	Silt %	Clay %	Organic carbon %
A_1	Dark grey sand	7·6	56	36	5	3	1·0
A_2	Bleached white sand	2·8	56	35	6	3	0·4
B_1	Dark brown loamy sand	2·5	52	29	9	8	2·5
B_2	Red-brown sandy loam	4·3	49	28	10	12	1·5

Results

Both the nitrogen and phosphate fertilizers affected pH, especially in the surface A_1 and the bleached A_2 horizons. The pH in the B_1 and B_2 horizons was similar except that ammonium sulphate had acidified all horizons of plots given 'no P'; on plots given basic slag or rock phosphate, the pH was lessened by ammonium sulphate in the A_1 and A_2 horizons only.

In the A_1 and A_2 horizons the pH correlated with total exchangeable cations, but the regressions showed that the A_1 horizon had greater cation exchange capacity than A_2, because it contained more organic matter. Exchangeable cation content was greatest in the B_1 horizon of plots that were not given phosphates. The results emphasised how organic matter determines cation exchange capacity of this soil, which contains very little clay.

In the plots where K was not given, all the nitrogen fertilizers lessened exchangeable K in the A_1 and A_2 horizons, but increased it in the B_1 and B_2 horizons; the total amount of K in the profile was the same with all treatments. Where potassium chloride was applied, ammonium sulphate lessened exchangeable K in each horizon, whereas 'Nitro-Chalk' and crushed hoof lessened exchangeable K in the A_1 and A_2 horizons only; all the N fertilizers lessened the total amount of exchangeable K in the profile. A potassium balance sheet, calculated from crop analyses over several years, shows that the crops have taken up 23 per cent of the K applied; 7 per cent is retained in the exchangeable form in the horizons analysed, and 70 per cent has been leached from the top 17 in. of soil.

The exchangeable sodium exceeded the exchangeable potassium in each horizon of all the plots, even those given an average of 66 lb. per acre of K annually for 15 years. In a soil with such a small buffering capacity for K, the relative amounts of K and Na in the soil after leaching during the winter is probably much influenced by the composition of the rain. Salt carried from the sea by rain probably explains the large Na/K ratio at this site, which is only a few miles from the Dorset coast.

Calcium was the main exchangeable cation in all plots, and was much increased by the applied phosphate fertilizers. Both ammonium sulphate and crushed hoof lessened exchangeable calcium significantly in the A, but not in the B, horizons. 'Nitro-Chalk' maintained exchangeable calcium of the A horizon at the same amounts as in the plots not given N fertilizers. Calcium is probably the most important exchangeable cation because of the exchange characteristics of the organic matter, which has a much greater affinity for calcium than for the other major cations (Russell 1961).

Table 19 summarizes the mean pH, exchangeable cations and total phosphate in the four horizons of all plots.

Table 19

MEAN ANALYSES OF EACH HORIZON FOR ALL 32 PLOTS OF THE EXPERIMENT

Horizon	pH (water)	Exchangeable (m-equiv./100 g)				Total P ppm
		Ca	Mg	K	Na	
A_1	5·3	2·41	0·16	0·02	0·09	170
A_2	5·0	1·21	0·12	0·02	0·07	126
B_1	4·6	1·83	0·19	0·06	0·10	348
B_2	4·7	0·57	0·10	0·04	0·10	203

The total-phosphate analyses (by fusion) showed that much of the applied P, which Mattingly showed was leached from the A_1 horizon, accumulated in the B horizons, especially on those plots that were given superphosphate. Total phosphate in the B_1 and B_2 horizons was much larger in the plots given superphosphate than in those given rock phosphate or basic slag (Table 20). Although only 14 per cent of the applied superphosphate P (in relation to the 'no P' plots) was recovered from the surface horizon; recovery from the whole profile was nearly 90 per cent.* Uptake by the transplants accounts for a further 8 per cent of the applied P, showing that only a small amount of P is leached below 17 inches into the C horizon.

Table 20

TOTAL PHOSPHATE CONTENT (PPM) OF THE HORIZONS (EACH FIGURE IS THE MEAN OF ALL THE NITROGEN, POTASSIUM AND MAGNESIUM TREATMENTS)

Horizon	'No phosphate'	Basic slag	Rock phosphate	Superphosphate
A_1	74	240	239	127
A_2	74	129	118	186
B_1	156	332	366	536
B_2	137	212	174	351

Conclusions

The distribution of cations remaining in the soil from fertilizer applied annually to a sandy podsol for 15 years was influenced primarily by the cation exchange characteristics of the organic matter contained in the four major horizons, namely A_1, A_2, B_1, B_2. Approximately 70 per cent of the applied potassium had leached from the profile. Calcium was the dominant exchangeable cation.

Much of the P applied as superphosphate had leached out of the A_1 horizon, but it was adsorbed by the B horizons, so that there was little leaching from the whole profile. Basic slag and rock phosphate were retained mainly in the A_1 horizon.

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* The slight differences in estimates of total recovery and analyses, between our results and those given by Mattingly, are due to differences in the plots sampled (we included both the 'no-N' and the 'ammonium sulphate' plots), depths of sampling the A_1 horizons, year of sampling and method of calculation of recovery.

RESIDUAL VALUE OF CUMULATIVE DRESSINGS OF SUPERPHOSPHATE, ROCK PHOSPHATE AND BASIC SLAG ON A SANDY SOIL AT WAREHAM, DORSET

By G. E. G. MATTINGLY

Rothamsted Experimental Station, Harpenden, Herts.

There is little information on the relative value of residues in soil from repeated dressings of different phosphate fertilizers. A long-term factorial experiment (W 41) with spruce transplants, which started in 1949 at Wareham Nursery in Dorset (Benzian, 1965), provided soils suitable for studying this problem. Soil samples (0–6 in.) were taken in the early springs of 1955, 1959 and 1963 from plots given either 'no phosphate', or else equivalent annual dressings of superphosphate, Gafsa rock phosphate or basic slag. All plots sampled has nitrogen either as 'Nitro-Chalk' or as hoof; plots without nitrogen or with ammonium sulphate were avoided. The soils were air-dried and sieved to a size of <2 mm. The residues of phosphate fertilizers applied in the field were evaluated in glasshouse experiments, and the distributions of phosphate in different particle-size fractions of the soil were measured in the laboratory.

Changes in Total P Content and Isotopically-exchangeable Phosphorus

Table 21 gives the cumulative amounts of phosphorus applied up to each sampling date, the total P in the soils (by fusion analysis), the labile or isotopically-exchangeable P from glasshouse experiments (Mattingly, 1957) and yields of ryegrass in the glasshouse.

Total and labile P decreased slightly with time, where phosphate was not given, increased slightly where superphosphate was given, and increased much more where rock phosphate or basic slag were given. Assuming an acre of soil 6 in. deep weighs 2,000,000 lb., then 1 gram P per square yard should increase total P in soil by approximately 5 parts per million. On this assumption, the total recoveries of phosphate in 8 years, from superphosphate, rock phosphate and basic slag are, 21, 220 and 136 parts per million, or 7 per cent, 67 per cent and 41 per cent respectively of the amounts applied. Bolton and Coulter (1966) sampled the whole experiment in 1964, including 'no N' and ammonium sulphate plots. They reported somewhat larger recoveries of P, especially from superphosphate, when calculated from the differences between the P contents of treated and 'no phosphate' plots.

Evaluation of Fertilizer Residues in the Glasshouse

In each sampling year, the soils were cropped in the glasshouse with ryegrass (*Lolium perenne*). Potassium dihydrogen phosphate (5·0 parts per million P, labelled with 10 μC ^{32}P per pot) was mixed uniformly with all the soils, which also received adequate, uniform, dressings of N, K, Mg and micro-nutrients. The total isotopically-exchangeable P in the soils (Table 21) was calculated from the $^{32}P/^{31}P$ ratio in the ryegrass.

Table 21

CUMULATIVE AMOUNTS OF P ADDED TO WAREHAM SOILS, TOTAL P CONTENTS OF SOILS, LABILE (ISOTOPICALLY-EXCHANGEABLE) P IN SOILS AND YIELDS OF RYEGRASS IN 1955, 1959 AND 1963

Treatment	Cumulative amounts of P added (g. per sq. yd.)			Total P in Soil (ppm)			Labile P in Soil (ppm)			Yield: grams dry matter per pot		
	1955	1959	1963	1955	1959	1963	1955	1959	1963	1955	1959	1963
None	—	—	—	97	90	81	10	9	8	2·14	3·77	3·29
Superphosphate	18	42	78	120	126	141	32	43	52	7·58	10·56	8·42
Rock phosphate	18	48	84	130	220	350	33	71	91	8·66	14·59	13·50
Basic slag	18	48	84	123	196	259	28	70	130	7·37	13·78	13·09

Standard error—± 0·395 ± 0·133

Although the total amount of superphosphate gained by the soil between 1955 and 1963 was small (21 parts per million), the plots receiving this fertilizer contained 60 parts per million more total phosphate in 1963 than the 'no phosphate' plots; and 44 parts per million of this was isotopically-labile P (Table 21). These residues increased yields three-fold, and uptakes of P six-fold, compared with the control (Table 21). This large residual effect from so little superphosphate arises from the very small amount of labile P (8 parts per million in 1963) in the 'no phosphate' plots at Wareham. Residues from superphosphate increased the labile P in the soil to 52 parts per million in 1963 (Table 21). Yields increased exponentially, and uptakes linearly, with the labile P content of soil.

Yields and P uptakes from residues of rock phosphate were slightly greater than from residues of superphosphate in 1955, and much greater in 1959 and 1963. Yields and P uptakes from residues of basic slag were also greater than from superphosphate residues in 1959 and 1963, but were slightly smaller than from rock phosphate residues. Labile P values (Table 21) were larger in 1959 and 1963 with rock phosphate or basic slag, than they were with superphosphate.

Distribution of Phosphate in Different Particle-size Fractions of Soil

The total, and the labile, P contents of the soils, and their behaviour in the glasshouse experiments, shows that much of the phosphate applied as rock phosphate or basic slag has accumulated. Both are in fine particles about the size of coarse and fine sand (2000–20μ). To measure the distribution of phosphate in different particle-size fractions, the soils were dispersed by shaking with water, and then separated by sieving and decantation. The total P in each fraction was measured after igniting a sample at 550°C for 2 hours and extracting the residue with 0.2N H_2SO_4 for 2 hours.

Changes in the distribution of acid-soluble P in different particle-size fractions of the soils, between 1955–1963, showed that the small amount of phosphate retained from superphosphate accumulated mostly in the $<20\mu$ size fraction, and in solution. The P content of all fractions increased where rock phosphate or basic slag were given. The phosphate in fractions of soil of a size $>75\mu$ was much greater with rock phosphate than with basic slag. This was probably because ground rock phosphate contains a larger proportion of coarse material (50–70 per cent $>75\mu$) than basic slag (28–30 per cent $>75\mu$) and because slag is more soluble in acid soils.

Conclusions

Chemical analysis of the top six inches of soil from an experiment at Wareham Nursery shows that about 7, 67 and 41 per cent of the phosphate applied between 1955 and 1963 as superphosphate, Gafsa rock phosphate and basic slag respectively has been retained by the soil. These results on a very light sand (1–2 per cent clay $<2\mu$) differ greatly from those for heavier soils which retain all the phosphorus applied as superphosphate in the ploughed layer. The average annual rainfall at Wareham (about 35 in.) seems enough to leach more than 90 per cent of the applied water-soluble phosphate from the top 6 in. of soil.

Plots given superphosphate contained 60 parts per million more total P in 1963 than 'no phosphate' plots, 44 parts per million of which remained isotopically-exchangeable. These residues gave yields and uptakes by ryegrass, in the glasshouse, three- and six-fold respectively greater than those from controls.

Much of the rock phosphate remains in the soil in the coarse and fine sand ($>75\mu$). Residues of basic slag accumulate in the fine sand and silt ($>75\mu$) and in solution. The small amounts of phosphate from superphosphate were retained in finer fractions ($<20\mu$) and in solution.

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PATHOLOGY EXPERIMENTS ON SITKA SPRUCE SEEDLINGS

By G. A. SALT

Rothamsted Experimental Station, Harpenden, Herts.

Effect of Partial Sterilants and Fungicides on Seedling Survival and Growth

At Ringwood Nursery in Hampshire (R. 93), and Kennington Nursery near Oxford (K. 96), the effects on seedling survival and growth of three soil sterilant treatments—nil, formalin and dazomet; three fungicide treatments nil, nabam and quintozene; two seed dressings—red lead and 50 per cent thiram dust; two fertilizers—ammonium sulphate and 'Nitrochalk'; and two qualities of seed containing 18 per cent and 69 per cent viable seeds were compared in a 3 × 3 × 2 × 2 × 2 factorial experiment.

At Ringwood both the sterilants and the fungicides significantly increased numbers (Table 22) but only the sterilants increased growth (Table 23). Increases in numbers due to partial sterilants and fungicides were not additive, so that fungicides had no beneficial effect when applied, at sowing time, to soil that had already been partially sterilized. Partial sterilants increased growth significantly, whether nabam was applied subsequently or not, whereas they failed to increase growth where quintozene was applied. Although this suggests that quintozene might be phytotoxic, this fungicide did not noticeably delay germination, and it increased the number of seedlings that survived. At Kennington fewer seedlings emerged, and treatments rarely increased seedling numbers significantly (Table 22). More than 50 per cent of the viable seed sown failed to emerge, even where treated with thiram, sown in partially sterilized soil and drenched with fungicide at sowing time. Soil-borne pathogens were therefore unlikely to have been the main cause of poor emergence in this experiment. If seed-borne pathogens were responsible, their activity seemed to depend on soil conditions, because seed from the same 'bulk,' sown in other nurseries and sown at Kennington at different times yielded widely different numbers of seedlings (Table 24). Drought was the most likely cause of poor emergence from late sowings but not from April sowing at Kennington.

Laboratory experiments showed that germination capacity, measured at 20°C, declined rapidly after 10 days when sown seed was incubated at 10°C or less. The embryo and endosperm of many ungerminated seeds yielded a slow-growing septate mycelium when plated on potato dextrose agar and incubated at 5°C. The pathogenicity of this fungus has not been tested, but the isolate resembles in several respects the new psychrophilic fungus reported by Epners (*Canad. J. Bot. 42*, 1964) as causing germination failure of conifer seeds at low temperatures.

There was no evidence, either at Ringwood or Kennington, that seed-borne pathogens had spread from non-viable to viable seed in the seedbed. Poor quality seed sown at 9,900 grains per sq. yd., and good quality seed sown at 2,600 grains per sq. yd. both being intended to give 1,800 viable seeds per sq. yd., both produced similar numbers of seedlings. The emergence of neither was improved by treatment with 50 per cent thiram dust (Table 25).

Table 22

NUMBERS OF SEEDLINGS PER SQUARE YARD IN PARTIAL STERILIZATION EXPERIMENTS, MEASURED IN OCTOBER 1964

Sterilant	Ringwood (R.93)				Kennington (K.96)			
	Fungicide				Fungicide			
	Nil	Nabam	Quintozene	Mean	Nil	Nabam	Quintozene	Mean
		(±62·5)		(±36·1)		(±103·0)		(±59·5)
Nil	834	1,100	1,252	1,062	505	766	630	634
Formalin	1,336	1,345	1,359	1,346	830	851	787	823
Dazomet	1,360	1,267	1,211	1,279	652	943	768	787
Mean	1,176	1,237 (±36·1)	1,274	1,229	662	853 (±59·5)	728	748

Table 23

HEIGHTS IN INCHES IN PARTIAL STERILIZATION EXPERIMENTS, MEASURED IN OCTOBER 1964

Sterilant	Ringwood				Kennington			
	Fungicide				Fungicide			
	Nil	Nabam	Quintozene	Mean	Nil	Nabam	Quintozene	Mean
		(±0·1394)		(±0·0805)		(±0·0923)		(±0·0533)
Nil	0·607	0·792	0·603	0·667	1·148	1·156	0·805	1·036
Formalin	1·925	1·663	0·953	1·514	1·347	1·371	0·962	1·226
Dazomet	1·657	1·459	0·898	1·338	1·620	1·424	1·238	1·427
Mean	1·396	1·305 (±0·0805)	0·818	—	1·372	1·317 (±0·0533)	1·002	—

Table 24

NUMBERS PER SQUARE YARD IN PARTIAL STERILIZATION EXPERIMENTS IN OCTOBER 1964

Sowing date	Ringwood		Kennington	
	Soil treatment		Soil treatment	
	Nil	Formalin	Nil	Formalin
	(±66·4)		(±79·3)	
6–9 April	1,008	1,188	664	814
4 May	898	1,160	1,055	1,118
26–27 May	581	743	1,065	1,024
18–19 June	406	512	700	494
13–14 July	281	259	294	320
Mean	635	773	756	754
	(±29·7)		(±35·5)	

Table 25

NUMBERS PER SQUARE YARD IN RED LEAD AND THIRAM EXPERIMENTS IN OCTOBER 1964

Seed quality	Ringwood		Kennington	
	Seed treatment		Seed treatment	
	Red lead	Thiram	Red lead	Thiram
18 per cent viable SS.61 (7986)1	1,290	1,247	734	742
69 per cent viable SS.60 (7111)1	1,197	1,182	751	764
	S.E. Vertical comparisons (±29·7) Horizontal comparisons (±36·2)		S.E. Vertical comparisons (±29·4) Horizontal comparisons (±52·8)	

Persistent Effect of Soil Treatments

Formalin, metham-sodium and dazomet, applied in December 1962 to plots cropped in 1963, also increased numbers and growth of the following crops sown in April 1964. Except for numbers of seedlings at Kennington these increases were all significant statistically.

Table 26

PERSISTENT EFFECTS OF SOIL TREATMENTS APPLIED DURING WINTER 1962–1963 ON NUMBERS AND GROWTH IN OCTOBER 1964

Treatment	Ringwood		Kennington	
	Numbers per yd.²	Height in inches	Numbers per yd.²	Height in inches
	(±71·0)	(±0·0926)	(±95·7)	(±0·0732)
Nil	929	0·834	497	1·067
Formalin	1,316	1·498	545	1·427
Metham-Sodium	1,346	2·021	478	1·481
Dazomet	1,247	1·616	552	1·565
Quintozene	1,210	0·943	382	0·929
Nabam	1,046	0·799	644	1·290
Mean	1,182	1·285	516	1·293

Re-inoculation of Formalin-treated Soils

At Ringwood and Wareham Nurseries, half the number of plots treated with formalin in December 1963 were re-inoculated in March 1964 with soil and root residues taken from adjacent untreated plots, at the rate of 0·3 kilogrammes per square yard. This was forked into the top six inches, along with basal fertilisers, and the plots were sown a month later. Re-inoculation had no detrimental effect on either the survival or growth of seedlings.

Table 27

RE-INOCULATION OF PARTIALLY STERILIZED SOILS

Treatments	Ringwood (R.87)		Wareham (W.95)	
	Numbers per yd.²	Height in inches	Numbers per yd.²	Height in inches
	(±57·0)	(±0·109)	(±39·9)	(±0·0201)
Nil	1,138	0·913	1,411	1·298
Formalin	1,318	1·462	1,395	1·451
Formalin re-inoculated	1,331	1·525	1,423	1·519
Chloropicrin (Residual)	1,323	1·840	1,441	1·184

At Ringwood the growth response to chloropicrin applied in December 1962, was greater than that to formalin applied in December 1963, but this was not so at Wareham. The failure to produce stunting in formalin-treated plots, by re-inoculation, is consistent with the long-lasting growth response to partial sterilization, despite contamination from surrounding untreated soil by wind, rainsplash and the growth of micro-organisms in soil. Even stunted transplants raised in untreated seedbeds recovered when transplanted to formalin-treated soil, and grew as well as did transplants that had been raised in formalin-treated seedbeds. The reasons why partial sterilization has such persistent effects on growth are still not understood. The results suggest that changes in the nutritional status of the soil may be more important than the control of harmful soil micro-organisms.

Pathogenicity Tests

Unsterilized root residues from Ringwood and Kennington Nurseries, and autoclaved residues inoculated with the fungi *Cylindrocarpon radicicola* and *Fusarium oxysporum*' caused no measurable decreases in seedling growth when mixed at the rate of 3 gm. fresh weight of residue to 300 gm. quartz grit in pots, and given a nutrient solution weekly. Autoclaved residues inoculated with *Pythium irregulare* Buism. and *P. ultimum* Trow. caused 100 per cent mortality of seedlings from seed, and of transplants about 8 weeks old.

Effect of Soil Chemicals on Root Surface Microflora

Pythium species, especially *P. irregulare*, were more frequently isolated from seedling roots early in the season than late. They were rarely found on seedlings from soil treated with formalin, dazomet or nabam, but were not controlled in soil treated with quintozene. *Cylindrocarpon radicicola* Wr., *Fusarium oxysporum* Fr. and *F. solani* Mart. were controlled more by nabam than by quintozene, and most effectively by formalin and dazomet. Populations of the nematode *Hoplolaimus uniformis* Thorne were halved by nabam, and almost eliminated by formalin, dazomet and by the fungicide quintozene. In the second season after treatment, *Pythium* and *Cylindrocarpon* were as frequent on seedlings from treated as from untreated plots, whereas the numbers of *Fusarium* species and the nematode *Hoplolaimus* were still much less in treated soil. For example, in one experiment (R.91) the percentage of root segments infected with *Fusarium* at the end of the second season after treatment with formalin, metham-sodium, dazomet, nabam and quintozene were 10, 2, 8, 16 and 15 per cent respectively, compared with 39 per cent in untreated soil. *Hoplolaimus* was still rare in plots treated in the previous season with partial sterilants and with quintozene, and common in those treated with nabam.

Where formalin treated soil was re-inoculated with untreated soil only, numbers of *Fusarium* remained substantially below those in untreated soil. *Fusarium* was isolated at the end of the season from 11 per cent of root segments in formalin-treated soil, 8 per cent in re-inoculated soil, and 42 per cent in untreated soil. Numbers of *Trichoderma* and *Penicillium* remained large in formalin-treated (20 per cent), and in re-inoculated soil (26 per cent), whereas they were isolated from only 1 per cent of root segments from untreated soil. Formalin did not control *Hoplolaimus* as well in this experiment as it did in others. The numbers of adults extracted from 100 gm. soil in untreated, formalin-treated, re-inoculated and chloropicrin-treated plots, were 56, 39, 38 and 1 respectively. However, the numbers recovered from the roots of seedlings, by steeping samples of 20 seedlings in water for 24 hours, were 74, 22, 94 and 2 respectively. Thus inoculation increased the numbers of nematodes on the roots of seedlings, but not the numbers in soil away from roots. The importance of pathogenic micro-organisms in causing stunting is still difficult to assess. The control of the fungus *Fusarium* and the nematode *Hoplolaimus* was often associated with growth responses, and anomalous results could be explained if (a) quintozene, which controlled the nematode without increasing growth, itself inhibited growth, and (b) the population of nematodes on roots in re-inoculated soil built up too late in the season to affect growth. Among the fungi it seems unlikely that *Pythium* and *Cylindrocarpon* are a major cause of stunting, because in the second year after treatment their numbers had increased to become similar to those in untreated soil, yet growth responses persisted.

SUMMARY

Although treatment of seedbeds with partial sterilants and fungicides increased the emergence and survival of Sitka spruce seedlings, more than 50 per cent of the viable seed sown in certain experiments at Kennington failed to emerge, despite partial sterilization of the soil and the application of fungicides to soil and seed. There was no evidence that soil-borne pathogens survived these treatments and the possible existence of a seed-borne fungus, active mainly at low temperatures, is being investigated.

The striking growth response to partial sterilization of seedbeds at Ringwood persisted in the second season after treatment, and also persisted after re-inoculation of formalin-treated soil with untreated soil. The effects of these treatments on the root surface microflora is discussed.

THE BIOLOGY OF FOREST SOILS

By G. W. HEATH

Rothamsted Experimental Station, Harpenden, Herts.

An experiment to investigate leaf litter disappearance under different forest conditions has been under way in Glenbervie Enclosure, Alice Holt Forest, since January 1964.

Four sites have been chosen. Site AO in Compartment 54 is on light soil and was planted with oak in 1820; it is now a deciduous woodland with oak predominating. Site AP is nearby and on the same soil type; it is of Corsican pine planted in 1937 on the site of a Scots pine plantation planted in 1890. The BO site is on a heavier soil about ½ a mile away and is of oak planted in 1938. The BP site is nearby on a similar soil and is of Sitka spruce planted in 1929 and replanted in 1939.

Oak leaf discs have been buried in the leaf litter in all four sites, enclosed in both small (1mm.) and large (4mm.) mesh bags. Needles of Corsican Pine have been similarly buried on all four sites, but no results from these can be reported yet.

Figs. 2 and 3 summarise the disappearance of oak discs as measured by the methods described by Heath, Edwards and Arnold (1964). Results are not yet complete, but there is a strong indication of the effect of earthworms on the BO site (i.e. when large mesh bags on BO are compared with large mesh bags on AO). Sampling for earthworms in the Spring of 1965 revealed an average of 1·8 worms per square foot on the BO site and 0·15 worms per square foot on the AO site. Taxonomic determination of the worms collected is not yet complete, but those collected on the AO site appear to be *Dendrobena octahedra*, whilst those on the BO site appear to be mainly *Lumbricus rubellus* and some *Allolobophora longa*. In view of the small number of earthworms found on the AO site it is surprising that disappearance of discs from small mesh bags was not as great as from large mesh bags. The differences between Fig. 2 and Fig. 3 are thought to be caused by the large population of dipterous larvae that are found on the site in mid-summer (see Fig. 4), some of which are too large to enter the small mesh bags. They also occur in large numbers on the AP site, and so the difference in disappearance of oak discs from large bags buried in the coniferous woodlands is reversed; the greatest disappearance is from the A site and not the B site as was found with the deciduous woodlands.

The results obtained, until October 1964, of sampling the litter of all sites for arthropods are summarised in Fig. 4. Apart from the striking differences in dipterous larvae the BO site contained fewer Acarina than any other site. The rise in numbers of all arthropods on the BO site in October is due to the way in which the results are expressed; in October the main leaf fall has not yet occurred, there is very little of the old litter still remaining, so the animals are concentrated into it.

The litter in the BP site (Sitka spruce) differs from the other sites, always being drier. It usually has most Acarina, and a good deal of the litter layer consists apparently of mite pellets. There is, however, little sign of an accumulation of litter on the site, but the plantation is still relatively young. It is too early to draw any further conclusions from the experiment, which is being

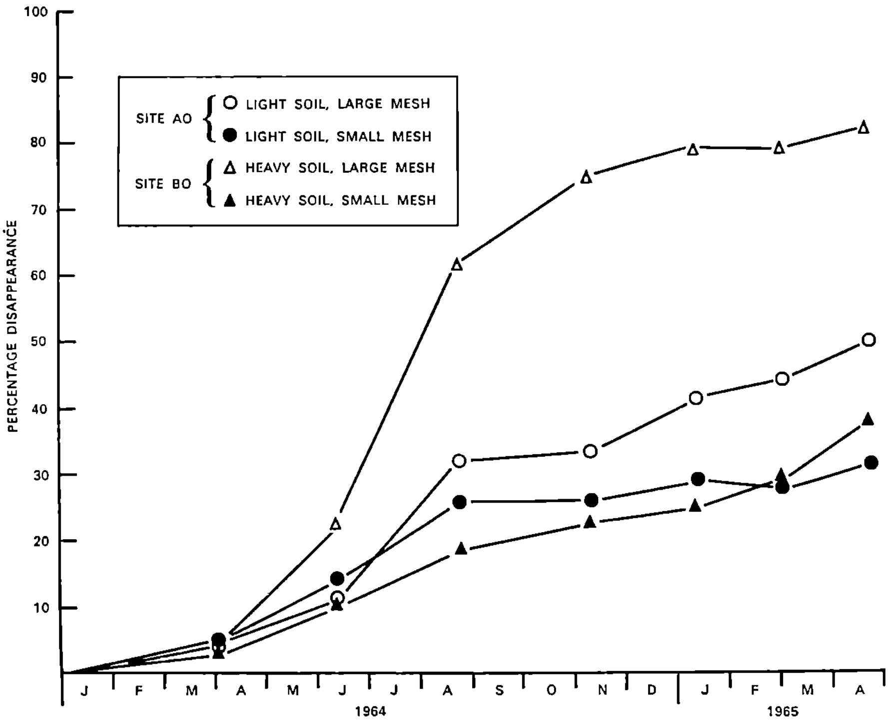

FIGURE 2. Disappearance of oak leaf discs in deciduous woodland.

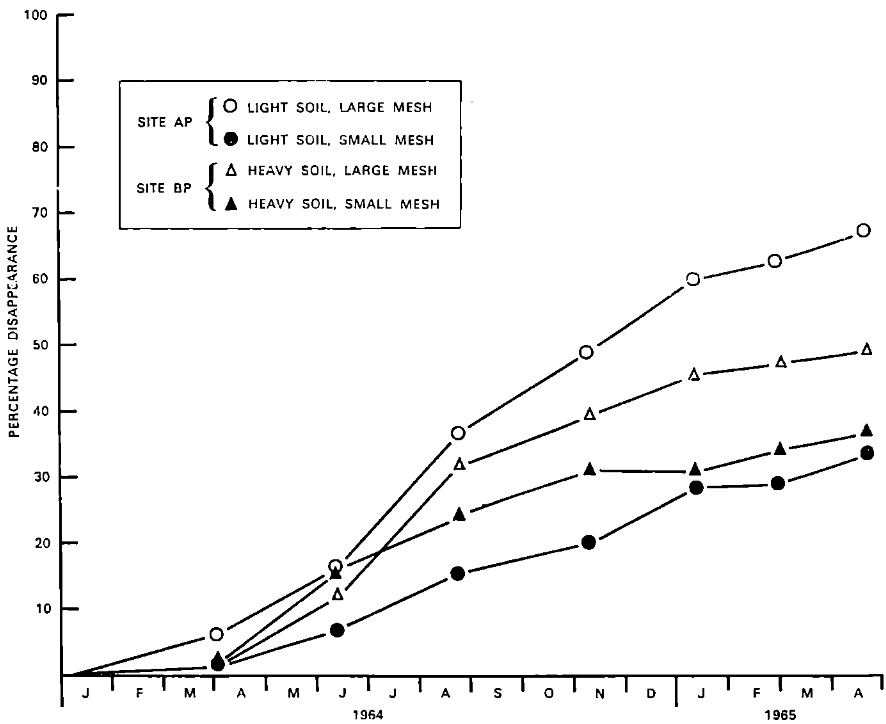

FIGURE 3. Disappearance of oak leaf discs in coniferous woodland.

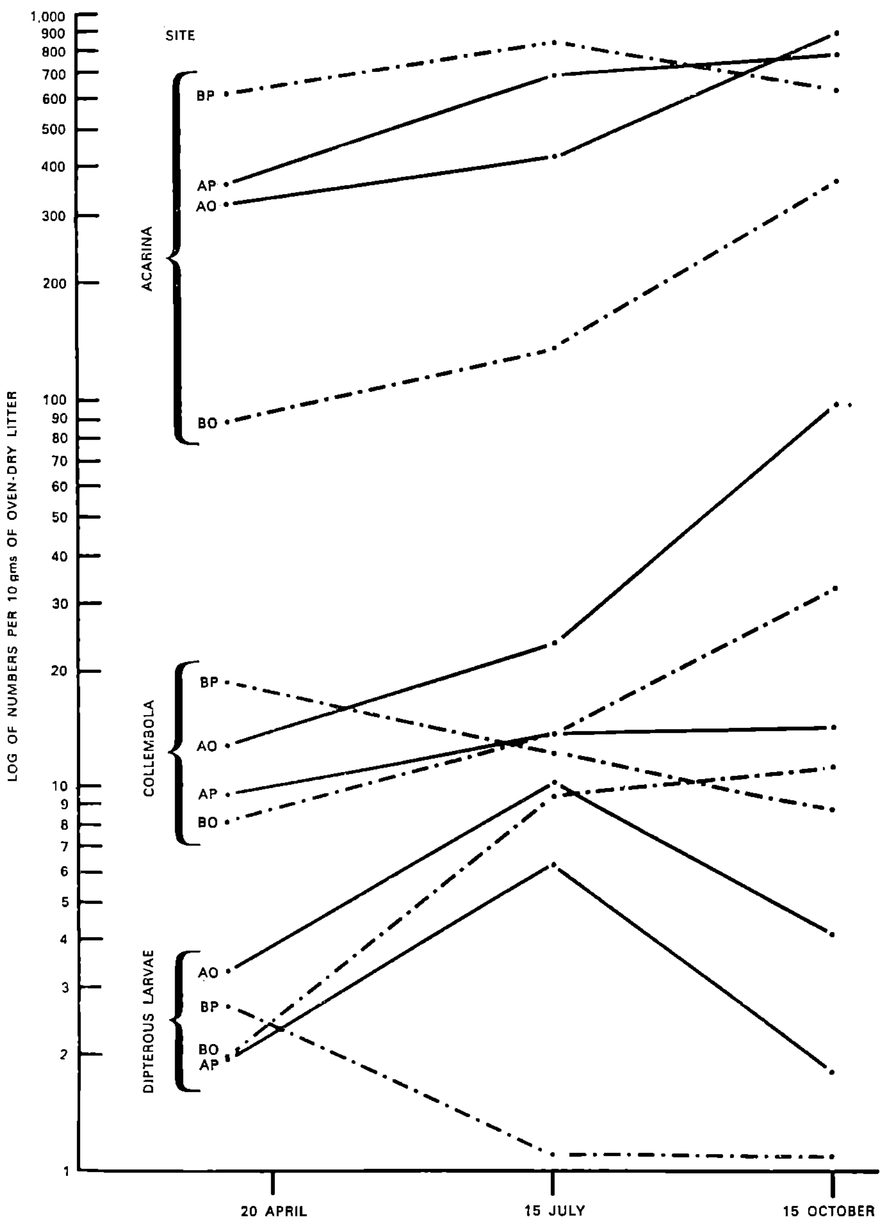

FIGURE 4. Soil arthropod populations on four woodland sites.

continued. In the coming year arthropod populations will be determined both as numbers per unit area and number per 10 gms. of litter in an attempt to overcome the difficulties encountered on the BO site.

SUMMARY

Oak leaf discs have been buried in nylon mesh bags in oak woodland on both light, sandy and heavier clay soils. They have also been buried in coniferous woodlands on similar soils. Results are given to show the disappearance of the leaf disc lamina, and the soil animal populations found. Disappearance of discs is fastest on the heavier soil carrying oak woodland. The greater population of earthworms on this site is thought to be the reason for this.

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STUDIES ON THE MYCOLOGY OF SCOTS PINE LITTER

By A. J. HAYES

Department of Forestry and Natural Resources, Edinburgh University

In October, 1964, the writer was appointed to the staff of the University of Edinburgh, and therefore relinquished the Forestry Commission Research Assistantship.

During the last six months of the tenure of this appointment, the examination of the microdistribution of fungi on Scots pine litter in the Black Wood of Rannoch was continued. Samples were taken from a single defined block within the experimental area, four feet by two feet in size. One square was sampled each week, so that the whole block was sampled once every two months. This examination confirmed the findings published in the 1964 *Report on Forest Research* (p.102). *Phoma humicola*, now assigned by the Commonwealth Mycological Institute to the genus *Graphium* was found to occupy a dominant position on newly fallen litter. (Table 28).

Table 28

PERCENTAGE OF SAMPLES CONTAINING ONLY GRAPHIUM SPECIES

February 1964	April 1964	June 1964	August 1964	October 1964*	December 1964
22	5	20	7	40	7

* = Recruitment of newly fallen litter.

The *Graphium* species is still comparatively common, but is accompanied by *Trichoderma viride*. Isolated samples containing *Verticicladium trifidum* were found in the first four months after needle-fall, but the incidence of this species did not show an appreciable increase until the sixth month.

There was some suggestion of competition between *Penicillium funiculosum* and *Trichoderma viride*, since the number of occasions on which the two species were present in the same sample was small, compared with the number of occasions on which each species was found occurring separately. Since both species occur frequently in litter taken from the Black Wood, it might have been expected that both species would occur in the same sample. (Table 29).

Table 29

OCCURRENCE OF PENICILLIUM FUNICULOSUM AND TRICHODERMA VIRIDE

	Square 1			Square 2		
	P. funic. + T. viride	P. funic.	T. viride	P. funic. + T. viride	P. funic.	T. viride
Number of isolations	1	24	21	6	41	18

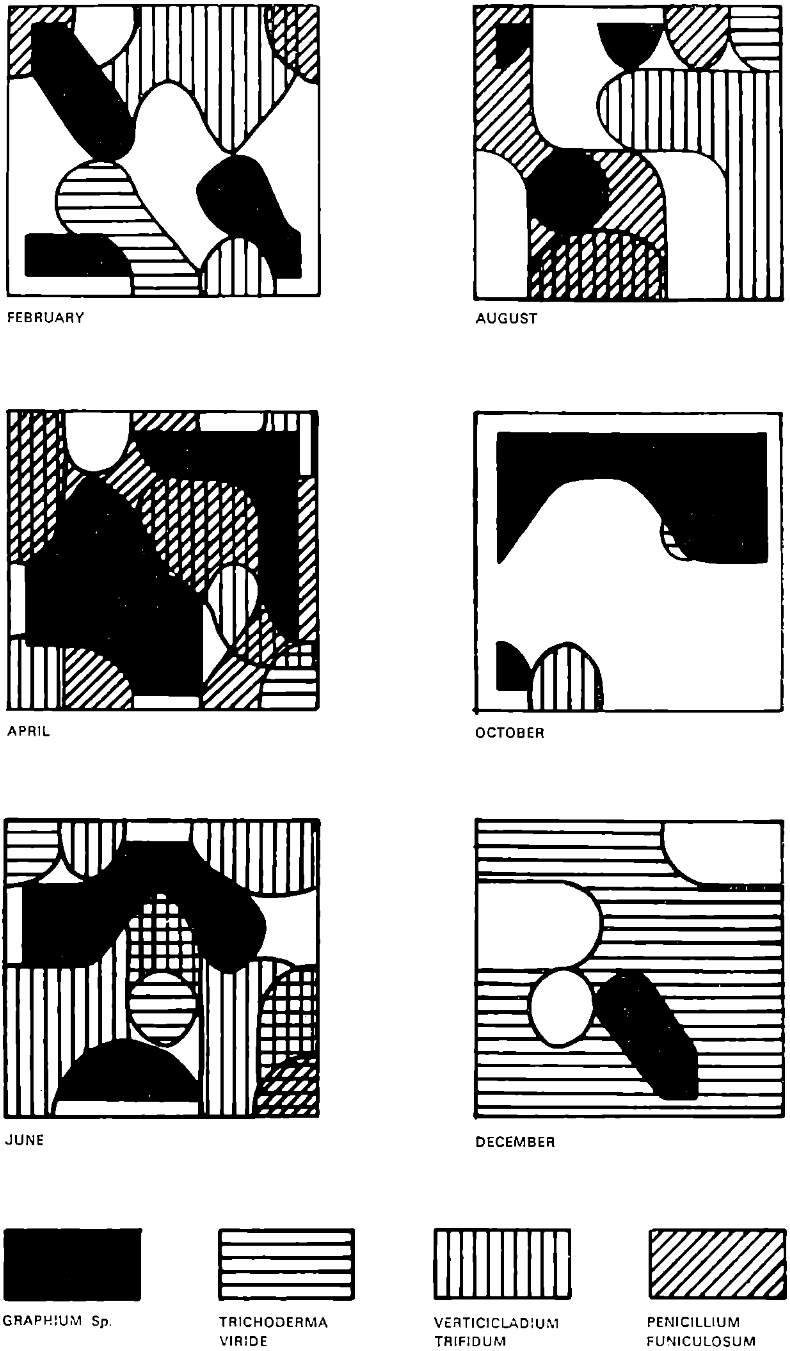

FIGURE 5. Changes in distribution of four common fungal species through 1964. (October diagram shows recruitment of newly-fallen litter.)

Unfortunately, there has not yet been time to test this hypothesis, but it is hoped to do so in the near future. A series of 'in vitro' controlled growth experiments, using different proportions of each species, would undoubtedly clarify their competitive ability. The changes in species composition and distribution throughout the period of sampling may be seen in fig. 5.

Physiological Studies

Preliminary examinations of the rate of oxygen uptake by certain selected fungi, using various sugars and amino acids as substrates, have been made, and it is hoped to extend these studies very considerably over the next year.

Turbidimetric studies on growth rates of the common fungi *Graphium sp.*, *Aureobasidium (Pullularia) pullulans*, *Penicillium funiculosum*, *P. spinulosum*, *Trichoderma viride*, *Mucor hiemalis*, *Verticicladium trifidum*, *Geotrichum candidum* and *Pachybasium hamatum*, have been continued, using certain sugars and amino acids as substrates. These indicate that where mycelium of these fungi has been previously grown on sugars, there is a relatively long lag phase before either aspartic acid or amino-butyric acid (two of the more common pine needle amino-acids) are utilised. In contrast, if the previous substrate was an amino-acid, little or no lag in uptake occurred, suggesting that induction of the necessary enzymes must occur before amino-acids can be utilised. An examination of the culture media for organic intermediates is also in progress.

Graphium sp., *Mucor hiemalis* and *Trichoderma viride* were all found to grow freely on the following sugars:—

	Hexoses		*Pentoses*
Monosaccarides	Disaccharides	Trisaccharides	
Glucose	Sucrose	Raffinose	Xylose
Fructose	Lactose		Rhamnose
	Maltose		

Verticicladium trifidum, however, was apparently unable to grow freely on glucose and sucrose, which may explain, in part, the fact that this species does not appear until a later stage in the succession.

CHEMICAL CHANGES IN FOREST LITTER: FOURTH REPORT, MAY 1965

By J. TINSLEY and A. A. HUTCHEON

Department of Soil Science, Aberdeen University

The aims of this study and the design of the field experiments under Scots Pine at Bramshill Forest, Hampshire, involving the application of urea, ammonium sulphate and ammonium phosphate as sources of nitrogen, with and without liming, were stated in the first report by Tinsley and Hance (1962). Some results of the analysis of samples from the experimental plots, and of drainage waters from the microlysimeters, were presented in the second and third reports by Tinsley and Lennox (1963) and Tinsley (1964). Sampling and analysis will be continued until the Autumn 1965, and the full results will be presented in the final report.

The present report is concerned with the composition of the organic matter passing the 2 mm. sieve, and with the humified portion of it soluble in anhydrous formic acid. This work has been conducted by Mr. A. A. Hutcheon since his appointment as research assistant from October 1st, 1964.

Analysis of Samples from Experimental Plots

As stated in the second and third reports, the litter samples taken at six monthly intervals were dried and then screened on a 2 mm. sieve to remove undecomposed needles, cones and twigs. The sieved material contained from 67 to 79 per cent of organic matter, while the nitrogen content varied surprisingly little from a mean value of about 1·5 per cent of the organic matter, calculated on an ash-free basis.

It was decided to compare the carbohydrate content of the sieved organic matter from the N_0, N_1 and N_3, but *not* the N_2, treatments since it appeared likely that the different fertilizer and liming treatments would affect the microflora in the litter and so influence the humification processes. 10 mg. samples of finely ground material were each hydrolysed by heating with 5 ml. of 3N sulphuric acid in a sealed tube for 12 hours at 100° C. After neutralising the hydrolysate with barium carbonate, the total reducing sugars brought into solution were determined by a colorimetric copper-arseno-molybdate method as described by Parsons and Tinsley (1961).

The results presented in Table 30 show the overall mean reducing sugar content was 9·17 per cent of the organic matter, calculated on an ash-free basis. There appears to have been a steady rise, during the two years interval, between the autumn samplings in 1962 and 1964. The two spring samplings show a mean value of 8·87, which is distinctly lower than the value of 9·47 for the mean of the three autumn samples, though the statistical significance of this difference has not yet been calculated. The most striking feature is that there appears to be no difference of any consequence in the reducing sugar content, due either to the rates or the forms of nitrogen applied, but liming seems to have encouraged the accumulation of carbohydrate material. The overall mean of the five samplings from the unlimed plots was 8·98, and from the limed plots 9·48 per cent, but the statistical analysis must await the results of the final sampling in the autumn of 1965.

Extraction of Samples with Anhydrous Formic Acid

In order to compare in more detail the chemical composition of the organic matter from the plots, all samples from the N_0, N_1 and N_3 treatments up to the autumn 1964 have so far been extracted with formic acid-acetyl acetone mixture, according to the procedure outlined by Tinsley and Lennox (1963).

The yields of organic matter recovered from the formic acid extracts by precipitation with five volumes of di-isopropyl ether containing 1 per cent v/v acetyl chloride, are recorded in Table 31. These results show an overall mean yield of 23·08 per cent of the organic matter, with very little difference due to rate or form of nitrogen applied, or to liming. The only difference worthy of note is in the slightly lower yields from the 1963 autumn samples of the plots that had received nitrogen applications in the spring of 1962.

Composition of Material Extracted with Formic Acid

Besides determining the ash and total nitrogen contents of these materials, small samples have been hydrolysed with 3N sulphuric acid for the determination of total reducing sugars as described above; others with 6N hydrochloric acid for the determination of total α amino acids by the ninhydrin reaction and of the amino sugar contents as described by Parsons and Tinsley (1961).

The results for total nitrogen on an ash-free basis are presented in Table 32, for reducing sugars in Table 33, for amino acid nitrogen expressed as a percentage of the total nitrogen content in Table 34, and for amino sugar nitrogen expressed in the same way in Table 35

The mean nitrogen content of the organic matter extracted with formic acid is 2·74 per cent; it shows little variation due to the rates or forms of nitrogen applied, or to time of sampling, but the mean value from the limed plots is slightly lower than from the unlimed plots, the values being 2·69 and 2·79 per cent respectively—though this difference may not be significant. However, the important point is that the nitrogen content of the extracted material is appreciably higher than the value of 1·5 per cent in material before extraction, indicating that the more highly humified material with a narrower C:N ratio has been dissolved by the formic acid extraction.

The mean reducing sugar content of the extracted material is 12·92 per cent, compared with 9·17 per cent in the material before extraction, indicating an enrichment of the humified material in carbohydrate. But it should be noted that this is probably different in composition, being soluble in formic acid, because wood cellulose is known not to dissolve to any appreciable extent. For this reason it is intended to examine the pattern of the component sugars in the respective hydrolysates, either by paper chromatography, or by gas chromatography methods.

The most striking feature of the results is the much higher carbohydrate content of the organic matter extracted from the limed plot samples, compared with the unlimed, the mean values being 14·85 and 10·99 per cent respectively. These results emphasise the trend shown by the reducing sugar contents of the unextracted materials, and suggest a greater microbiological synthesis of carbohydrate in the humification processes operating after liming.

Table 34 shows that the α amino nitrogen contents of the extracted material represent about two-thirds of the total nitrogen, with no very marked difference due to rates or forms of nitrogen applied, or to liming, but the values for the spring samples are definitely higher than those of the autumn samples, the mean values being 68·69 and 56·43 per cent respectively.

These results for the α amino nitrogen are complemented to some extent by those for the amino sugar nitrogen contents shown in Table 35. The overall mean value is 2·64 per cent of the total nitrogen in the extracted materials. The mean values for the unlimed treatments and the autumn samples are generally somewhat higher, and those for the limed treatments and spring samples are mostly lower, though some of the analyses need to be checked before final conclusions are drawn.

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Table 30

COMPOSITION OF ORGANIC MATTER PASSING 2MM. SIEVE

Percentage Yields of Reducing Sugar Hydrolysed by Sulphuric Acid

(*a*) **Autumn Samples**

Year	Lime	N_0	Urea N_1 50 lb/acre	Urea N_3 200 lb/acre	Ammonium sulphate N_1 50 lb/acre	Ammonium sulphate N_3 200 lb/acre	Ammonium phosphate N_1 50 lb/acre	Ammonium phosphate N_3 200 lb/acre	Mean
1962	L_0	8·67	11·05	7·28	7·63	7·57	9·37	7·90	8·50
	L_1	7·94	9·49	7·65	8·72	6·27	8·10	7·10	7·90
1963	L_0	9·61	9·44	9·75	7·55	10·06	10·32	9·66	9·48
	L_1	10·64	7·70	10·07	11·89	9·23	10·26	10·05	9·98
1964	L_0	9·51	9·17	10·19	11·56	10·51	9·54	9·15	9·95
	L_1	9·18	11·31	12·54	12·00	10·87	10·26	10·99	11·02
Mean		9·26	9·69	9·58	9·89	9·09	9·64	9·14	9·47

(*b*) **Spring Samples**

Year	Lime	N_0	Urea N_1 50 lb/acre	Urea N_3 200 lb/acre	Ammonium sulphate N_1 50 lb/acre	Ammonium sulphate N_3 200 lb/acre	Ammonium phosphate N_1 50 lb/acre	Ammonium phosphate N_3 200 lb/acre	Mean
1963	L_0	8·79	9·73	7·76	8·49	8·06	6·61	7·56	8·14
	L_1	9·50	8·55	8·36	9·68	9·63	9·09	8·36	9·02
1964	L_0	9·43	7·19	9·27	10·52	10·37	9·00	6·00	8·83
	L_1	10·32	9·30	9·94	7·64	10·85	9·90	8·42	9·48
Mean		9·51	8·69	8·83	9·08	9·73	8·68	7·59	8·87

Unlimed: Mean 8·98
Limed: Mean 9·48
Overall Mean 9·17

Table 31

COMPOSITION OF ORGANIC MATTER PASSING 2MM. SIEVE

Mean Percentages extracted by Formic Acid

(a) Autumn Samples—Unlimed

			Urea		Ammonium sulphate		Ammonium phosphate		
Year	Block	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1962	I	20·94	26·70	27·37	24·59	21·23	23·05	27·32	24·46
	II	22·95	29·16	22·78	27·09	26·79	25·36	20·68	24·97
Mean		21·90	27·93	25·08	25·84	24·01	24·21	24·00	24·72
1963	I	24·28	20·10	18·47	17·77	23·22	20·99	16·87	20·24
	II	24·74	14·93	25·39	15·64	19·50	18·62	20·71	19·93
Mean		24·51	17·52	21·93	16·71	21·36	19·81	18·79	20·09
1964	I	23·40	23·13	21·39	23·50	23·28	23·01	21·81	22·79
	II	24·07	22·96	20·91	23·46	23·03	20·99	23·59	22·72
Mean		23·74	23·05	21·15	23·48	23·16	22·00	22·70	22·76
Treatment Means		23·58	22·83	22·72	22·01	22·84	22·00	21·83	
			22·78		22·43		21·91		

Block Means I 22·50
II 22·54
Overall Mean 22·52

(b) Autumn Samples—Limed

			Urea		Ammonium sulphate		Ammonium phosphate		
Year	Block	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1962	I	22·27	33·03	17·23	29·81	24·73	23·75	23·25	24·87
	II	24·59	17·41	24·87	27·60	33·70	18·29	23·78	24·32
Mean		23·43	25·22	21·05	28·71	29·22	21·02	23·52	24·60
1963	I	25·91	17·44	19·35	20·28	23·09	19·63	21·12	20·97
	II	23·08	26·72	20·18	18·93	13·26	36·89	19·85	22·70
Mean		24·50	22·08	19·77	19·61	18·18	28·26	20·49	21·84
1964	I	23·52	24·67	26·29	23·15	25·66	23·53	23·78	24·37
	II	24·81	21·98	23·73	22·55	26·48	24·00	24·63	24·03
Mean		24·17	23·33	25·01	22·85	26·07	23·77	24·21	24·20
Treatment Means		24·03	23·54	21·94	23·72	24·29	24·35	22·74	
			22·74		24·00		23·55		

Block Means I 23·40
II 23·68
Overall Mean 23·52

Table 31 (*contd.*)

COMPOSITION OF ORGANIC MATTER PASSING 2MM. SIEVE

Mean Percentages extracted by Formic Acid

(c) Spring Samples—Unlimed

		Urea		Ammonium sulphate		Ammonium phosphate		
Year Block	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1963 I	24·37	23·69	21·36	22·85	24·01	22·34	23·35	23·14
II	24·73	24·42	22·80	21·96	23·39	22·11	24·62	23·43
Means	24·55	24·06	22·08	22·41	23·70	22·23	23·99	23·29
1964 I	23·49	17·88	22·90	23·71	23·16	24·86	21·22	22·46
II	25·46	19·24	22·58	22·73	23·37	24·31	25·14	23·26
Means	24·48	18·56	22·74	23·22	23·27	24·58	23·18	22·86
Treatment Means	24·51	21·31	22·41	22·81	23·48	23·41	23·58	
		21·86		23·15		23·50		

Block Means I 22·80
II 23·35
Overall Mean 23·08

(d) Spring Samples—Limed

		Urea		Ammonium sulphate		Ammonium phosphate		
Year Block	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1963 I	25·01	23·99	21·84	23·91	22·18	22·66	22·60	23·17
II	25·05	25·27	22·96	24·78	25·06	23·78	22·97	24·27
Means	25·03	24·63	22·40	24·35	23·62	23·22	22·79	23·72
1964 I	22·91	22·28	23·01	19·71	23·39	23·32	22·01	22·38
II	24·24	23·52	22·54	22·92	21·77	21·18	22·10	22·61
Means	23·58	22·90	22·78	21·32	22·58	22·25	22·06	22·50
Treatment Means	24·30	23·77	22·59	22·83	23·10	22·74	22·42	
		23·18		22·97		22·58		

Block Means I 22·78
II 23·44
Overall Mean 23·11

Table 32

COMPOSITION OF ORGANIC MATTER EXTRACTED BY FORMIC ACID

Nitrogen Content as Percentage Ash-Free Material

(a) Autumn Samples

			Urea		Ammonium sulphate		Ammonium phosphate		
Year	Lime	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1962	L_0	2·96	2·73	2·68	2·81	2·74	2·78	2·84	2·79
	L_1	2·68	2·60	2·73	2·71	2·62	2·64	2·78	2·68
1963	L_0	2·81	2·66	2·50	2·81	2·75	2·61	2·84	2·71
	L_1	2·68	2·58	2·55	2·63	2·65	2·52	2·87	2·64
1964	L_0	2·86	2·86	2·94	2·94	2·95	3·02	3·08	2·95
	L_1	2·82	2·58	2·56	2·86	2·78	2·48	2·85	2·70
Mean		2·80	2·67	2·66	2·79	2·77	2·68	2·88	2·75

(b) Spring Samples

1963	L_0	3·03	2·87	2·81	2·79	2·55	2·78	2·89	2·82
	L_1	2·64	2·59	2·77	2·61	2·90	2·66	2·85	2·72
1964	L_0	2·78	2·61	2·57	2·70	2·75	2·64	2·86	2·70
	L_1	2·59	2·61	2·75	2·89	2·65	2·56	2·80	2·69
Mean		2·76	2·67	2·73	2·75	2·71	2·66	2·85	2·73

Unlimed: Mean 2·79
Limed: Mean 2·69
Overall Mean 2·74

Table 33

COMPOSITION OF ORGANIC MATTER EXTRACTED BY FORMIC ACID

Percentage Yields of Reducing Sugar Hydrolysed by Sulphuric Acid

(a) Autumn Samples

			Urea		Ammonium sulphate		Ammonium phosphate		
Year	Lime	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1962	L_0	9·69	10·77	10·61	11·46	11·17	8·70	10·71	10·44
	L_1	11·45	16·96	15·86	15·46	17·57	19·07	16·67	16·15
1963	L_0	8·88	10·27	10·99	9·25	9·72	11·09	9·62	9·97
	L_1	11·44	15·54	13·14	14·29	15·26	17·01	15·09	14·54
1964	L_0	9·15	8·07	8·93	11·30	7·70	10·60	8·12	9·12
	L_1	10·05	15·24	12·78	12·88	14·77	14·05	14·39	13·45
Mean		10·11	12·81	12·05	12·44	12·70	13·42	12·43	12·28

(a) Spring Samples

1963	L_0	13·68	13·59	13·62	13·53	13·74	13·25	15·69	13·87
	L_1	14·29	15·98	14·60	15·31	18·98	17·99	16·48	16·23
1964	L_0	13·59	9·21	11·75	12·23	12·95	12·51	9·74	11·71
	L_1	14·96	15·06	15·03	13·16	14·17	15·28	13·61	14·55
Mean		14·13	13·61	13·75	13·56	14·97	14·76	13·63	14·06

Unlimed: Mean 10·99
Limed: Mean 14·85
Overall Mean 12·92

Table 34

COMPOSITION OF ORGANIC MATTER EXTRACTED BY FORMIC ACID

Amino Acid Nitrogen as Percentage of Total Nitrogen

(a) Autumn Samples

Year	Lime		Urea		Ammonium sulphate		Ammonium phosphate		
		N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1962	L_0	57·10	58·61	54·48	55·88	51·83	53·60	47·20	54·10
	L_1	47·40	59·24	63·70	61·25	57·26	57·20	62·23	58·33
1963	L_0	51·30	59·76	58·00	58·37	55·64	57·10	56·35	56·65
	L_1	63·10	60·50	54·13	60·10	62·65	57·15	57·50	59·30
1964	L_0	54·90	55·26	55·44	53·74	56·61	54·97	54·55	55·07
	L_1	48·90	58·20	58·90	54·20	48·93	62·50	54·04	55·10
Mean		53·80	58·60	57·44	57·26	55·49	57·09	55·31	56·43

(b) Spring Samples

Year	Lime	N_0	Urea N_1	Urea N_3	Ammonium sulphate N_1	Ammonium sulphate N_3	Ammonium phosphate N_1	Ammonium phosphate N_3	Mean
1963	L_0	68·33	74·23	69·77	71·33	75·70	70·50	86·20	73·58
	L_1	69·70	62·57	63·54	70·90	67·38	66·94	69·50	67·22
1964	L_0	75·20	67·10	69·27	74·10	65·82	55·70	63·30	67·21
	L_1	58·70	77·02	68·74	54·70	71·34	69·54	66·10	66·59
Mean		67·98	70·23	67·83	67·76	70·06	65·67	71·28	68·69

Unlimed: Mean 61·32
Limed: Mean 61·31
Overall Mean 61·32

Table 35

COMPOSITION OF ORGANIC MATTER EXTRACTED BY FORMIC ACID

Amino Sugar Nitrogen as Percentage of Total Nitrogen

(a) Autumn Samples

			Urea		Ammonium sulphate		Ammonium phosphate		
Year	Lime	N_0	N_1	N_3	N_1	N_3	N_1	N_3	Mean
1962	L_0	2·31	3·44	3·10	3·10	2·88	3·89	3·13	3·12
	L_1	0·81	3·07	2·93	2·84	3·38	2·72	2·15	2·56
1963	L_0	2·31	3·20	3·36	2·95	2·36	2·95	2·71	2·83
	L_1	1·89	3·17	1·82	2·73	2·56	1·88	2·54	2·37
1964	L_0	2·76	2·69	2·93	3·06	3·09	3·71	2·63	2·98
	L_1	1·56	2·43	3·93	1·88	2·19	4·10	1·86	2·56
Mean		1·94	3·00	3·01	2·76	2·74	3·21	2·50	2·74

(b) Spring Samples

1963	L_0	2·11	2·32	2·05	1·67	2·73	2·21	2·00	2·16
	L_1	2·67	2·27	1·91	2·31	1·74	1·16	2·68	2·11
1964	L_0	3·62	2·90	2·21	2·86	2·45	2·50	1·38	2·56
	L_1	2·51	3·45	3·23	2·74	3·95	2·73	2·94	3·08
Mean		2·73	2·74	2·35	2·40	2·72	2·15	2·25	2·48

Unlimed: Mean 2·73
Limed: Mean 2·54
Overall Mean 2·64

WATER RELATIONS OF TREES AND FORESTS

By L. LEYTON, E. R. C. REYNOLDS and F. B. THOMPSON

Department of Forestry, Oxford University

The Water Balance of a Forest Stand

As stated in previous *Reports*, one of the aims of this research programme is to make a quantitative study of certain physical and biological factors operating in the hydrological balance of forests.

The field work has been largely carried out in a Norway spruce stand planted in 1942 in Bagley Wood near Oxford. Following a number of years studies on the original unthinned stand, mainly devoted to the development of suitable techniques, investigations have begun to determine the effect of thinning on various phases of the hydrological cycle. Particular attention has been paid to interception, throughfall and stemflow. In the winter of 1963–64, the stand was thinned to a uniform basal area of about 105 square feet, quarter-girth measure per acre. Four sub-plots each 70 feet × 70 feet were marked out and measurements of these quantities continued for a year as a test of uniformity. In the winter of 1964/65, two of the sub-plots were further thinned to a basal area of about 80 square feet per acre and measurements have been continued.

Throughfall is measured by randomly-placed troughs and annular stem gauges (to sample regions immediately around the tree stems). The troughs are fitted with individually-calibrated fibre glass tipping buckets, and their catches are recorded automatically on Post Office counters actuated by mercury switches; this system appears to be working very satisfactorily. Rainfall is measured by two Nipher shielded gauges mounted above the canopy, supplemented by standard gauges and by a Dines recording gauge situated in a nearby open area.

Studies are continuing on the application of the heat-flow technique for determining sap-flux in tree stems, and ultimately transpiration losses. A number of tests have been made in which short heat pulses were automatically applied at selected time intervals, and the course of the temperature difference between thermojunctions, mounted on either side of the heater, was recorded on a multipoint recording millivoltmeter.

On the whole this technique has given quite consistent results, but in order to obtain an accurate calibration in terms of absolute values, a more rigorous mathematical analysis of the temperature difference curves has proved necessary; observations of a variable time-lag between sap-flux and transpiration rates indicate that allowance must also be made for this lag factor if the method is to be of practical value in the field.

The current method of measuring transpiration rates via changes in the moisture content of air passed through a plastic bag surrounding the crown, though giving apparently reliable results, has not proved particularly well suited to routine practice. A new method is being introduced in which a closed circulatory system is used and the moisture transpired from the crown into the bag is condensed by a specially built refrigerator unit installed within the system; with control of temperature and humidity, this should allow for continuous and direct measurements of water losses from the crown.

Evidence is accumulating that substantial losses of water from a stand may occur as a result of the relatively rapid rate of evaporation of water intercepted by tree crowns. It is intended to study the energy relations involved in this process by measurements of net radiation. In order to allow for the heterogeneous nature of the canopy, a net radiometer has been installed at the end of a boom which rotates over the canopy, describing a circle 24 feet in diameter at 1 revolution per minute; the output from the radiometer is recorded on a recording milliammeter. Trials of this method are currently in progress.

Some studies have begun on the penetration of drainage water into the soil, to complement other investigations on soil moisture in relation to the hydrological cycle. Of a number of fluorescent dyes tested, pyranine has proved most suitable for tracing drainage patterns. This dye can be detected in the soil several weeks after application, and its distribution on the face of a pit can be recorded photographically in ultra-violet light. Preliminary trials have emphasized the unwettability of raw humus after a dry summer, and the localized penetration of rainwater in the region of tree trunks and bracken fronds, where stemflow occurs.

Depletion of Soil Moisture by Tree Roots

It has usually been argued that the relatively high water consumption of forest trees in comparison with grasses or herbs, as suggested by catchment experiments, is due to the generally deeper rooting habits of trees. Little is known however, about the relative effectiveness of different parts of a given root system in water uptake from the soil. In planning investigations designed to obtain more information on this problem, attention has first been directed to developing methods for sampling and describing root systems which best characterise their functions in this respect. In preliminary trials in a Douglas fir stand planted in 1929, random samples were taken at different points below the crowns by a specially constructed volumetric soil sampler (4·5 cm. diameter, 15 cm. deep). Roots were separated using an automatic washing apparatus specially constructed for the purpose. Relatively high concentrations of fine roots were confined to regions immediately adjacent to the stems and below the outer portions of the crowns, although areas of relatively sparse rooting could be found at any point between the trees. Investigations are continuing to determine how far this pattern of root distribution corresponds with the pattern of throughfall below the stand.

In order to obtain information on the extent of soil moisture depletion by different parts of the root system, methods have been sought which would indicate the micro-distribution of water in the soil around roots. A number of techniques have been examined including *in situ* determinations of freezing point, 'natural' osmometers (*Xanthium* seed), uptake by various porous materials —filter papers, powders, and glass beads—brought into contact with the soil, and the colour change of a double salt of mercury and silver in gelatine emulsion (Sivadjan's hygrophotographic method): the results of these trials are now being assessed.

Interception by Vegetative Covers Other Than Trees

For the unthinned Norway spruce stand in Bagley Wood, on the average almost 30 per cent of the annual rainfall fails to reach the ground (Reynolds and Leyton, 1963); interception values of up to 50 per cent have been quoted in the literature for other stands, under varying rainfall conditions. If, as has already been suggested, the rate of evaporation of water intercepted by trees far exceeds that of transpiration under the same environmental conditions, then interception would represent a substantial net loss in the supply of water to the soil. In the context of land use in catchments and water yields however, the effect of a forest cover must be judged in comparison with the corresponding behaviour of alternative vegetative covers, e.g. grasses or shrubs. In many cases interception values of the same order as those for forest stands have been quoted for such covers; on the other hand it would seem that, for grasses at least, losses due to the evaporation of intercepted water may be almost completely compensated by corresponding reductions in transpiration (Burgy and Pomeroy, 1958). Many more investigations on interception and evaporation are essential if a comparison is to be made between the hydrological effects of one vegetative cover and another.

Few relevant studies have been made on vegetative covers characteristic of catchment areas in Britain. Aranda and Coutts (1963) report similar values (on the average, 50–60 per cent) for the proportion of incident rainfall penetrating the canopies of Scots pine stands, Sitka spruce stands and heather cover in Aberdeenshire, but, since stemflow was not included, the comparison between these covers is not entirely satisfactory: furthermore, no information is available as to the rates of evaporation of the intercepted water. Comparisons between one cover and another are further complicated by the fact that values for interception are not unique for a particular cover, but vary in time with changes in the morphology and density of the cover, and with the intensity and duration of the rainfall. Much thought has been given to the possibility of developing a universal approach to the problem by a detailed analysis of the factors which are involved. Essentially interception by a plant cover is determined by two factors:

(1) The maximum amount of water that can be retained by the plants, the so-called maximum interception storage capacity.

(2) The interaction between vegetation and climate during rainfall (nature and intensity of rainfall, evaporative conditions) which determines, whether and at what rate, the storage capacity is satisfied.

Since the morphology and density of the plant cover are the most important vegetative characteristics which influence these factors, the problem may be dealt with by using a point quadrat approach, supplemented by observations of those morphological features that determine the efficiency with which water is retained. Because of the interaction, detailed observations on interception during individually-characterized storms are also essential.

Tests on the above approach have begun on three plant covers, heather (*Calluna*), Purple moor grass (*Molinia*) and bracken (*Pteridium*), growing near each other on moorland near Halifax (Yorks). For each of these species four plots, each 1 metre square, have been laid out, bordered by aluminium edging, and the soil surface has been smoothed by covering with sand, stabilized with a butadiene-styrene latex (Intex 100) and finally sealed with neoprene latex. Since with such relatively low growing vegetation any other scheme would be impractical, the aim is to determine interception from measurements of total throughfall and precipitation. The soil surface is therefore sloped gently (5°) to one corner of the plot where surface water flow is collected and led to the measuring system; the soil below is aerated by perforated polythene tubing laid within the sand. Figure 6 shows the general arrangement. A guard area, 30 cms. wide and surrounding each plot, has been similarly levelled and sealed

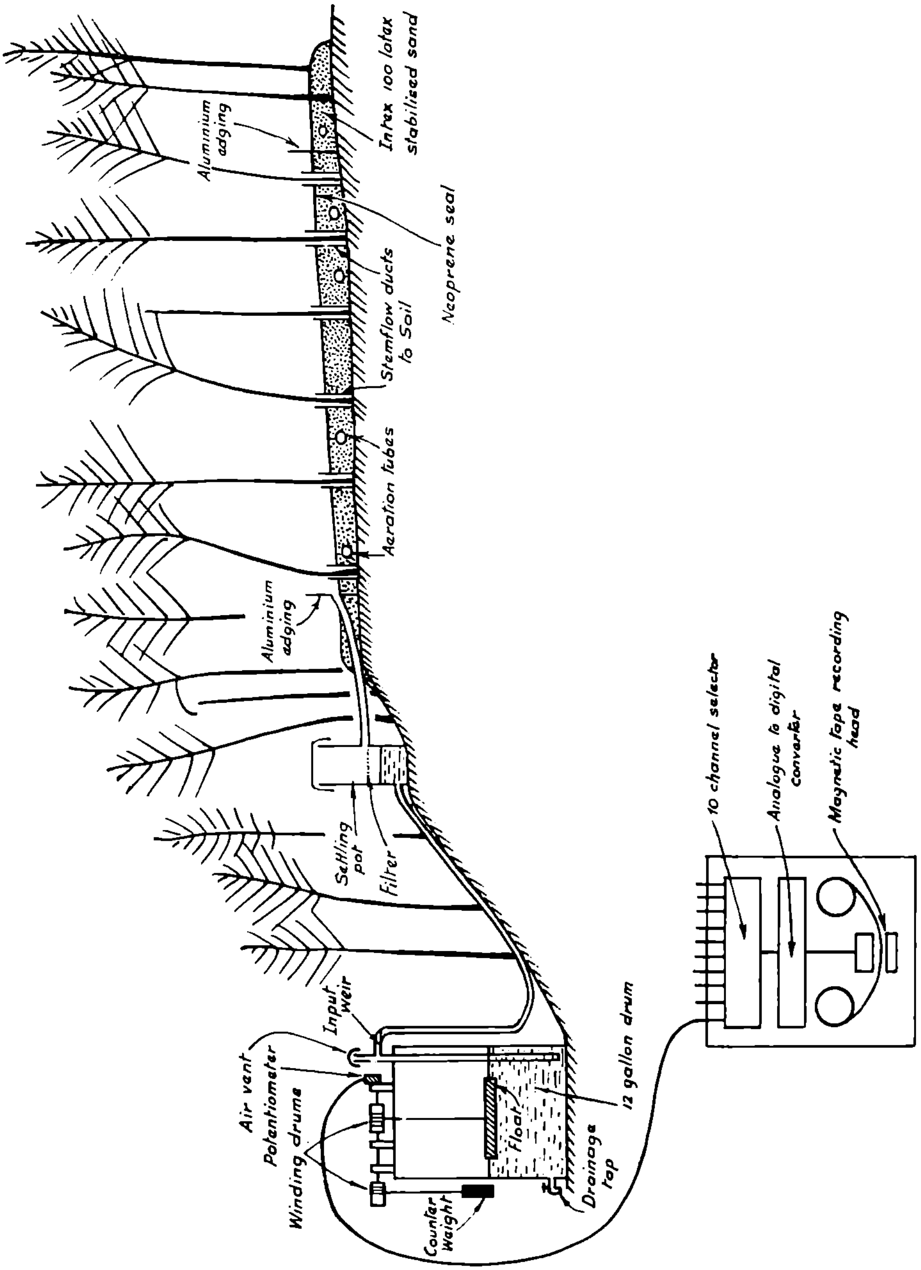

FIGURE 6. Bracken interception plot with stem flow ducts, measuring drum and magnetic tape recorder.

so as to allow for errors due to splash. In two plots of each cover, stemflow or clumpflow (in the case of *Molinia*) is led into the soil so that this quantity can be determined separately from differences between pairs of plots.

For routine determinations of interception, water yield from each plot is led into a 12-gallon drum fitted with a float which actuates a low torque potentiometer; with a constant voltage source, the potential drop across this resistance is proportional to the amount of water collected, and this is recorded at 3-minute intervals on the magnetic tape of a 10-channel 'Limpet Logger'. The system, which is entirely automatic in operation, is designed to record for 10 plots rates of water flow up to rainfall equivalents of almost 4 inches per hour, with a precision of ± ·002 inches.

The maximum interception storage capacity of each plot is determined under fairly uniform conditions, and at relatively high rainfall intensity, to reduce evaporative losses during wetting: measurements are made using artificial rain from a 25-nozzle spray rig, 1·6 metres square in area and mounted 1 metre above the vegetation. A number of measurements have already been made; for example, in November 1964, when the fronds were dead but still standing, the *Pteridium* plots were found to have a storage capacity of 0·05 inches (67–85 per cent cover); it is of interest that this is of the same order as values quoted for conifer stands (0·2–0·07 inches).

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EXPERIMENTS ON THE SPREAD OF FIRE

By P. H. THOMAS and MARGARET LAW

Ministry of Technology and Fire Offices' Committee
Joint Fire Research Organization
Boreham Wood, Herts.

The analysis of laboratory experiments referred to in previous *Reports* has shown that the rate of spread of fire in cribs of wood could be interpreted as due to the heating of the material ahead of the fire by radiation transmitted from the surfaces of the fuel already burning[1] and the same model appeared to be applicable[2] to the beds of pine needles studied by Curry and Fons[3] and more recently by Anderson and Rothermel[4]. McCarter and Broido[5] have since confirmed experimentally the relative unimportance of heat transfer from the flames above cribs.

The best estimate of the rate of spread of fire, R, for thin fuels, is:

$$R = \frac{k}{\rho_b}$$

where ρ_b is the bulk density of the fuel,
and k is approximately a constant (5 to 8 mg. cm.$^{-2}$ s^{-1}) over a wide range of specific surface and fuel bed porosity.

Since we may write:

$$\rho_b = w/h$$

where w is the amount of fuel per unit area of ground,
and h is the height of the fuel bed,
it follows that the rate of spread is proportional to the height of the fuel bed for a given fuel loading.

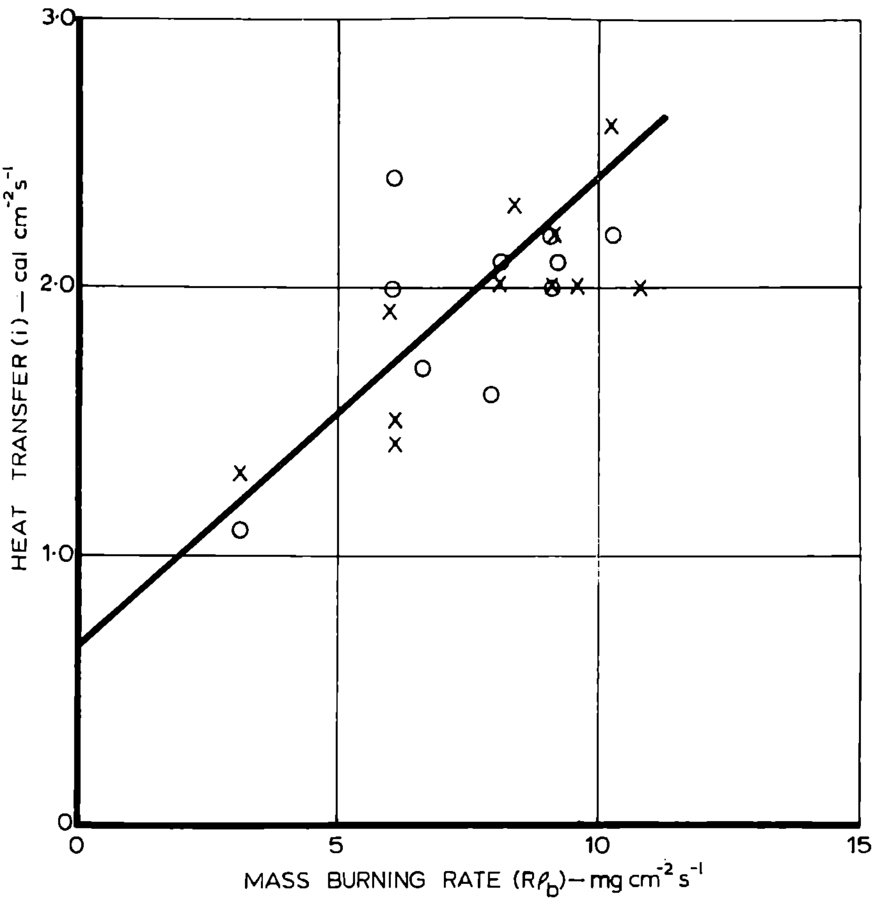
Heat Transfer Measurements

Values of the heat transfer calculated from the rate of spread of fire in cribs gave realistic values of 1 to 2 cal cm^{-2} s^{-1}; this has recently been confirmed by Simms and Wraight who made direct measurements of the heat transfer in burning cribs, using two calorimeters. The cribs were of $\frac{1}{4}$, $\frac{1}{2}$ and 1-inch wood sticks, the ratio of the horizontal spacing between the sticks to their thickness being 3 for the $\frac{1}{2}$ and 1-inch sticks, and 5 and 11 for the $\frac{1}{4}$-inch sticks. Measurements from both calorimeters are given in Fig. 7. One pair of results for a crib with every third stick replaced by an inert material (asbestos) is included. The straight line is a theoretical line for thin sticks expressing the heat balance for the unburnt material[1], namely:

$$R \rho_b \Delta H = i - a \alpha \theta \qquad (1)$$

where ΔH is the enthalpy rise of uniformly heated wood at the temperature of ignition by a pilot flame; it is taken here for a mean moisture content of 10 per cent as 180 cal/g.
i is the forward flux of heat.
α is the cooling coefficient taken as 8×10^{-4} cal cm^{-2} s^{-1} deg C^{-1}.
θ is the temperature rise to ignition $\simeq$ 300 deg C.
and a is a coefficient which allows for non-uniform direction of the radiation heating; it is taken here at a theoretical value of $2\frac{2}{3}$[1].

No allowance has been made in equation (1) for the fact that the surface of a thicker stick is hotter than its interior, so that ρ_b is an overestimate of the mass of wood heated. The agreement shown in Fig. 7 is therefore somewhat fortuitous at the upper end of the range corresponding to the thicker sticks.



X Disc calorimeter
O 'U' tube calorimeter

The theoretical line is $R\rho_b \, \Delta H = i - 2{\cdot}67\alpha\theta$

ΔH for nominal 10 per cent moisture content is 180 cal/g

$\alpha\theta$ is taken as 0·24 cal cm^{-2}s^{-1}

No account has been taken of the fact that the larger sticks are not thermally thin

FIGURE 7. Heat transfer rates in cribs.

Field Data

It is unrealistic to expect that fire spread in real vegetation, where the fuel conditions are not uniform, will be exactly the same as in idealised laboratory conditions, but the understanding gained from laboratory experiments will provide a framework for correlating field data, and to this end, a questionnaire was prepared to obtain information from the programme of controlled burning in the field during the early part of 1965. An analysis will be made of the data on fire spread, fuel loading etc., from the completed questionnaire.

Prior to this programme a number of radiometers, of the type developed at the Bush Fire Research Station in Australia(6), were made and calibrated in order to make direct measurements of the heat transfer in one of these fires.

In a controlled burn in gorse in the New Forest, Hampshire, the rates of spread of a 'backing fire' and a 'flank fire' were measured as the fire passed through two plots 40 feet × 20 feet and 50 feet × 75 feet in area respectively. A 'backing fire' is when the rear of a fire goes backwards against the wind. A 'flank fire' is when one side of a fire goes sideways, at right angles to the wind.

The value of k for the backing fire was within the range of the laboratory data. The bulk density of the unburnt fuel was used for ρ_b although some of the thicker stems were not burnt throughout.

Samples of the gorse were removed so that the proportions of fuel of various surface area could be measured. The highest radiation intensities recorded were about 0·9 cal cm^{-2} s^{-1} which is somewhat less than that measured in laboratory experiments on cribs.

As well as taking measurements of the radiation intensity, an approximate measure of the total amount of heat received at a particular place was obtained by measuring the temperature rise of water in cans distributed in the path of the fire. An estimate was made of the time the fire took to pass over these cans and from this a mean radiation of 1·1 cal cm^{-2} s^{-1} was calculated, which agreed satisfactorily with the direct measurements.

Heat Contribution of Flames Above the Fuel Bed

It has previously been shown (7) that the flame length L can be related to the burning rate, and a simple equation for a thin burning zone in still air is

$$L = \frac{47}{g}\left(\frac{gm}{\rho_a}\right)^{\frac{2}{3}}$$

where $m = R\rho_b h$ – the burning rate per unit width of fire front in a fuel bed of depth h,

g is the acceleration due to gravity,

and ρ_a is the density of air.

If L is in cm and m is in g cm^{-1} s^{-1}, $L/m^{\frac{2}{3}}$ is 400(8).

We thus obtain the ratio of the flame height to the height of the fuel bed as

$$\frac{L}{h} = \frac{47}{g}\left(\frac{gk}{\rho_a}\right)^{\frac{2}{3}}\frac{1}{h^{\frac{1}{3}}}$$

so that as fuel beds become deeper, the flame above the fuel bed is expected to be relatively *less* important as a source of heat compared with heat transferred through the fuel bed, and conversely *more* important as they become shallower.

If fire spreads through a particular fuel bed by means of radiation from the burning zone, with the flames above it not contributing a significant amount of heat, then it is to be expected that the same mechanism would obtain in deeper beds e.g., crown fires, at least in still air. But shallower ones such as layers of dried grass or pine needles might become controlled by heating from the flame above the fuel bed. Where radiation transfer through the fuel bed is the predominant source of heat to the unburnt fuel in still air, it is expected that in a light wind this radiation transfer would still be the main controlling process; in this connection it is interesting to consider some recent experiments made by Byram *et al*[9] on the effect of wind.

Effect of Wind

Byram[9], who is continuing the work started in America by the late Wallace Fons, and his collaborators, have measured the rates of fire spread through cribs of wood with winds ranging from 3 to 13 feet per second. The data all refer to 'one stick thickness,' namely, $\frac{1}{4}$ inch, but the stick spacing varied from $\frac{1}{2}$ to $4\frac{1}{2}$ inches, i.e. a variation in bulk density by a factor of 9. The length of the flames and their deflection ϕ from the vertical were recorded for each experiment.

It is customary in discussing flame propagation in gases to refer to the flame speed perpendicular to the flame front, and a similar speed $R \cos \phi$ can be defined for the spread of fire (see Fig. 8). Accordingly the results reported by Byram *et al* are re-plotted in Fig. 9 which shows that the mass rate of spread $R \rho_b \cos \phi$ is effectively constant for their experiments.

The data for 'still air' lie below the line in Fig. 9, which means that an extrapolation through the data for still air would tend to underestimate $R\rho_b$ at high wind speeds. This may well be due to an increase in the radiation level brought about by the higher wind speeds, but the effect is not unduly large in the range of these experiments. The use of the mass burning rate, which allows for the change in the bulk density, is seen to bring the data for different spacing together. No data are available for the inclination of the fire front in the fuel bed, as opposed to the inclination of the flames, but if these are assumed to be similar, then the above results can be interpreted as due to the radiation from the burning zone propagating the fire through the fuel bed at an angle ϕ to the horizontal, in the same way as horizontal propagation in still air.

Results obtained from earlier experiments with non-spreading fires[7] show that the inclination of the flames can be largely related to wind speed and the rate of burning. For a thin burning zone this takes the form:

$$\cos \phi \simeq 0{\cdot}7\, \Omega^{-0.49} \qquad (\Omega > 1)$$

where

$$\Omega = \frac{U}{\left[\dfrac{gR\rho_b h}{\rho_a}\right]^{\frac{1}{3}}}$$

and

U is the wind speed.

It is possible that this relationship is to some extent affected by the properties of the fuel bed, since these will largely control the air flow through it and hence the inclination of the convection currents and the radiation front. Nevertheless the combination of this approximate expression for $\cos \phi$, and the assumption that $R\rho_b \cos \phi$ is constant, would seem to be a useful first approximation for

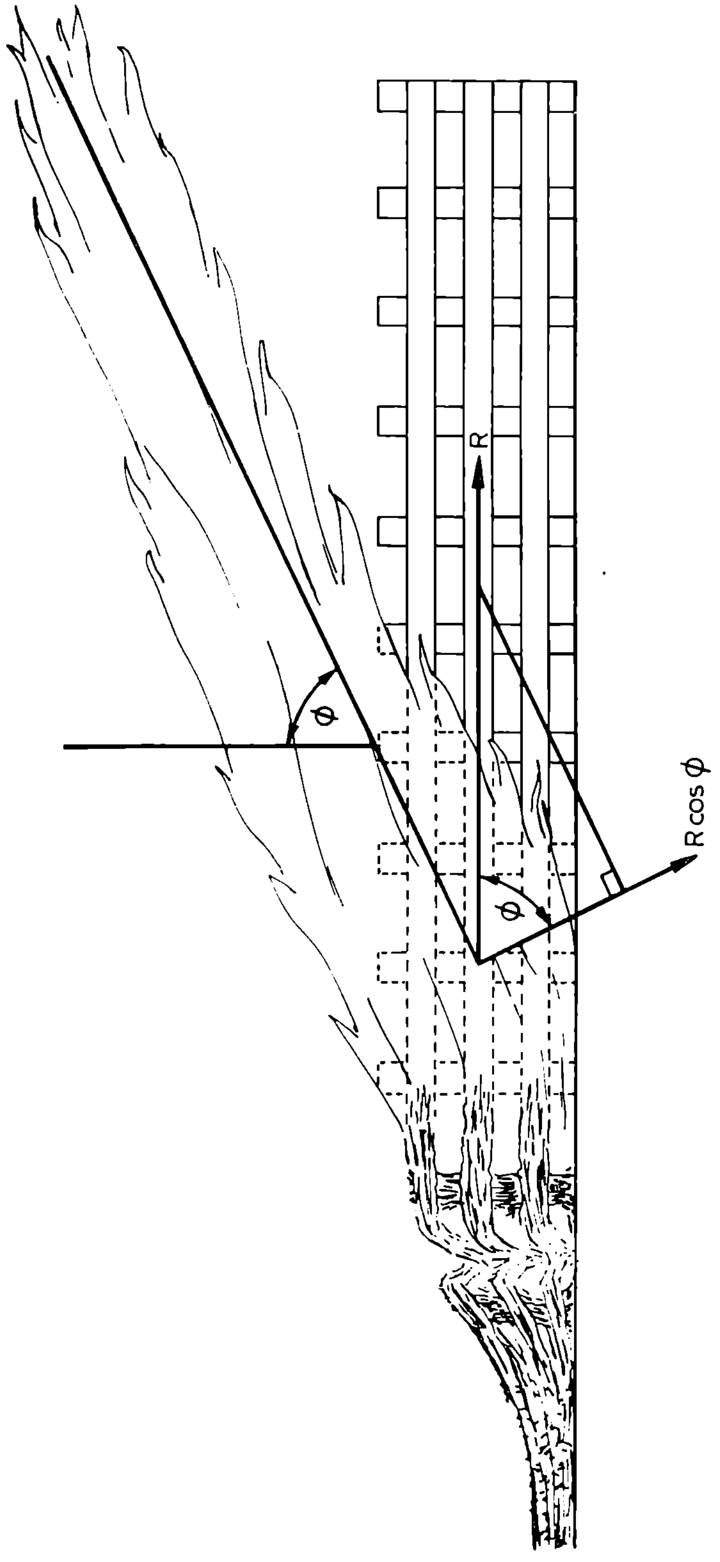


FIGURE 8. Deflection of flames and front of burning zone.

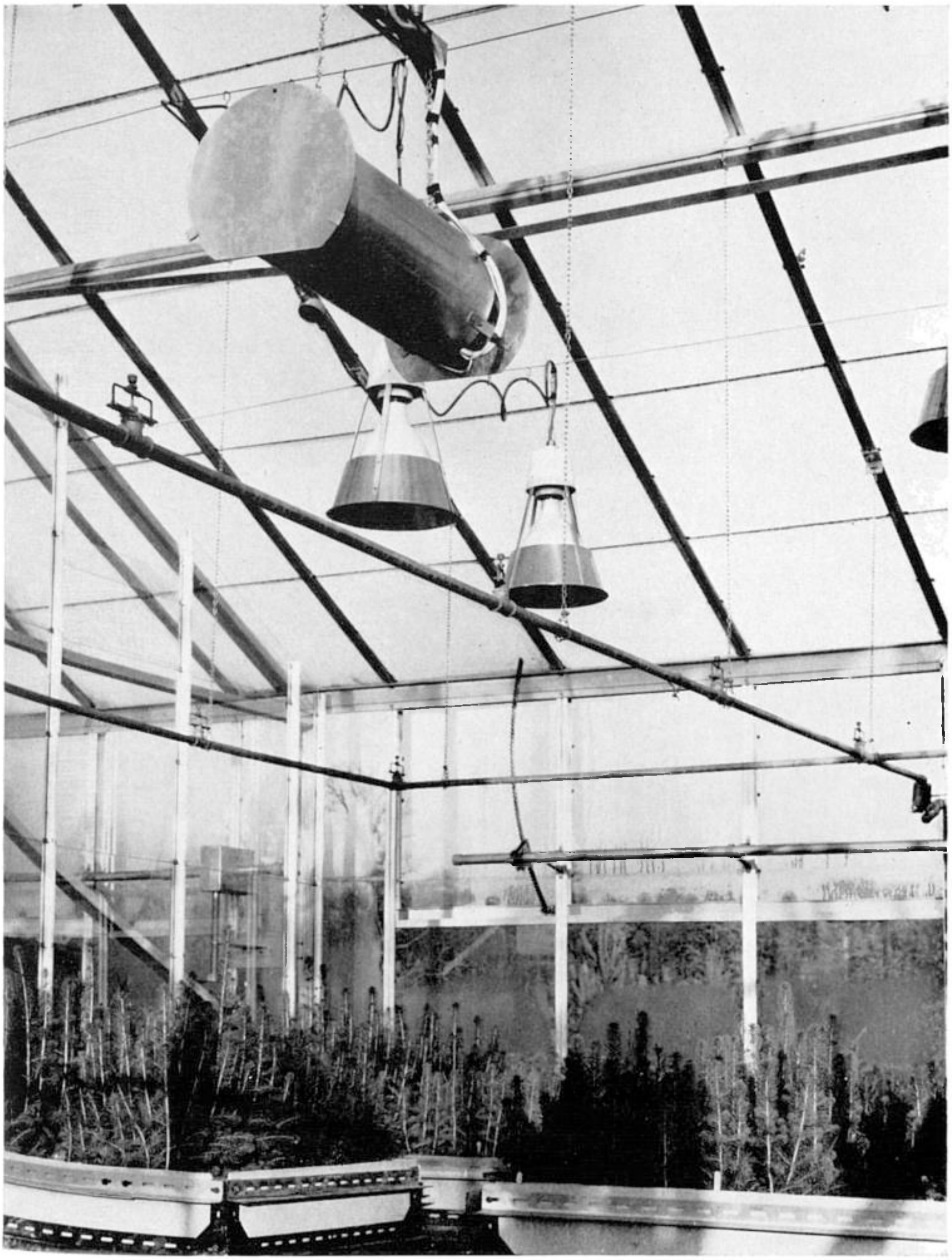


PLATE 1. Faulkner; Genetics. (p. 60)
Genetics greenhouse showing the arrangement of mist irrigation and artificial lighting. Top centre—aspirated thermostat screen for control of space heating.

PLATE 2. Lines and Mitchell; Phenology of Sitka Spruce. (p. 173)
Sitka Spruce standard flushing stage:
Buds dormant.

PLATE 3. Buds swollen.

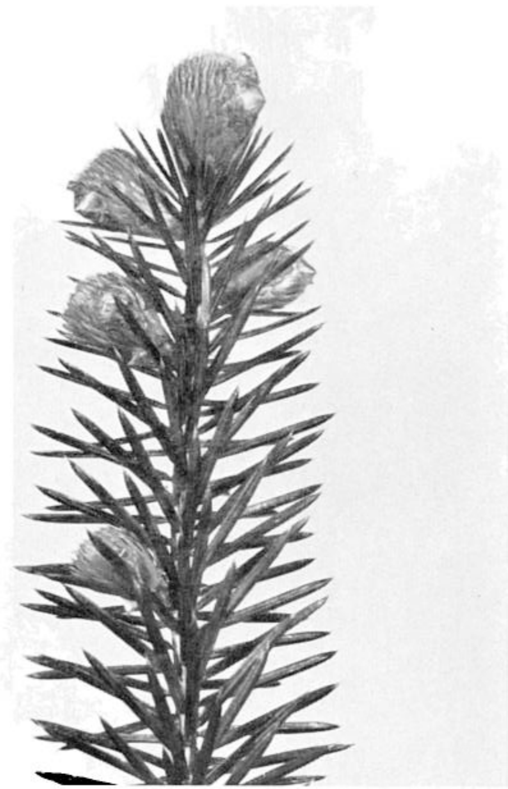


PLATE 4. Buds just open.

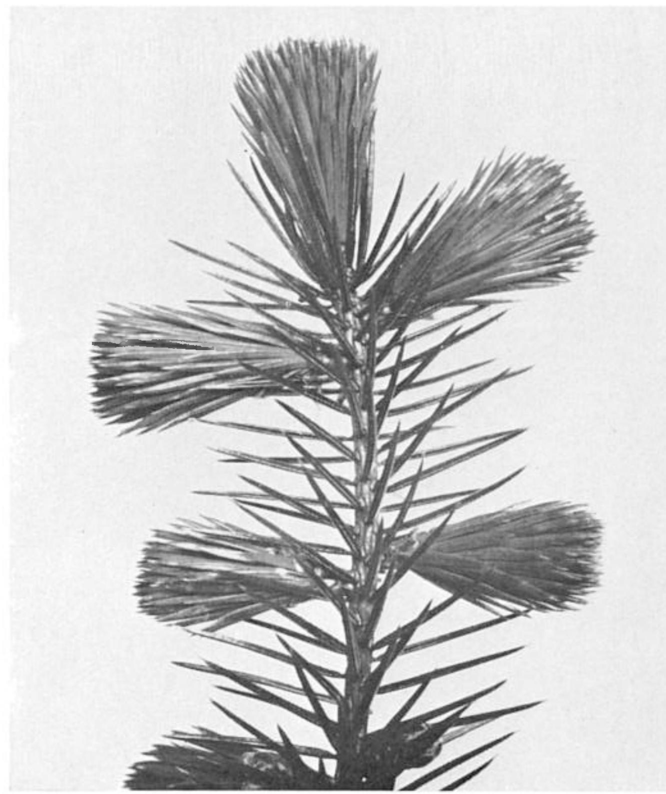
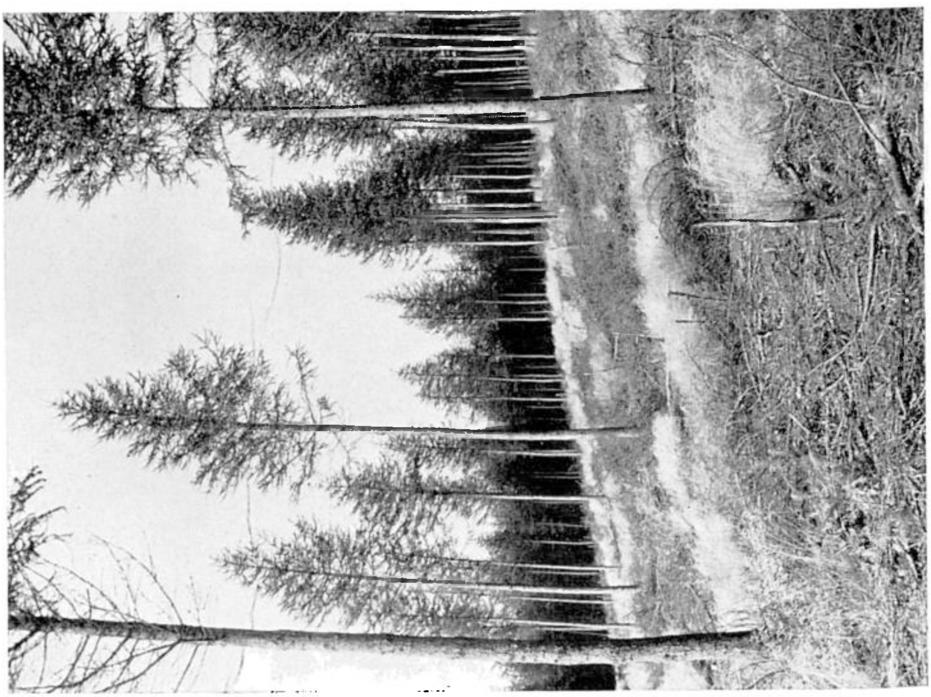


PLATE 5. Needles free.



PLATES 6–8. Neustein; Underplanting of Japanese Larch. (p. 31) Underplanting of Japanese larches planted 1931, Drumtochty Forest, Kincardine, with different degrees of overhead cover.

PLATE 6. 40 stems per acre, proportion of full light reaching forest floor 98% in 1964.

PLATE 7. 80 stems per acre, proportion of full light reaching forest floor 79% in 1964.

PLATE 8. 200 stems per acre, proportion of full light reaching forest floor 51% in 1964. Under normal stocking, light value was 17%.

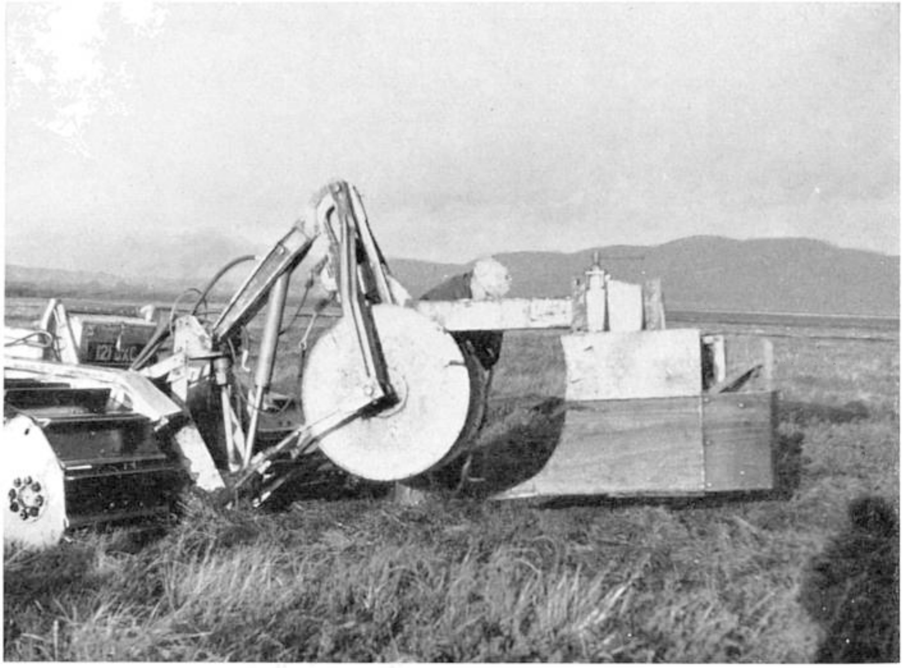


PLATE 9. Henman; Drainage of Deep Peat. (p. 29)
Prototype Parkgate draining plough for peat, mounted on County Bogmaster tractor with Ede self-levelling linkage.

PLATE 10. Henman; Drainage of Deep Peat. (p. 29)
Very wet raised bog ploughed with draining plough as shown in plate 9. Flanders Moss, Loch Ard Forest.

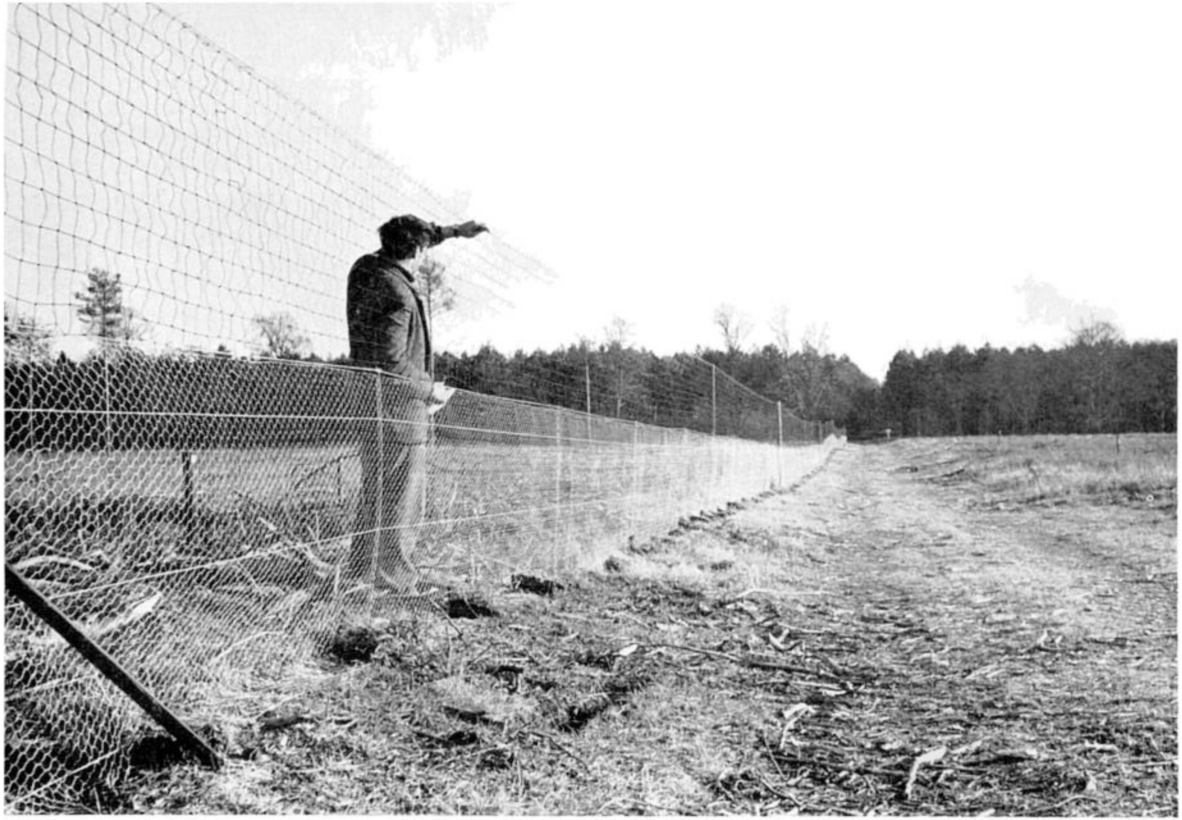


PLATE 11. Rowe; Mammals and Birds, Fencing. (p. 68)

"Swyf-tyte" fence converted to deer fence by use of black polythene netting slung from high tensile wire stretched to extended corner posts.

PLATE 12. Lines and Mitchell; Provenance of Sitka Spruce. (p. 41)

A demonstration in Wykeham Nursery, Allerston Forest, showing clinal variation in rate of growth with latitude of origin. Left to right: 1. Juneua, Lat. 58¼°N; 2. Cordova, 60½°; 3. Sitka, 57°; (all South-east Alaska). 4. Terrace, British Columbia, 53°; 5. Skidegate, Queen Charlotte Islands, B.C., 53°; 6. Sooke, Vancouver Island, B.C., 48¼°; 7. San Juan River, Vancouver Island, B.C., 48½°; 8. Forks, 48°; 9. Hoquiam, 47°; (both coast of Washington). 10. Jewell, coast of Oregon, 46°. The tally marks the latitude of the nursery in this range.

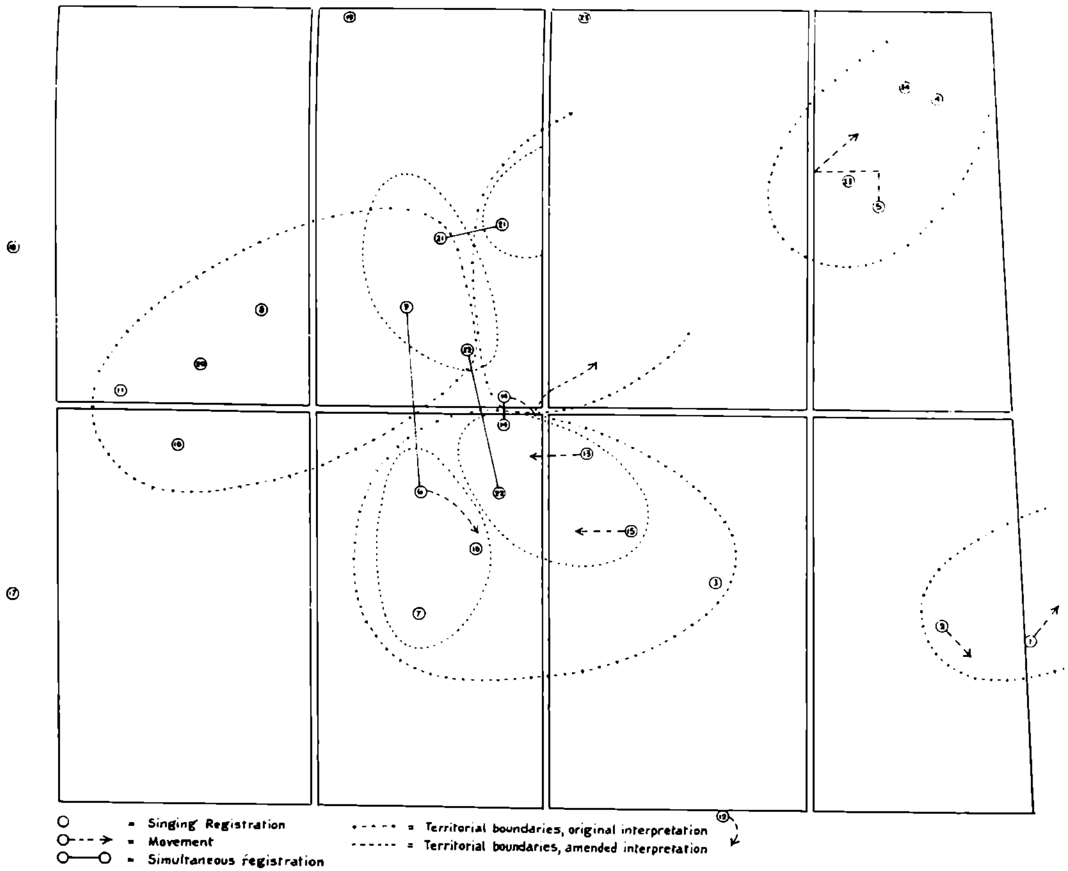


PLATE 13. Myles Crooke; Culbin Tit Studies. (p. 190)

Registrations of singing male coal tits in Plot 1, 1962. Original and amended interpretations of positions of territories are shown. Scale: 1 inch = 300 feet.

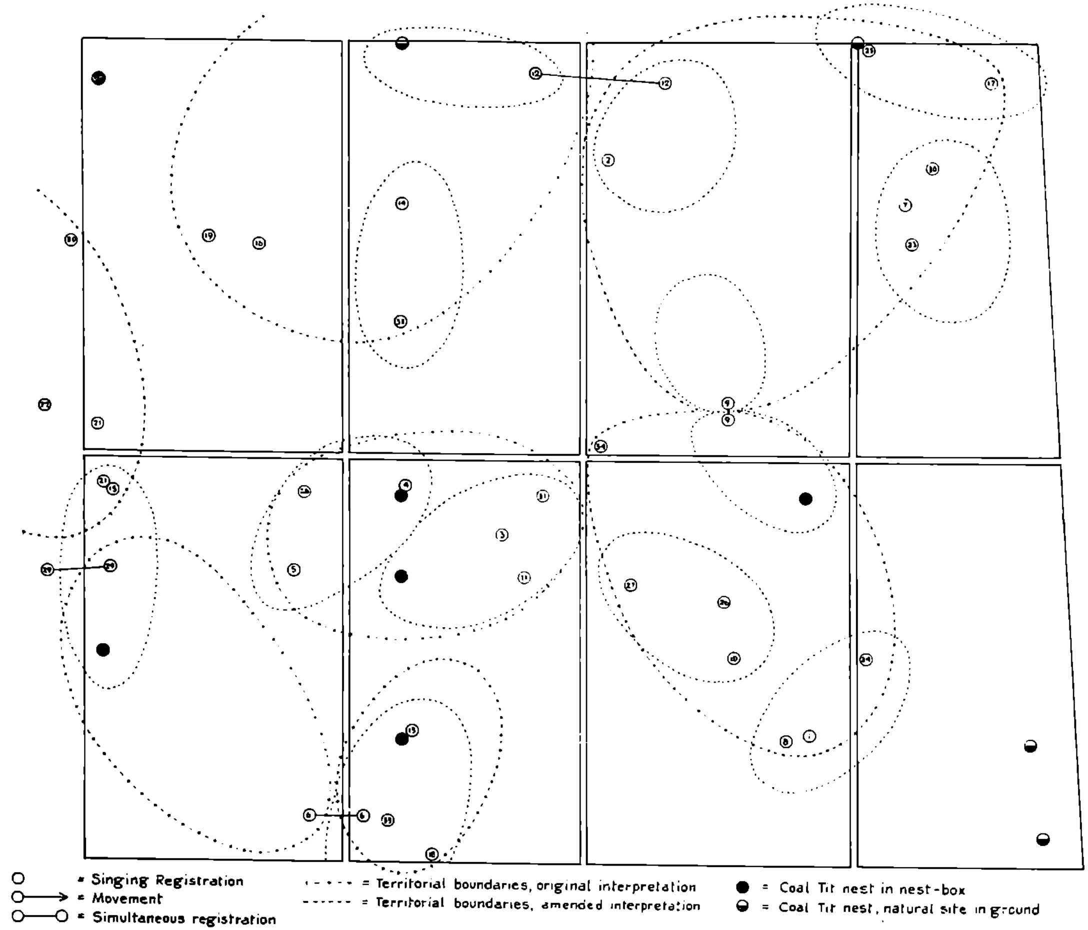


PLATE 14. Myles Crooke; Culbin Tit Studies. (p. 190)

Registrations of singing male coal tits in Plot 1, 1963. Original and amended interpretations of positions of territories are shown. Locations of coal tit nests are also indicated. Scale: 1 inch = 300 feet.

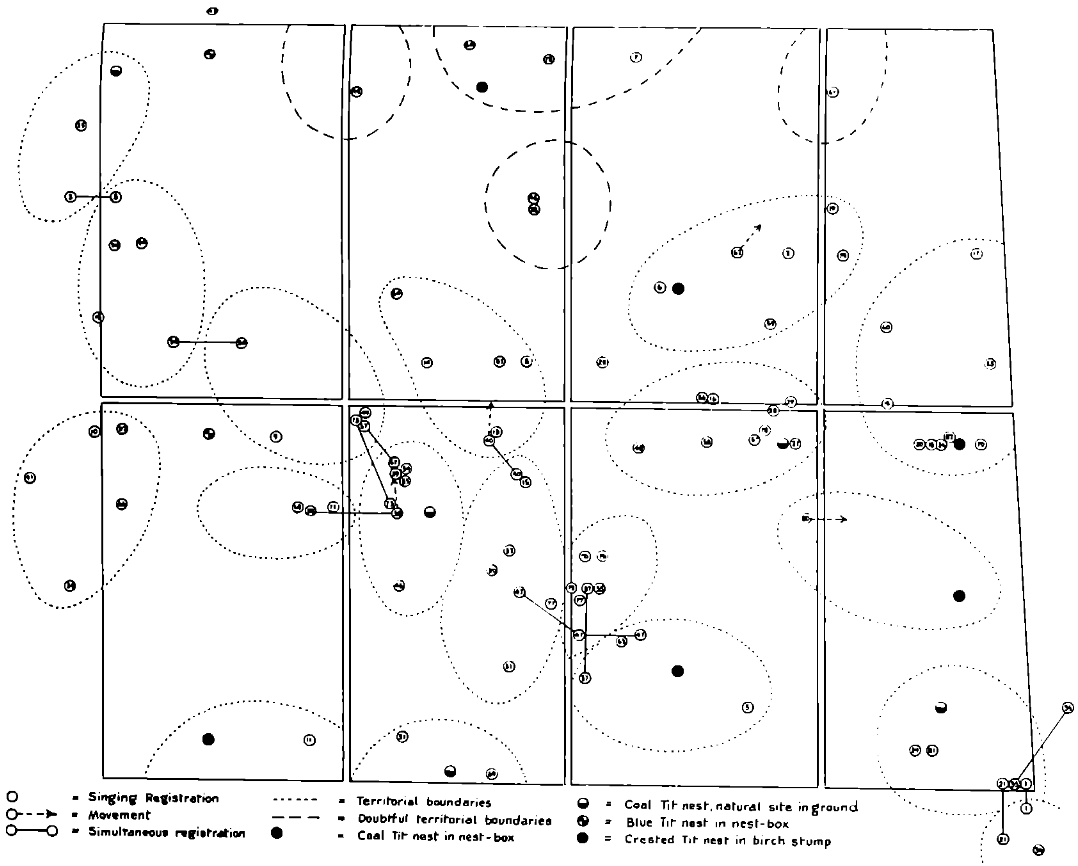


PLATE 15. Myles Crooke; Culbin Tit Studies. (p. 190)

Registrations of singing male coal tits in Plot 1, 1964. Positions of territories are shown, and locations of coal tit, blue tit and crested tit nests are indicated. Scale: 1 inch = 300 feet.

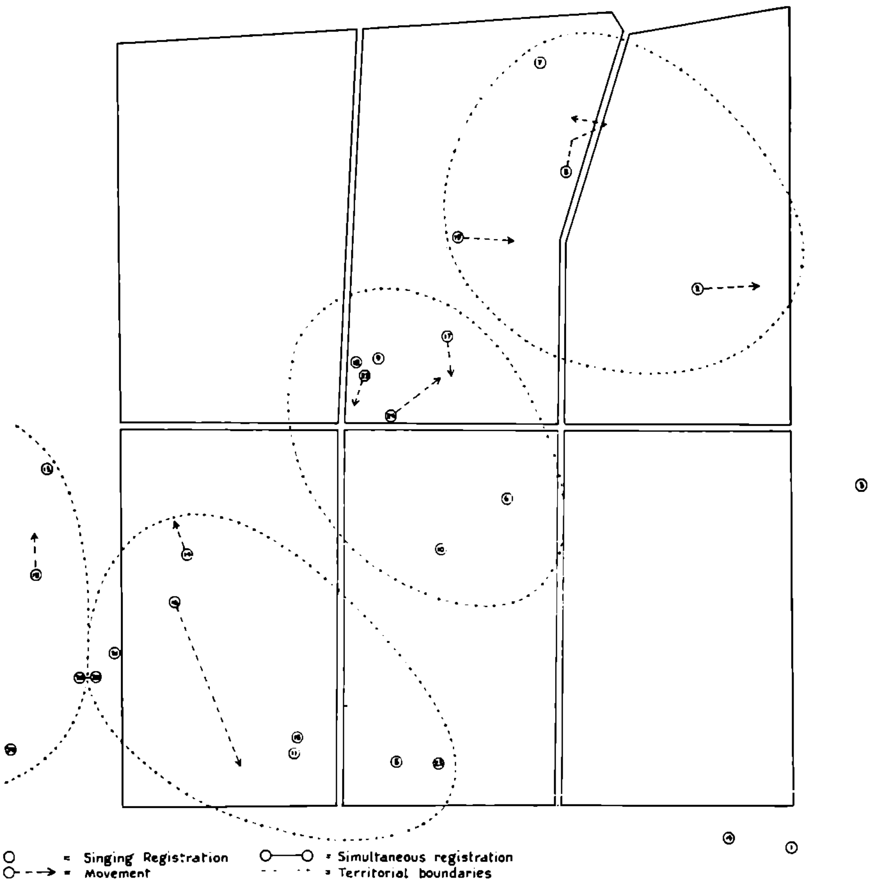
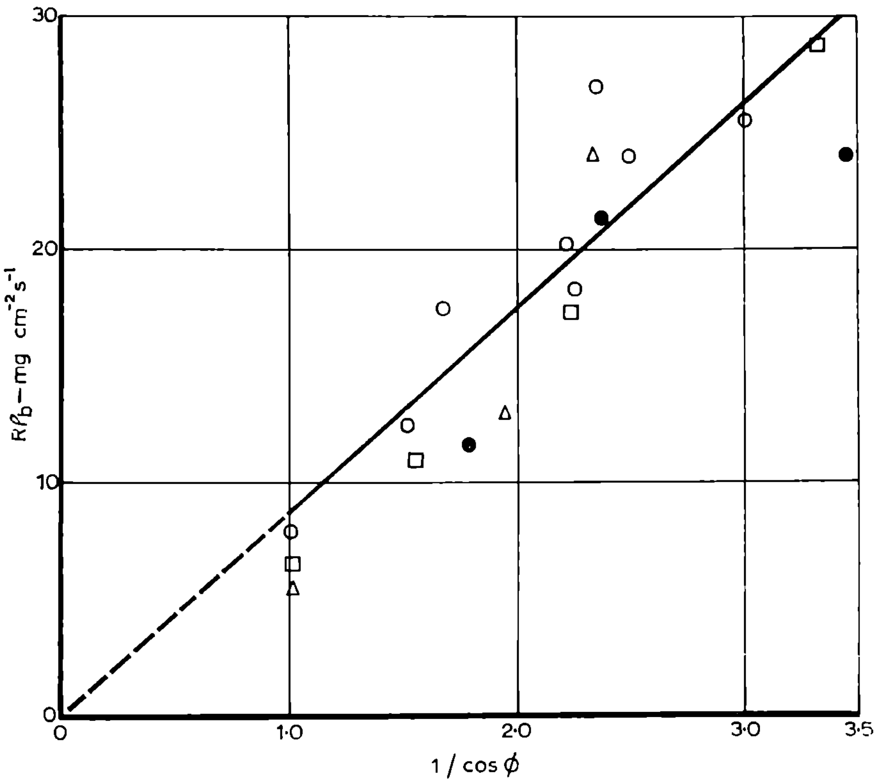


PLATE 16. Myles Crooke; Culbin Tit Studies. (p. 190)

Registrations of singing male coal tits in Plot 2, 1962. Original and inaccurate interpretations of territorial positions are shown. Scale: 1 inch = 330 feet.

estimating the effect of wind on fire spread in deep fuel beds; it will be tested by the results of the controlled fires referred to above.

Work is continuing with a view to finding the criteria which separate this kind of fire spread from that in grass and pine needles, which latter would appear to be largely controlled by the flames above the fuel bed for which, as yet, no satisfactory quantitative theory exists.



Symbol	Spacing between $\frac{1}{4}$-in sticks in
●	4·5
□	2·5
○	1·5
△	0·5

FIGURE 9. Effect of wind on crib fires.

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MEASUREMENTS OF LIGHT INTENSITY

By W. A. FAIRBAIRN

Department of Forestry and Natural Resources, Edinburgh University

The programme of light intensity measurements was continued, using a number of photo-integrators and associated equipment at Corrour Estate, Inverness-shire, Cawdoor Wood, Nairnshire and Forest of Ae, Dumfriesshire.

Measurements were made at Corrour in a gap of approximately 0·45 acres, in the vicinity of *Abies grandis* (planted 1914) and Sitka spruce stands (planted 1909), with successful natural regeneration of the latter only. The light intensity in the spruce was 13·6 per cent of full light, in the *Abies* 45·9 per cent, and in the gap 67·0 per cent. There was more light in the western portion (where there was a greater amount of spruce regeneration), due to differences in the densities of the surrounding stands.

Measurements were also made in two 0·05 acre gaps in a Sitka spruce stand (planted 1912), which had been under-planted in 1961 with *Abies grandis:* the light intensity averaged 16·4 in the middle and 8·3 per cent on the southern edges of the two gaps; the young plants seem to be established, but it is doubtful if there is sufficient light for satisfactory growth.

Light intensity was measured at Cawdor in an aged mixed hardwood stand in a 0·25 acre gap planted in 1956. The light varied from 24·0 per cent on the southern edge to 57·5 in the centre, and regeneration was poor. In a gap of approximately 0·75 acres in a mixed larch-hardwood stand, successful natural regeneration of European larch was obtained with light intensities of 53·8 per cent on the southern edge and 63·1 per cent of full light at the centre.

In the Forest of Ae, measurements in different grades of thinnings in Sitka spruce stands showed that in the C/D grade the light intensity was 3·3 per cent, while in the ' Scottish eclectic ' type it was 1·9 per cent. These results illustrate the effect of the difference in structure of the individual stands from the two different types of thinning. The following results were obtained, in the gaps of different sizes created in 1962:

(i) In the 1·0 acre gap, with 9 remaining Sitka spruce, light intensity was 34·3 in the centre and 21·2 per cent on the southern perimeter.

(ii) In the 0·1 acre gap (clear felled), light intensity was 49·7 in the centre and 42·2 per cent on the perimeter.

(iii) In the 1·0 acre gap light intensity was 60·8 in the centre and 57·1 per cent on the perimeter.

(iv) In the 0·3 acre gap, the light intensities (at the north, east, south and west on the perimeter) were 41·4, 29·8, 8·0 and 7·7 per cent, respectively.

(v) In the 1·0 acre gap the light intensities at the north, east, west and south points on the perimeter were 57·7, 46·2, 38·4 and 43·9 per cent, the increases being due to the larger size of the gap.

RECREATIONAL USE OF FORESTS

By W. E. S. MUTCH

Department of Forestry and Natural Resources, Edinburgh University

During the summer of 1964 field studies of recreation use were made in four national forests: Cannock Chase, Staffordshire; Allerston, Yorkshire; Loch Ard Forest in the Queen Elizabeth Forest Park, Perthshire and Stirlingshire; and Queens' Forest in the Glen More Forest Park, Inverness-shire. Four surveyors interviewed more than 1,100 respondents, using a comprehensive questionnaire designed to establish personal preference and attitudes to the use and development of forests for recreation. We also attempted to find out how much money people were prepared to pay for recreational access.

The information obtained in the interviews has been transferred to 80-line punch cards and is now being analysed, but a preliminary study of the data has revealed the following points.

Most of the visitors, especially to the English forests, travel only short distances; at Cannock the mean distance travelled was only 17 miles, and forty per cent of the visitors had travelled less than 10 miles. Although about 98 per cent were motorists, most visitors were in favour of restricting access for cars. In all the areas sampled, most respondents had been before, and the rate of recruitment of first-time visitors was low.

An important part of the questionnaire was concerned with ranking personal opinions on the improvement of access and the provision of tourist facilities in the forests. The answers seem to show a marked change of opinion once the intensity of tourist use increases beyond a rather low threshold. In brief, at low intensities of use the demand is for 'wilderness', involving the provision of few, if any, facilities; as the number of visitors increases, the need for lavatories, for example, quickly becomes clear and in the day-visited forests the demand for these facilities is strong.

Certain criticisms of camping and caravan sites occurred frequently in the answers to the questionnaire. The final analysis is therefore likely to be useful to anyone designing new camp sites or improving existing facilities.

PART III

Reviews of Continuing Projects, Interim Reports, Methodology, etc.

PARAQUAT AS A PRE-EMERGENCE SPRAY FOR CONIFER SEEDBEDS*

By J. R. ALDHOUS

Introduction

Vaporising oil, as a pre-emergence spray at 60 gallons per acre applied 3 to 4 days before the emergence of the crop, has been in general use in forest nurseries for the last twelve years. It has been most effective in this role especially with the slower-germinating conifer species. Paraquat has the similar properties of killing a wide spectrum of young weeds and having no effect after it has reached the soil, being rapidly inactivated there (at least in soils containing some clay.) A series of experiments in the years 1962 to 1964 show that paraquat can be used safely as an alternative to vaporising oil.

Experiments were carried out in 1962, 1963, and 1964; on four species at Kennington, Oxford in 1962; on four species each on three sites in 1963 (Kennington, Oxford; Farnham, Surrey and Wareham, Dorset), and on thirteen species on nine sites (several species per site) in 1964. These sites included those used in 1963. The experiments laid down in 1962, 1963 and some in 1964, were carried out in Forestry Commission Research nurseries. The rest of the 1964 experiments were carried out in Forestry Commission production nurseries on routine sowings. The soils in all the nurseries were acid or very acid, the pH (measured in water) ranging from 4·3 to 5·5. Many soils were sandy with very little or no content of clay.

In all experiments, several rates of applications were compared, and in all experiments in research nurseries the effect of date of application in relation to sowing and emergence was also tested.

Method and Materials

Paraquat was applied by a small hand-held precision sprayer (working on the same principle as the 'Oxford' precision sprayer), a 'Mysto' hand sprayer, or a knapsack sprayer. The unit area sprayed in all the 1962 and 1963 experiments, and in the more complex 1964 experiments, was 1 yard by 1 yard. In the simpler experiments carried out in production nurseries in 1964, the sprayed plots were 6 feet long and the full width of a seedbed (i.e. 3 feet or 3½ feet.). All treatments were replicated three or four times according to the particular experiment.

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* This and the two following papers first appeared in the *Proceedings of 7th Weed Control Conference*, Brighton, 1964.

Table 36

NUMBER OF SEEDLINGS ASSESSED IN EXPERIMENTS TESTING THE EFFECT OF PARAQUAT PRE-EMERGENCE SPRAYS ON CONIFER SEEDBEDS

Year	Nursery	Dates, by day and month				Rate of application of Paraquat (pounds active ingredient per acre)						Oil	Control, hand weeding only*	Standard Error
		Sown	Spray	Emergence	Assessment	¼	½	1	1½	2	4			
						Sitka Spruce								
1962	Kennington	12/4	6/5	11/5	7/6	—	—	177	—	160	178	158	—	± 13·5
1963	Alice Holt	20/3	26/4	30/4	28/6	—	140	119	146	140	—	128	—	± 12·3
	Wareham	23/4	10/5	16/5	5/7	—	121	149	126	151	—	124	—	± 13·1
	Kennington	16/5	30/5	4/6	1/7	—	172	176	186	169	—	185	—	—
1964	Alice Holt	15/4	4/5	11/5	21/7	372	370	368	—	—	—	383	367	± 30·4
	Wareham	29/4	14/5	16/5	6/8	368	381	338	—	—	—	360	336	± 18·7
	Kennington	4/6	19/6	19/6	12/8	284	272	295	—	—	—	322	268	± 24·8
	Maelor	31/3	8/5	11/5	27/7	269	256	238	—	—	—	283	—	± 12·0
						Japanese Larch								
1962	Kennington	12/4	6/5	6/5	7/6	—	—	99	—	90	100	96	—	± 7·3
1963	Alice Holt	20/3	26/4	30/4	28/6	—	48	48	41	33	—	60	—	± 7·1
	Wareham	23/4	10/5	13/5	5/7	—	51	47	45	54	—	57	—	± 7·4
	Kennington	16/5	30/5	4/6	1/7	—	78	78	72	89	—	76	—	± 9·2
1964	Kennington	4/6	19/6	19/6	10/8	106	111	108	—	—	—	111	111	± 8·4

						Western Hemlock								
1963	Alice Holt	20/3	26/4	28/5	28/6	—	157	177	154	136	—	139	—	± 11·2
	Wareham	23/4	10/5	21/5	5/7	—	99	126	93	87	—	89	—	± 15·3
	Kennington	16/5	30/5	11/6	1/7	—	147	92	129	178	—	127	—	± 18·9
1964	Kennington	5/6	22/6	24/6	13/8	293	323	322	—	—	—	344	233	± 19·9
	Maelor	31/3	8/5	18/5	27/7	429	421	399	—	—	—	407	—	± 17·4
						Scots Pine								
1964	Roudham	7/4	27/4	30/4	28/5	205	218	216	—	—	—	241	—	± 13·6
						Corsican Pine								
1964	Roudham	10/4	27/4	30/4	28/5	139	126	131	—	—	—	114	—	± 9·1
						Beech								
1964	Ystwyth	14/4	7/5	7/5	28/6	10	10	10	—	—	—	13	—	± 2·1

Note. * Hand weeding only = No herbicides used, plots weeded by hand only.

In all experiments in 1962 and 1963, there were four species on each sprayed plot, each species being sown on a strip 4 × 36 inches across the plot, and being separated from neighbouring strips by 5 inches of bare soil. In 1964 each sprayed plot was broadcast-sown with seed of one species only. The numbers of seedlings in 1962 and 1963 experiments given in the tables were obtained by counting all live seedings in each 4 inch × 36 inch strip. The numbers shown in the 1964 experiments were obtained by counting those seedlings in five sample areas, each 2 inches × 36 inches, taken from the broadcast-sown plots, i.e. two and a half times the area of the strips used in earlier experiments.

Seedlings have normally been counted twice during the growing season, and once again after growth has finished for the year. The control of weeds has been assessed by the time taken to hand-weed plots during the early part of the growing season. Usually, the first two hand weedings showed the effects of the spray treatment: thereafter differences were lost. Times are shown in minutes per square yard.

The rate of paraquat used in each year's experiments varied according to the ideas at the beginning of the year of what was likely to be both an economic, effective and safe rate for general use. At present day prices a pre-emergence spray of vaporising oil costs between £5 and £6 per acre (materials only). Paraquat at 1 pound of active ingredient per acre would cost £3 5s. 0d. per acre.

Results

Paraquat on the Crop

Table 36 gives representative results of the effect of paraquat on several species. Only in one experiment out of forty was there any significant reduction in the yield (or any other effect on the yield) of conifer seedlings following a paraquat pre-emergence spray. In this experiment at Alice Holt in 1963, the yield of Japanese larch seedlings was significantly reduced following a pre-emergence spray of paraquat at rates from 0·5 to 2 lb. active ingredient per acre. In four other experiments Japanese larch was unaffected.

Date of Application

In the experiments in 1962 and 1963, all applications were made before any crop species germinated. In most experiments from 3 to 8 days elapsed between spraying and first crop germination. In 1964, attempts were made to see how close to the date of first germination sprays could be applied without affecting the crop. All the evidence (except for the solitary instance of the Japanese larch already pointed out), indicates that spraying up to two or three days before seedlings first emerge is safe.

In the 1964 series of experiments, some post emergence treatments were applied. While ultimately almost all sprayed seedlings died, several species took a long time to react to paraquat. This is illustrated in Table 37. All the pines, spruces and Douglas fir reacted slowly; on the other hand the larches, Western red cedar and Western hemlock, behaved much in the same way as the weeds present, most being straw-coloured and desiccated within a week of spraying.

Weather at the Time of Spraying

In Britain, seed of all conifers and many hardwood species are almost invariably sown on the soil surface and covered with a lime-free and silt-free coarse sand

Table 37

NUMBER OF LIVE SEEDLINGS COUNTED SHOWING THE DELAYED EFFECT OF PARAQUAT POST-EMERGENCE APPLICATION ON CONIFER SEEDLINGS

Date sprayed	Rate of Paraquat (pounds active ingredient per acre) ¼	½	1	¼	½	1
	Corsican Pine—Alice Holt Nursery *Sown 10/4/64 1st Emerged 24/4/64*					
	Assessed 14/5/1964			*Assessed 12/6/1964*		
22/4	158	161	149	155	166	160
29/4	154	158	161	152	121	141
1/5	155	152	155	145	137	102
5/5	143	152	111	119	92	42
V.O./H.W.	145/171			145/178		
	Norway Spruce—Wareham Nursery *Sown 29/4/64 1st Emerged 12/5/64*					
	Assessed 9/6/1964			*Assessed 5/8/1964*		
11/5	364	372	359	358	362	352
15/5	302	272	137	201	172	93
20/5	349	296	235	291	240	79
22/5	340	170	81	121	36	26
V.O./H.W.	356/343			344/353		
	Western Red Cedar—Wareham Nursery *Sown 30/4/64 1st Emerged 20/5/64*					
	Assessed 8/6/1964			*Assessed 6/8/1964*		
19/5	174	147	142	206	176	191
22/5	148	134	109	187	182	154
27/5	88	69	64	123	108	78
2/6	10	0	0	29	30	22
V.O./H.W.	170/170			226/181		

Notes. V.O. = Plot sprayed pre-emergence with Vaporising Oil at 60 gallons per acre.
H.W. = Hand weeding.

or fine grit. To reach the soil and become inactivated, paraquat has to pass the seed. Obviously it is important to know if the germinating seed is threatened by paraquat sprays under any particular weather conditions.

Notes made at the time of spraying give no indication that any particular weather conditions enhance or reduce the value of paraquat as a pre-emergence spray. However, at the beginning of 1964 there was insufficient evidence of the possible action of rain washing paraquat into the soil. Experiments were therefore laid down, applying paraquat at 1 lb. active ingredient in 40 gal. of water per acre and following this about 1 hour later by heavy sprays of water corresponding to 0·05 and 0·20 inches of rain or 29 and 116 gallons per acre respectively. These sprays were applied on the same dates as the experiments quoted in Table 37. Again, the pre-emergence sprays did no damage to the crop, with one possible exception, as shown in Table 38. In this case, the number of European larch seedlings on plots given the heaviest application of water, following paraquat spraying, was appreciably less than on other plots; but this difference was not statistically significant. Table 38 also shows that the watering treatment had no effect on the control of weeds.

Table 38

EFFECT OF ADDITIONAL WATER FOLLOWING PARAQUAT SPRAYING ON YIELD OF SEEDLINGS AND WEEDING TIMES

Nursery	Species	Additional water in inches 0	0·05	0·20	Standard Error
		Number of Plants			
Kennington	Western hemlock	214	248	243	19·6
	Scots pine	178	155	158	14·8
Wareham	Norway spruce	342	338	343	13·5
	Sitka spruce	315	335	296	16·1
Alice Holt	European larch	150	138	110	22·0
	Douglas fir	120	175	119	24·01
		Weeding Times Min./sq. yd.			
Wareham	Norway spruce	1·6	1·5	1·5	0·54
	Sitka spruce	2·6	2·8	2·5	0·52
Alice Holt	European larch	0·10	0·07	0·12	0·035
	Douglas fir	2·3	2·1	2·4	0·23

Weed Control

In all these experiments the control of weeds was measured by the time taken to hand weed plots in the two months following spraying. Note was also made of all weed species present, but none was found resistant to paraquat.

Table 39 gives the handweeding times in each experiment. The weeding times make an inconsistent picture because of the considerable random variation in weed growth from one plot to another and very few of the quite big differences apparent in the table are statistically significant. Sometimes vaporising oil appears to have worked better than paraquat at 0·5 or 1 pound per acre and sometimes the opposite has occurred. Vaporising oil is variable in composition and this might account for part of the difference in response.

In the 1964 experiments, the lowest rate of paraquat tested, 0·25 pounds active ingredient per acre has consistently given a poorer control of weeds than 0·5 pounds active ingredient per acre. However, only at Alice Holt in 1964 is there any indication that 1 pound active ingredient per acre might be preferable to 0·5 pounds active ingredient per acre.

In each of the Research nurseries in 1964, the time taken to weed the sprayed plots varied markedly from one experiment to another. This is partly due to some areas in each nursery being weedier than others, but more to the different germination speed of different conifers. Those which germinated quickly, e.g. Scots pine, European larch, emerged at the same time as the earliest weeds.

Table 39

TIME TAKEN TO WEED PLOTS SPRAYED WITH PARAQUAT (MINUTES PER PLOT)

Year	Nursery	Species sown on weeded plots	Interval between sowing and spraying (days)	Rates of application for Paraquat (pounds active ingredient per acre)						Vap. oil	Control hand weeding only	Standard Error
				¼	½	1	1½	2	4			
1962	Kennington	Four*	—	—	—	11	—	8	6	7·5	—	—
1963	Kennington	Four*	14	—	0·5	0·2	—	0·2	0·5	0·3	—	0·4
	Wareham	Four*	17	—	3·8	3·6	—	2·4	2·3	5·9	—	—
	Alice Holt	Four*	37	—	0·8	0·6	—	0·5	0·4	3·4	—	—
1964	Wareham	Norway spruce	12	19·7	11·6	8·2	—	—	—	10·8	56·1	6·1
		Lodgepole pine	15	7·8	3·9	1·9	—	—	—	0·8	15·1	1·3
		Sitka spruce	15	14·6	11·3	7·2	—	—	—	4·2	34·6	1·4
		Western red cedar	19	5·5	4·2	5·1	—	—	—	3·5	17·0	2·0
	Alice Holt	Corsican pine	10	6·1	5·5	6·0	—	—	—	6·2	5·4	0·70
		European larch	10	5·0	5·8	4·8	—	—	—	4·9	6·9	0·54
		Sitka spruce	27	6·1	2·4	2·2	—	—	—	3·4	11·1	0·92
		Douglas fir	34	1·4	0·5	0·4	—	—	—	1·4	3·6	0·31
	Ystwyth	Beech	23	2·7	1·7	2·3	—	—	—	2·2	—	0·35
	Roudham	Scots pine	20	4·2	3·3	3·6	—	—	—	12·7	—	0·91
		Corsican pine	17	4·2	4·3	3·3	—	—	—	10·2	—	1·15

Note. * Four species per plot: 1962 Sitka spruce, Japanese larch, Lodgepole pine, Douglas fir.
1963 Sitka spruce, Japanese larch, Western hemlock, Douglas fir.

For these species, there was little benefit from any pre-emergence spray and there were many weeds to be removed by hand subsequently. The slower germinating conifers, on the other hand, could effectively be given a pre-emergence spray, whether of paraquat or vaporising oil.

Discussion

The results given indicate that paraquat can safely be used on seedbeds of most common conifers as a pre-emergence spray. There is a slight uncertainty about the larches, and the possibility exists that under certain weather conditions, these species may sustain damage as germinating, but not yet emerged, seedlings. It has been mentioned already that many of the experiments were sited on acid sandy soils. Such soils contain little or no clay and the fate of paraquat sprayed onto them is uncertain. These experiments, however, indicate that there is little short-term risk from paraquat residues in such acid sandy soils.

No firm conclusion can be reached whether paraquat is more or less effective than vaporising oil as a pre-emergence measure for controlling weeds. Paraquat at 0·5 pounds per acre seems sufficient to control weeds—there is little evidence that 1·0 pounds per acre gives better control. At this lower rate, paraquat has a distinct cost advantage over vaporising oil, but this advantage would be easily lost if subsequent evidence shows that it does not control weeds as well as vaporising oil does.

Summary

In experiments in 1962–64, pre-emergence sprays of paraquat did not affect most of the commonly sown conifers. Only in one experiment was the yield of any species (Japanese larch) reduced significantly. The control of weeds achieved with paraquat at 0·5 pounds active ingredient per acre (the recommended rate) was sometimes better and sometimes poorer than that following sprays of vaporising oil.

Post-emergence sprays killed all conifer species under test but pines and spruces took several weeks to react to post-emergence sprays.

The Effect of Paraquat, 2,6-dichlorothiobenzamide and 4-amino-3,5,6-trichloropicolinic Acid ('Tordon') on Species Planted in the Forest*

By J. R. ALDHOUS

Introduction

This report describes five series of recent forest experiments carried out in England and Wales. In it, the response by the forest crop species has been emphasised and with one exception, only a broad outline is given of the response by the many weed species present on the experiment sites.

Two of the herbicides tested, paraquat and 2,6-dichlorothiobenzamide have killed a very wide range of the herbaceous weed species present in the forest, and could supplement or even replace hand weeding. (About one and a quarter million pounds were spent on hand weeding by the Forestry Commission in 1963, mainly on hand weeding herbaceous weeds in young conifer plantations.) The third material, 4-amino-3,5,6-trichloropicolinic acid ('Tordon') was given a small-scale preliminary trial as an alternative to 2,4,5-T, testing it in water compared with 2,4,5-T in oil on species controlled by 2,4,5-T, and comparing it with ammonium sulphamate on species resistant to 2,4,5-T. These tests constitute one of the series of experiments described here.

Three of the five series of experiments concern paraquat—not so much on its effect on weeds as its effect, in specified circumstances, on tree crop. One series arose from the claims made that a physical shield provides adequate protection to young trees (Lacey, 1964; Jack, 1964). Nevertheless in a trial of a prototype shield in the spring of 1963, in the Forestry Commission Research Nursery at Alice Holt, several trees were killed by girdling at the soil surface, apparently through the bark having been sprayed under the base of the shield. The other two series arose from information from Northern Ireland which suggested that in late summer Sitka spruce could be sprayed overall and sustain negligible damage, and that good control of heather, *Calluna vulgaris* (a weed which can check growth of spruces for long periods) could be achieved at the same time.

Three series of experiments with paraquat were therefore laid down testing (a) the effect of paraquat on bark of young conifers, (b) the effect of paraquat sprayed overall on conifer foliage and (c) the effect of paraquat on *Calluna*.

The experiments testing 2,6-dichlorothiobenzamide were designed to give information on both crop response and control of weeds under conditions in which it might be used in large-scale practice.

Results

Paraquat on Conifer Bark

Between March and September 1964, paraquat was sprayed, or painted to 'run-off' round the stem of a range of species, from ground level to a height of about 3 inches. Two concentrations of paraquat solution were used, 1:800 and 1:400, corresponding to applications of 0·5 and 1·0 pounds active ingredient in 40 gallons per acre.

*See footnote, p. 133.

Table 40 gives the health scores of treated trees, assessed in September, 1964. The table clearly shows that many species were severely damaged by the treatment applied between April and June, and that spruces were markedly less affected than other species. For most species it was impossible to say in September, when this assessment was made, whether trees with damaged bark would recover or die. The apparent increasing resistance to sprays later in the season shown in the table may also turn out to be illusory, in that in most cases several months elapsed before foliage became discoloured following death of the bark at ground level. It is quite possible therefore that trees treated late in the summer which did not show up in Table 40 as damaged, will deteriorate.

Table 40

THE HEALTH SCORE IN SEPTEMBER, 1964 OF TREES TREATED AT THE ROOT COLLAR WITH PARAQUAT IN SPRING AND SUMMER 1964 (APPLICATION TO BARK, NOT TO FOLIAGE)

Species	Location (Forest)	Month and rate of treatment											
		March		April		May		June		July		August	
		½	1	½	1	½	1	½	1	½	1	½	1
Scots pine	Thetford	Not treated		1	3	4	3	3	3	1	0	1	0
Corsican pine	Thetford			3	3	4	4	3	3	1	3	0	0
Lodgepole pine	Gwydyr	3	3	2	3	1	4	3	3	1	2	1	1
Japanese larch	Gwydyr	1	3	1	4	2	3	1	3	0	1	0	0
Sitka spruce	Gwydyr	0	1	0	1	2	3	1	1	1	1	0	0
Norway spruce	Gwydyr	1	1	1	1	0	2	1	1	0	1	0	0
Serbian spruce	Alice Holt	0	0	0	0	0	0	0	0	0	0	0	0
Western hemlock	Alice Holt	3	4	4	3	2	3	1	1	0	1	0	0
Western red cedar	Forest of Dean	1	4	4	4	3	4	0	4	1	0	0	0
Douglas fir	Forest of Dean	1	0	0	0	0	1	0	0	0	0	0	0
European larch	Forest of Dean	1	1	0	1	1	2	1	3	0	0	0	0
Sitka spruce	Forest of Dean	0	1	0	1	1	3	0	0	0	0	0	0
Grand fir	Forest of Dean	0	1	0	3	1	1	0	0	0	1	0	0
Western hemlock	Forest of Dean	1	3	2	3	3	3	0	0	0	0	0	0

Footnote

Six trees were treated at each time of application. The figures in the table indicate the following:—

0 = Bark healthy (sometimes slightly thickened).

1 = Bark killed in patches on stem, or resin bleeding from bark, on from 1 to 3 trees. No trees completely girdled or markedly discoloured.

2 = From 4 to 6 trees damaged as described for 1 above.

3 = The bark of from 1 to 3 trees completely killed at ground level, or tree markedly discoloured and with moderate or severe resin bleeding from the treated bark, or tree dead.

4 = From 4 to 6 trees affected as described for 3 above.

In the table heading, ½ = sprayed with 1 : 800 dilution of paraquat, as would be used when spraying ½ pound of active ingredient in 40 gallons water per acre.

1 = sprayed with 1 : 400 dilution of paraquat, as would be used when spraying 1 pound of active ingredient in 40 gallons water per acre.

Paraquat Overall Spray

Eleven common conifer and three common hardwood species were sprayed overall in 1963 using paraquat at 0·5, 1, 2 pound active ingredient in 40 gallons of water per acre. Sprays were applied by knapsack at one of six (or seven) dates, the first being in July and the next five at successive intervals of three weeks from the first. In North Wales, paraquat was also applied overall on Sitka and Norway spruce in mid-January. Most of the spraying took place in the forest, but several species were sprayed in Alice Holt research nursery. These plants were younger and smaller than the others.

There were three plants per plot in those experiments carried out in the forest. In the experiment at Alice Holt nursery, there were a minimum of ten plants per treatment. The health of all plants was assessed, two and six weeks after spraying and again during the following growing season in the following year.

Sitka spruce (in the forest but not in the nursery), Norway spruce and *Abies grandis* were able to withstand a foliage spray at the rate of ½ pound of paraquat active ingredient per acre when applied between mid-August and mid-October, sustaining only a little scorch at the time and recovering subsequently. All three species similarly withstood sprays at 1 pound active ingredient per acre during this same period but at one or another time sustained quite heavy damage.

Three pine species, Lodgepole pine, Scots pine and Corsican pine were usually severely damaged by the two higher rates of paraquat, but those few individuals that showed only a little damage six weeks after spraying, survived and recovered in 1964. In contrast, Western red cedar and Lawson cypress apparently sustained more damage than was visible six weeks after spraying; very few plants survived any treatment, not even those assessed six weeks after spraying as showing 'slight', or 'moderate' damage to foliage only. The three hardwood species, beech, oak and sycamore, responded much more quickly than the evergreen conifers, being defoliated by the time they were assessed six weeks after spraying. Those plants which were not dead by this time subsequently recovered. Some assessed as 'dead' six weeks after spraying, sent up basal shoots in the following year. European and Japanese larch and Western hemlock were also rapidly and severely defoliated but did not recover. Trees were more resistant to paraquat after shoot elongation had ceased. Younger trees continued to grow after older trees had stopped, and so Sitka spruce transplants still growing in the nursery were severely damaged when older plants of the same species in the forest had hardened off and were more resistant. Plants which were growing rapidly were highly susceptible and showed the symptoms of paraquat damage within a few days of treatment. On the other hand, most species sprayed in September or October did not develop symptoms immediately. Many plants assessed two weeks after spraying showed little sign of damage, but by the time the six week assessment was made, had deteriorated markedly. Those spruces sprayed in mid-January took even longer to show symptoms of damage; six weeks after treatment these plants looked little affected, yet when seen 10 weeks after spraying, the treated trees had quite a lot more brown foliage than adjacent untreated trees.

Paraquat on Calluna vulgaris (Heather)

In both the two sites chosen for these trials (at Clocaenog and Ceiriog Forests in North Wales), Sitka spruce had grown 18 to 48 inches tall but was in check (i.e. was making slow growth and carrying yellow-green instead of blue-green foliage). The ground vegetation was dominated by the dwarf shrub *Calluna vulgaris* (heather or ling), which was dense on both sites and had grown to about 18 inches tall. There was also a little *Erica cinerea*, *Erica tetralix*, and *Vaccinium myrtillus* (all dwarf shrubs). *Festuca ovina* was present on the Ceiriog site.

Paraquat was applied at 0·5, 1 and 2 pound active ingredient in 40 gallons of water per acre in late July, mid-August and early September, 1963 and in January 1964. The spray was applied overall, using a knapsack and spraying right up to the trees in the plot, but not spraying over them (except where they were concealed under the *Calluna*). No guard was used to protect the young trees.

Table 41 gives the percentage reduction in ground cover (*Calluna*) on the two sites, assessed in September 1964.

Table 41

PERCENTAGE REDUCTION IN GROUND COVER OF CALLUNA VULGARIS FOLLOWING OVERALL SPRAY WITH PARAQUAT. ASSESSMENT—SEPTEMBER, 1964

Rate of Paraquat (pounds active ingredient per acre)	Date and Site (Cl. = Clocaenog; Ce. = Ceiriog)							
	Late July		Mid August		Early September		Mid January	
	Cl.	Ce.	Cl.	Ce.	Cl.	Ce.	Cl.	Ce.
½	75	60	80	60	80	60	50	25
1	95	85	95	85	95	85	50	50
2	97	90	97	90	97	90	50	60

On all plots treated in the late summer, there were a few heather plants with one or more healthy stems remaining. This was probably due to uneven spraying when treatments were applied. On plots treated in January, 1964, the *Calluna* had died back for between 2 and 4 inches at the top of all the shoots, but there had been extensive shooting and recovery and no stems had been killed outright. The affected *Calluna* did not flower.

Of the other weed species present, *Erica tetralix* appeared to be resistant to paraquat. *Vaccinium myrtillus* was scorched in the autumn following treatment but had recovered completely by the end of the year following treatment. *Festuca ovina* appeared to have been killed out.

The crop, Sitka spruce, had improved in all the summer treatments. The colour of all the foliage was blue-green, and the current year's needles appeared to be larger than on trees in untreated plots. There was no sign of increased height growth, but other experience indicates that where spruce is released from 'check', the colour improves in the first year and any increases in height growth do not appear until the second year. Lateral branches caught by the paraquat had died back between 2 and 6 inches, but foliage and trees were otherwise healthy and could not be said to have suffered unduly as a result of the paraquat spray.

2,6-dichlorothiobenzamide

A 7½ per cent active ingredient granular formulation of this compound has been used in all experiments laid down between 1962 and 1964. Granules were distributed by hand over patches a yard square, each with a tree in the centre, planted at least six months and usually more than a year before treatment.

In 1962, a preliminary unreplicated trial was laid down in July at Thetford Forest, Norfolk, on a site planted with Corsican pine and carrying a moderate growth of grasses, mainly *Holcus mollis*, *Agrostis* spp. and *Agropyron repens*, together with a small proportion of mixed broadleaved weed species. Patches were treated at 2, 4 and 8 pounds active ingredient per acre. There was good control of weeds in the first year (Aldhous, 1964) on patches treated at 8 pounds per acre; these plots remained substantially free of weeds until the late summer of 1964, when there was a light but nearly full cover of seedling broadleaved weeds, mainly *Sonchus* sp. Patches treated at 4 pounds per acre could still be distinguished in late summer 1964, but were completely recolonised by weeds. No reliable conclusions could be drawn about the response by the crop.

In 1963 trials were laid down at Bere Forest, near Fareham, Hants, and at Lynn Forest, near Kings Lynn, Norfolk. The former site was on a heavy clay and carried a rank growth of a wide range of weed species, dominated by grasses, in particular, *Deschampsia caespitosa*. It had been planted with Norway spruce in 1958. The latter was on a sand and at the time of treatment carried a moderate ground cover of grasses, mainly *Arrhenatherum elatius* and *Holcus lanatus*, with a little bramble (*Rubus*) and willow herb (*Chamaenerion*). It had been single-furrow ploughed (i.e. one ridge and furrow every 6 feet across the site) and planted with Corsican pine in 1962.

Table 42 gives the mean percentage ground cover at Lynn Forest in October 1963, and the number of plants which died in 1964 as counted in September 1964.

Table 42

RESULTS FROM LYNN FOREST—CONTROL OF WEEDS AND NUMBER OF DEAD PLANTS (CORSICAN PINE)

Date of Application	Percentage ground cover in October, 1963 (pounds active ingredient per acre)					Number of dead plants September, 1964 (out of 12 per treatment) (pounds active ingredient per acre)				
	0	1	2	4	8	0	1	2	4	8
May 1963	92	80	65	35	15	0	0	0	0	3
June 1963	75	75	55	15	15	0	0	0	1	1
July 1963	85	90	50	25	15	0	0	0	6	6

Good control of grasses and herbaceous broadleaved weeds was obtained on plots treated at 8 pounds active ingredient per acre and quite satisfactory control on plots treated at 4 pounds. Bramble was not permanently affected though some foliage was slightly yellowed. In October 1963, many of the Corsican pine at Lynn looked unhealthy on plots treated at 8 pounds per acre. On other plots, trees survived though one or two looked yellow. Table 42 shows that a number of trees died in 1964 in plots treated at 4 and 8 pounds per acre.

At Bere, a similarly good control of weeds was obtained on plots treated at 8 pounds of active ingredient per acre. On plots treated at 4 pounds, the control of weeds was not as good as at Lynn while very little response could be seen on plots treated at 1 and 2 pounds of active ingredient per acre. By the end of 1963, a number of trees on plots treated at 8 pounds of active ingredient per acre had turned yellow. Responses were very slow to appear—an interval of two or three months between treatment and response being usual.

In 1964 experiments were laid down on Corsican and Scots pine at Thetford Forest (Norfolk/Suffolk border), on Norway and Sitka spruce at Gwydyr Forest (Caerns), on Douglas fir and Western hemlock in the Forest of Dean (Glos.), and on Corsican pine in Micheldever Forest (Hants). 2,6-dichlorothiobenzamide was applied at 4, 6, 8 and 12 pounds of active ingredient per acre in late April, May, June or July, except at Micheldever where treatments were applied in the first week in May, June, July and August.

Responses were similar on all sites. The following notes summarise the effects assessed in September, 1964.

Late April/early May treatments

Good control of herbaceous weeds was obtained on all patches treated at 6 pounds of active ingredient per acre or more and on almost all plots treated at 4 pounds of active ingredient per acre. Patches remained clear of weeds for the summer.

Late May/early June treatments

Control of herbaceous weeds was not as good as on patches treated on the earlier date, but plots treated at 6 pounds of active ingredient per acre or more were substantially free of herbaceous weeds.

Late July/early August treatments

On most sites, there was no visible response by the weeds to these treatments. (Mid-September assessment).

The young trees growing on the treated patches were generally unaffected by the lowest rates of application on all sites. Otherwise, the number of plants of all species which developed a characteristic discoloration increased with rate of application and was more marked the earlier in the year the herbicide was applied. Table 43 gives the number of discoloured Norway and Sitka spruce at Gwydyr forest and is typical of the results obtained in these 1964 experiments.

Table 43

NUMBER OF PLANTS OUT OF 30 PER TREATMENT, WITH MARKEDLY YELLOW FOLIAGE OR YELLOW AND DROPPING FOLIAGE, OR BROWN FOLIAGE (DEAD PLANTS)

Rate, active ingredient per acre	Norway Spruce				Sitka Spruce			
	Date applied				Date applied			
	April	May	June	July	April	May	June	July
4	0	1	0	3	0	2	0	0
6	4	2	10	6	2	1	2	0
8	2	5	1	0	1	1	0	0
12	10	10	16	3	4	5	7	1

The yellowing, or death, of plants appeared late in the summer, in some cases three or four months after treatments were applied. Most of the affected plants were uniformly yellow green or olive green, with no zoning or gradation of colour, either along needles or along the shoot. First year and second year needles were usually equally affected, though the latter were generally a darker shade of green than the first year's needles. The colour of the most severely affected plants remained yellow or olive green, but became duller, resembling that of plants which have dried out. The needles on dead plants were a foxy red-brown.

Individual species showed special additional characteristics when examined in September, 1964. Norway spruce shoots drooped on badly affected plants before the needles turned brown. Also, the current year's shoots lacked strength, and could be so easily detached from the plant that in one instance a leading shoot, and in another a lateral, had fallen and were found on the ground near the affected plants. Other current shoots could very easily be pulled from the plants, and could be snapped across the main axis of the shoot like a carrot; the woody tissue in the stem had not matured (this was observed in mid-September when the shoots on healthy plants were firmly attached and had a mature woody core).

A small proportion of the Scots pine on treated plots exhibited a marked yellowing on the tips of the current year's needles which otherwise appeared healthy.

The foliage of some of the Western hemlock developed a very pale upper surface, as though it had been bleached. Part of the mesophyll in such needles was brown.

Woody broadleaved weeds on all sites have continued to grow with little check. Most grasses formed on the experimental areas have been killed except at Gwydyr where the grass *Anthoxanthum odoratum* recovered after an initial check. At several sites, sedges, *Carex* spp., also appeared to recover after an initial check, as did rushes, *Juncus* spp., at Gwydyr and violets, *Viola* spp., and dog's mercury, *Mercurialis perennis*, at Micheldever.

4-amino 3,5,6-trichloropicolinic acid ('Tordon')

'Tordon' has been found to kill certain species resistant to 2,4,5-T or 2,4-D. Preliminary trials were made at Alice Holt Forest in August, 1963, testing 'Tordon' at 1·4 and 2·8 pounds of active ingredient per 100 gallons of water, on oak, ash and hazel. The last were old coppice stools, each with several stems. The stems of the oak were ten inches in diameter, and were girdled and herbicide poured into the fresh girdle. The ash stems, somewhat smaller, were felled and the stumps treated; the hazel was left standing and the base of the stem treated (basal bark spray). There were also both untreated controls and oak and hazel treated with 2,4,5-T at 15 pounds of active ingredient in 100 gallons of diesel oil, and ash stumps treated with ammonium sulphamate at 4 pounds per gallon of water.

Twelve months after treatment, the oak and ash had both been effectively controlled by 'Tordon' at both concentrations. The cambium of the treated oaks was dead, from 6 to 12 inches above the girdle, to below ground level, although the trees still carried some live foliage in early October, 1964. The ash stumps were not completely dead, but there were only one or two shoots per stump and these were weakly and unlikely to survive. Ash is resistant to 2,4,5-T.

'Tordon' applied as a basal bark spray had little lasting effect on the hazel. Some (smaller) stems in each stool died but on the remainder, the foliage, 12 months after treatment, was only a little distorted and the bark and cambium were live. The stools treated with 2,4,5-T were nearly quite dead by this time.

Discussion

The experiments on paraquat have to some extent confirmed what might have been expected knowing the properties attributed to paraquat. The severity of damage to trees following sprays to the bark is remarkable, but so is the apparent resistance of Sitka spruce and one or two other species to overall foliage sprays applied after growth has ceased. Heather, *Calluna vulgaris*, is one of the few woody species to be killed outright by a single moderate application of paraquat, and paraquat might compete with 2,4-D as a means of controlling *Calluna* in checked plantations.

The slow response to paraquat on the bark and also on the dormant foliage of some species must be taken as a warning, to those who may use paraquat for forest weeding, not to draw too hasty conclusions from inspections of the work only a few *days* after spraying. The weeds will be visibly affected but a young conifer crop may take two or three *weeks* or even *months* to show damage caused by the paraquat.

Evidence from other sources shows that paraquat can kill or cut back almost all the herbaceous weeds encountered in the forest, and it is likely that paraquat will become a valued aid to many foresters. These experiments emphasise the need to keep paraquat off the forest crop.

2,6-dichlorothiobenzamide has kept down herbaceous weeds for at least twelve months. The best control of weeds in the season of application has been achieved with applications in April or May. Mid-summer applications have taken their effect in the following year. Crop damage has been severe on plots treated at high rates early in the summer 1964, the possibility of further damage appearing several months after application cannot be dismissed. The future of this herbicide in the forest depends on achieving consistant weed control with minimum crop damage.

'Tordon' might prove a competitor with 2,4,5-T but more information on cost in use and effectiveness are required before firm conclusions can be reached.

Summary

(a) **Paraquat.** The bark of many young conifers is susceptible to damage by paraquat if applied in spring and early summer. The use of a shield may not confer full protection to the lower stem.

The foliage of conifers is killed by paraquat and many species sustain severe damage if sprayed overall with paraquat during the growing season. After growth has ceased, Sitka spruce, Norway spruce and *Abies grandis* become more resistant and are able to withstand overall sprays of 0·5 pounds per acre. *Calluna vulgaris* (heather) is killed or very severely weakened by paraquat at 0·5–2·0 pounds active ingredient per acre.

(b) **2,6-dichlorothiobenzamide** formulated as a granule containing 7·5 per cent active ingredient, has given good control of grasses and broadleaved herbaceous weeds in the year of treatment when applied at 4–6 pound active ingredient per acre or more in April or May. Heavier rates of application often cause crop damage. Rates of 8 pounds per active ingredient per acre applied in spring or summer, control herbaceous weeds for most of the season in the year following application.

(c) **'Tordon'** has only been used in preliminary trials but these suggest that 'Tordon' in water solution may be effective for controlling oak and ash but not hazel.

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BRACKEN CONTROL USING DICAMBA*

By J. R. ALDHOUS

Introduction

Hodgson (1964) reported effective control of bracken in 1963 following treatment with dicamba at 4 and 8 pounds active ingredient per acre in July and August 1962. In his experiments, the control from 2 pounds per acre was variable.

Information from the Velsicol International Corporation, who kindly supplied the material used in these experiments, indicated that effective first year control might be achieved with early summer applications.

The experiments described below were designed to cover these rates and dates.

Method and Materials

Chemical

An aqueous concentrate of the dimethylamine salt of 2-methoxy-3, 6-dichlorobenzoic acid containing 4·8 pounds of active ingredient per Imperial gallon.

Rate

2, 4, 6 or 8 pounds of active ingredient in 100 gallons of water per acre at each date of application.

Date of Application

Towards the end of April, May, June, July or August, 1964.

Plot Size

3 yards square (= 9 square yards). Each plot was separated from adjoining plots by a 2-yard buffer, and was replicated twice on each site.

Method of Application

Overall spraying onto the ground vegetation and litter and on as much bracken as had emerged at the time of spraying. In June, July and August, the bracken received practically all the spray. In April there was very little above the ground at any site.

Sites

Four sites were selected, all covered with dense bracken. None was planted with young trees.

Rogate Forest (near Liss, Sussex)

The site is on a sandy podzol over Lower Greensand with almost pure bracken reaching 3 to 4 feet in height. The rhizomes are mainly between three and six inches below the soil surface. The site was heavily burned six or seven years ago. Other species include *Betula pendula* seedlings, *Calluna vulgaris* and *Erica tetralix*. Together, the ground cover of other species did not exceed five per cent.

*See footnote, p. 133

Forest of Dean (Gloucestershire)

A loamy brown forest soil over Coal Measures. Bracken here reaches four to six feet in height, with rhizomes mainly between three and thirteen inches below the soil surface. The vegetation under the bracken was irregularly distributed but covered between 10 per cent and 50 per cent of the soil surface, and consisted mainly of the grasses *Agrostis tenuis* with some *Holcus mollis*, willow herb (*Chamaenerion angustifolium*), *Viola* sp; Foxglove (*Digitalis purpurea*), brambles (*Rubus fruticosus*) and raspberry (*Rubus idaeus*).

Gwydyr Forest (near Betws y Coed, Caernarvonshire).

A silty brown forest soil over Ordovician shales. Rhizomes are mainly between 8 and 12 inches below the soil surface and the fronds grow to between 4 and 6 feet tall. There is a 60 to 100 per cent grass cover under the bracken, mainly *Agrostis canina* and *Holcus lanatus*, with occasional *Rubus idaeus* and rowan, *Sorbus aucuparia.*

Brendon Forest (near Minehead, Somerset)

The site is on a brown forest soil over Devonian shales. The bracken reaches between 3 and 5 feet in height and the rhizomes mainly lie between 6 and 9 inches. The site has a mixed vegetation cover of grasses, covering up to 60 per cent of the soil surfaces under the bracken with a little *Rubus fruticosus*, *Rosa* sp. and bluebell, *Endymion nonscriptus*, etc.

Results

The following paragraphs describe results in mid-September 1964. On all sites very similar results were obtained. By far the biggest response was associated with date of application. Rate of application appeared to be less important.

April Treatments

Bracken was only just starting to come through when the plots were sprayed. On all sites, plots sprayed at 6 and 8 pounds per acre of active ingredient contained no live fronds of bracken in September. There were one or two green stems per square yard, but these were coiled like springs and had not expanded at all. At Rogate, there were no expanded fronds on the plots sprayed at 4 pounds per acre in April, but only coiled stems at ground level. On the other sites, there were one or two stunted and deformed fronds per square yard on plots sprayed at 4 pounds per acre and between one and eight fronds on plots sprayed at 2 pounds per acre. There were more fronds standing on grassy areas than where the soil was bare of vegetation. Both in these and in later treatments, fronds or parts of fronds which were growing at the time of treatment showed acute curving of all stems, reflexing of the segments (i.e. the small leafy parts of the frond) and die-back of the tips. The few fronds which emerged after treatment were stunted, the pinnules (i.e. those parts of the stem bearing segments) expanded incompletely or failed to develop at all, and those segments which did develop were reflexed and smaller than usual.

May Treatments

At the time of spraying, the bracken was growing rapidly, stems were up to 1½ or 2 feet tall, but none of the fronds had expanded much. In September, treated fronds were blackened and distorted. On all plots treated at 6 and 8 pounds per acre there were only one or two green stems remaining. Plots treated at 4 pounds per acre had up to two fronds per square yard remaining and plots treated at 2 pounds per acre had up to five fronds per square yard. All these were stunted and deformed like those on plots treated in April.

June Treatments

The fronds of the bracken were expanding rapidly at the time of these treatments and at Brendon were almost fully developed. In September the lower parts of the stems (presumably those parts which were mature at the time of treatment) were not distorted. Most of the leafy part of all the fronds were twisted, deformed and browned. The degree of browning was dependent on the rate of application, and ranged from about 60 per cent of the leafy parts browned on plots sprayed at 2 pounds to 100 per cent on plots sprayed at 8 pounds. Many of the main stems remained green even though the foliage was brown.

July Treatments

Fronds were almost completely developed when the July treatments were applied. At three sites, the tips of fronds were distorted and the other parts browned, the extent of the browning again being dependent on rate but not being quite as severe as on plots treated in June. Many stems remained green. At Gwydyr all the bracken went brown and started to collapse and grass was scorched. The reason for this different response is unknown.

August Treatments

These were applied when the bracken was fully developed. In September, only a few weeks after treatment, very little response by the bracken could be seen at any site. There was some browning or bronzing and this was more marked on the plots treated at the heavier rates.

Movement of Dicamba

Particular note was taken of the behaviour of bracken along plot boundaries. On all sites many bracken fronds outside plots treated in April and May showed clear symptoms of dicamba damage, being stunted and failing to expand fully. Most fronds emerging up to twelve inches away were affected, as were several up to eighteen inches. In September there were no healthy fronds inside any plot treated in April or May. This evidence suggests that dicamba can move along rhizomes and agrees with Hodgson's observations (Hodgson, 1964).

Effect on Other Species

Woody species growing at the time sprays were applied were generally defoliated and some species, e.g., birch, *Betula* sp. and heather, *Calluna vulgaris* killed. Others, e.g. rowan, *Sorbus aucuparia* and raspberry, *Rubus idaeus* recovered. Foliage of Japanese larch (*Larix leptolepis*) growing alongside the site at

Gwydyr—which was in a ride separating two plantations—was damaged, the very young foliage on elongating shoots being killed and the older foliage reflexed. Grasses were not affected.

Discussion

These results indicate that complete control of bracken for at least one growing season can be achieved by spraying dicamba at 4 pounds per acre in April or May. On the plots treated at 2 pounds per acre in April and May, the growth of bracken has been checked to such an extent that it could provide only very little competition for any species growing on the site. If the control of bracken achieved in these experiments persists, and these results are confirmed in other years, this chemical will have an important role both in hill farming and in forestry.

Assessments will be made of the growth and number of fronds, and their height and appearance in 1965. Young forest trees will be planted on the plots, some in Autumn 1964 and some in early Spring 1965.

SUMMARY

The dimethylamine salt of 2-methoxy-3, 6-dichlorobenzoic acid (dicamba) has given complete control of bracken (*Pteridium aquilinum*) for the growing season in the year of treatment when applied in April, May or June at rates from 4 lb. active ingredient per acre. The bracken remaining at the end of the growing season on plots sprayed at 2 lb. active ingredient per acre was sparse and seriously malformed. Sprays applied in July or August have caused discoloration and some deformation of bracken.

REFERENCE

HODGSON, G. L. (1964). Sodium 3, 6-dichloro-2-methoxybenzoate for the control of bracken (*Pteridium aquilinum* (L) Kuhn): Results of Preliminary Trials. *Weed Res.* 4, 167–168.

THE USE OF SEEDLINGS FOR FOREST PLANTING IN SCOTLAND AND NORTH ENGLAND

By J. FARQUHAR

The gradual improvements in methods of site preparation (especially on our important upland types) which has been effected over the last few decades, has at various times given rise to the hope that plants such as seedlings or undercut stock might replace the standard transplant type, with economies in cost of stock. Also, the transplant itself has changed markedly from improvements in nursery management, more especially in nutrition; and in the best nurseries the one-year seedling of a number of species is of a size which can be handled conveniently. Thus the transplant is now commonly based on the one-year seedling.

This paper deals with work done on seedlings, with special attention to certain large scale experiments conducted in the early 1950's on the use of one-year seedlings from heathland nurseries or partially sterilised seedbeds in the older types of nursery. Atterson (*Rep. For. Res. 1963*) dealt with experiments in the use of undercut stock, these experiments including 2 + 0 undisturbed seedlings—a very different type of plant to those dealt with here.

Early Trials

Seven experiments using nursery stock of different age and type were laid down in various Scottish forests in the years 1926 to 1929 by the Forestry Commission Research Branch (Guillebaud 1933). The results were conflicting, but the general conclusion was drawn that with Scots pine 1 + 1 or 2 + 1 transplants gave better results then either seedlings or older transplants. The experiments with Norway and Sitka spruces revealed that the usual post-planting check was overcome quicker by the older plants. As a result of a number of large-scale forest trials (involving 1½ million seedlings) in 1931, 1932 and 1933, it again appeared that seedlings could only be successfully and economically substituted for transplants provided they were of exceptional quality and planted on good sites with special care (Guillebaud 1935). An advance in nursery technique to improve size and quality of seedlings was advocated. 'Topgrade seedlings only should be used, profusion of roots and general sturdiness are more important qualities than height.' From the result of trials in two forests in Wales, Long (1932) concluded that two-year-old Sitka spruce seedlings raised under normal nursery conditions could be successfully planted on turfs if they were planted so deeply that only one inch or less of the shoot protruded. Gordon (1933) found that the survival of normal two-year-old Sitka spruce seedlings was between 50 per cent and 60 per cent, but increased to 85 per cent when selected stronger plants were used. Munro (1934) found two and three-year-old Sitka spruce seedlings successful on turfs, but where notched into mineral soil, weeding costs were considerably more than for transplants.

The detailed results of these early trials are of little interest since the size of seedlings used then (1 to 2 inches) bears little relation to the size achieved now (3 to 6 inches) by improved nursery methods.

Post-War Experiments

The post-war adoption of ploughing as normal practice on the heaths and peat-covered uplands redirected attention to the use of seedlings, in the hope that the economy so made would offset to some extent the increased cost of ground preparation. About the same time, the method of raising plants in heathland and woodland nurseries, and partial soil sterilization by steam or formalin in established nurseries, led to the production of large one-year seedlings. This combination of factors greatly renewed interests in the possible use of seedlings.

During the latter half of the 1940's and early 1950's, 41 experiments were laid down in various forests in different parts of Scotland and North-East England to test how far one-year seedlings, raised in heathland nurseries or on partially sterilized soil, could be used for planting on ploughed land. In one series of ten experiments using Sitka spruce, the results after six years showed that in 28 comparisons out of 34, 1 + 1 transplants were highly significantly taller than one year (1 + 0) seedlings, which also had poorer survival rates. In another series of eleven experiments, the average survival of Sitka spruce 1 + 1 transplants was 90 per cent, compared with 60 per cent for 1 + 0 seedlings, and height growth was four feet and three feet respectively after six years. A third series of seven experiments compared the forest performance of 1 + 0 Sitka spruce seedlings produced as a result of a large number of different nursery treatments; there were no transplant controls. All the seedlings had heavy losses.

The low survival value of seedlings in many of the experiments was often attributed to damage by rodents such as the blue hare, *Lepus timidus*, and the field vole, *Microtus agrestis*, and occasionally to deer, or even to trespassing sheep. While the transplants were subject to similar attacks, they were better able to survive and recover from the damage than the less robust and smaller seedlings. The same can be said for damage by frost and blasting winds. Although survival was somewhat higher on the heathland soils, the sites often proved unsuitable for spruce, and both transplants and seedlings went into 'check' at an early age.

In the series of eleven experiments referred to above, various positions and two depths of planting (normal and one-third of the shoot buried) both on the plough ridges and in furrows, were tried. Results with seedlings showed a trend similar to that with transplants, i.e. that the planting position giving highest survival rates on peat is in a 'step' cut on the side of the ridge, whereas the best planting position on the mineral soil of the heaths is in the bottom of the furrow. In nearly every case planting on the top of the ridges gave the highest number of failures. In contrast to Long's evidence (1932) there was no advantage in deep planting.

Towards the end of the 1940's, 1 + 0 seedlings raised in heathland nurseries were also tried in normal forest practice. These trials by Conservancy staff showed great variation in success on different site types; for example, planting on grassy sites at high elevations with a short frost-free period resulted in severe damage to small plants, while at others (including many heath sites) results were more promising.

In 1949, over 200,000 Sitka spruce one-year seedlings raised in a heathland nursery and planted in various forests in the West Scotland Conservancy had a survival rate seldom less than 90 per cent. The cost of planting the seedlings was, however, considerably higher than for transplants, since more care had to be taken with the preparation of the ground (planting position) and with actual planting, so that it was doubtful if the total cost was less. (Dier 1950).

Investigations carried out in 1949 (Edwards and Holmes 1951), on the effect of size of plant at time of planting, showed that growth and survival of 2 + 0 Sitka spruce seedlings were much more dependent on general sturdiness of the plants (as expressed by root collar diameter and by the proportion between height and diameter) than on height. Green and Wood (1957) found little advantage in initial survival from the use of fertilizers (phosphate, potash or nitrogen) on either one-year or two-year seedlings of nine species of conifers.

Zehetmayr, referring to the age and type of plant of the common conifer species planted on peat (1954) and upland heath (1960) sites, emphasises in nearly every case the superiority of transplants over seedlings. Only where Scots pine was planted on peat areas was seedling survival about as good as that of transplants; and only on *Calluna-Molinia* vegetation did seedlings of this species grow almost as well as transplants. He concludes, as did Guillebaud (1933), that one-year seedlings of several species could be used on some sites provided great care is taken in handling and planting.

Large Scale Trials on One-Year Seedlings

The 1951 Experiments

The new nursery techniques were capable of producing 1 + 0 seedlings 3 to 6 inches tall, and in 1951 two experiments were commenced to compare these seedlings with normal 1 + 1 transplants, which were about 4–10 inches tall. Using five commonly planted species, plots of these two types of plant were planted in pairs over the full range of conditions found in two forests selected to give a contrast in soil and climate. Scots pine, Lodgepole pine, Japanese larch, Norway spruce and Sitka spruce were used according to the type of ground; and to allow for the variation in climate from year to year, planting extended over five years. Glentrool, Kirkcudbrightshire, on deep peat in the West of Scotland (experiment 8 P.51–55) and Fetteresso, Kincardineshire, on the upland heaths of the east of Scotland (experiment 3 P.51–55) were chosen as being representative of the types of land where seedlings were likely to be used on a large scale.

Both forests have a peaty surface cover, which is often the top layer of a peaty podsol at Fetteresso, though true peat over 24 inches deep also occurs; whereas at Glentrool true peat is more common, and in parts is thirty inches deep or more. *Molinia* was the dominant species on the slopes at Glentrool, with *Trichophorum*, *Eriophorum*, *Erica tetralix* and *Sphagnum* on the flat, wet peat bogs. Some bracken with *Calluna* occurred on the drier knolls. At Fetteresso, the vegetation was mainly strongly-growing *Calluna* on the drier slopes, with *Trichophorum* and *Eriophorum* on the deeper and moister peat. Elevation of the plots ranges from 250 to 1,200 feet at Glentrool and 500 to 900 feet at Fetteresso. Exposure is moderate to severe at both forests. At Glentrool most plots have either a west or east aspect, whereas at Fetteresso they are on north or south-facing slopes. Mean annual rainfall is between 70 and 80 inches at Glentrool and about 35 to 40 inches at Fetteresso.

Between 20 and 30 pairs of plots were laid out in each of the five years at each forest. They were located to cover, as far as possible, the main vegetation types and the full range of physical site conditions encountered within the area. The chosen sites were classified according to depth of peat, vegetation type and elevation.

One species was usually chosen for each site type, but others were also planted where alternatives seemed suitable. Each plot consisted of 100 1 + 0 seedlings and 100 1 + 1 transplants, planted alongside each other. Frequently plots of two species were planted in three-row band mixtures, thus allowing two species to be compared on the same site type. Table 44 gives the number of plots planted for each species, in each of the five years of the experiments.

Table 44

SPECIES AND NUMBERS OF PLOTS, BY YEARS OF PLANTING

Forest	Planting year	Scots pine	Lodgepole pine	Japanese larch	Norway spruce	Sitka spruce	Total
Glentrool	51	3	8	6	6	16	39
	52	6	3	3	6	9	27
	53	6	6	3	—	12	27
	54	—	9	3	—	21	33
	55	3	12	3	3	12	33
Total		18	38	18	15	70	159
Fetteresso	51	11	9	11	—	9	40
	52	21	16	8	—	6	51
	53	19	18	5	—	14	56
	54	16	12	6	—	9	43
	55	12	13	6	—	8	39
Total		79	68	36	—	46	229

The plots planted in 1951 at Glentrool were all on single-furrow Cuthbertson ploughing, five feet apart. Over the other four years, spacing of furrows varied from five to thirty feet, turfs from the ridges being spread in the intervening spaces at the required planting distances. At Fetteresso all plots were on single-furrow tine ploughing, at five feet spacing. Planting was on or near the top of the ridges or turfs and was carried out each year during the months of March and April. All plants received the normal top dressing of approximately two ounces of ground mineral phosphate per plant soon after planting, except for fifteen plots in the 1953 planting area at Fetteresso in which phosphate was not considered necessary.

1 + 0 seedlings were supplied from heathland nurseries or from partially sterilized seedbeds in Research nurseries; only seedlings over a fixed minimum height (see Table 45) were used.

1 + 1 transplants were used in all cases, except for the Norway spruce in 1951 at Glentrool which were 2 + 2. Transplants were supplied from Research nurseries. The height of 1 + 1 transplants used for planting are given in Table 46.

The Norway spruce 2 + 2 transplants planted in 1951 at Glentrool ranged in size from 6 to 12 inches. Overall, the Japanese larch transplants were double the height of the seedlings; for other species, the transplants were 1½ to 2 times the height of the seedlings.

All planting was done by Research labour under the close supervision of a Forester.

Table 45

HEIGHT OF SEEDLINGS USED FOR PLANTING IN THE PLANTING SEASONS 1951–1955

inches

Species	Glentrool			Fetteresso		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Scots pine	2½	3	4	2½	3½	4
Lodgepole pine	2½	3	6	2½	3½	4½
Japanese larch	3	4	6	3	4	5
Norway spruce	2½	3½	5	—	—	—
Sitka spruce	3	4	6½	3	3¾	4½

Table 46

HEIGHT OF TRANSPLANTS USED FOR PLANTING IN THE PLANTING SEASONS 1951–1955

inches

Species	Glentrool		Fetteresso	
	Range	Average	Range	Average
Scots pine	3– 8	4½	4–10	6
Lodgepole pine	3– 9	4½	2– 9	5
Japanese larch	6–12	8	4–18	9½
Norway spruce	5– 8	6	—	—
Sitka spruce	4–12	7	3–11	7

Results of the Experiments after Six Growing Seasons

Comparisons between species within sites

The Glentrool plots were assessed for survival at the end of the first, third and sixth growing seasons, and for height growth at the end of the sixth. It was intended that the same frequency of assessment be done at Fetteresso, but, as a large number of the plots were inadvertently beaten-up with transplants of the same species between the third and sixth years, it was only possible to record first-year and third-year survivals. The detailed results showing the survival percentage and height in relation to species and site types, are summarised in Tables 48 to 51. The sixth-year survival and height growth for Glentrool and the third-year survival for Fetteresso are considered below by species, year of planting, site type, elevation, peat depth and incidence of damage.

Scots pine

Glentrool. For both transplants and seedlings, survival and height growth were best on the grass/bracken/*Calluna* knolls and slopes, where transplants had a survival rate of 87 per cent and seedlings 72 per cent. On other vegetation types the average survival rate was 76 per cent for transplants and 52 per cent for seedlings, while the difference in height growth was less than six inches.

Fetteresso

Transplant survival rate averaged just over 80 per cent and at worst (73 per cent) was better than the best seedling survival rate (72 per cent). The average seedling survival rate was 56 per cent.

Lodgepole pine

Glentrool

Omitting five plots, three on a poorly drained, infertile deep peat site and two severely damaged by rodents, survival rate was 79 per cent for transplants and 65 per cent for seedlings. Height growth of seedlings was only slightly less than that for transplants.

Of the six plots planted in 1953, three (referred to above) had to be abandoned because the sites proved unsuitable for the species chosen. The other three had unusually poor survival rates, averaging 35 per cent for transplants and 48 per cent for seedlings. While this was below the average survival rate for seedlings, it was exceptionally low for transplants. No explanation can be given for this unusual result.

Fetteresso

The average survival rate was 77 per cent for transplants and 56 per cent for seedlings. Survival of transplants in the plots planted in 1954 was lower (63 per cent) than for seedlings (70 per cent) and although this result is difficult to explain, extensive hare damage to some plots was reported; the dry summer of 1955 also caused a marked increase in the transplant losses during the second year.

Japanese larch

Glentrool

Over all sites the average survival rate was 87 per cent for transplants and 71 per cent for seedlings. On the *Molinia* and grass/bracken sites, transplants were over two feet taller than seedlings, but on the less fertile *Molinia/Calluna* areas, seedlings were taller than transplants by about one foot.

Fetteresso

Average survival rate for all sites was 77 per cent for transplants and 44 per cent for seedlings.

Norway spruce

Glentrool

Taking all site types together, survival rates averaged 87 per cent for transplants and 57 per cent for seedlings. Height growth of seedlings was approximately two-thirds that of transplants. Norway spruce was not used at Fetteresso.

Sitka spruce

Glentrool

On all but one of the site types, transplant survival rate was over 90 per cent. Seedling survival rate, which averaged 66 per cent, varied considerably, ranging from as low as 13 per cent on the poorer deep peats to as high as 91 per cent on the good grass and shallower peat sites. Height growth of seedlings on the grass sites was about three-quarters that of transplants; seedlings on the deep peat sites were about two-thirds as tall as transplants.

Fetteresso

The overall transplant survival rate was 90 per cent; as at Glentrool, the range for seedlings was considerable, from 26 per cent to 92 per cent with an average of 64 per cent.

Comparison between Years of Planting

Although both transplants and seedlings were carefully selected, they came from different nurseries and included different seed origins. In addition, the planting sites varied from year to year, so that comparisons cannot easily be made between the five planting years. At Fetteresso the survival rate for seedlings planted in 1955 was lower for all species than in any of the other planting years. At Glentrool differences in survival rate between years of planting were not important. As will be seen from Table 47 which compares the growing season rainfall at Glensaugh (six miles from Fetteresso), with that at Glenlee (eight miles from Glentrool), there was a notable lack of rain at Glensaugh for all months except May during 1955, whereas at Glenlee the rainfall that year was little below average.

Table 47

RAINFALL IN INCHES

APRIL—AUGUST 1951–1955

Glensaugh

Year	April	May	June	July	August	Total
1951	4·34	1·65	2·80	4·51	3·97	17·27
1952	2·34	3·69	3·68	2·37	4·76	16·84
1953	4·67	2·55	2·42	4·45	2·01	16·10
1954	1·10	5·09	2·30	3·25	4·33	16·07
1955	0·75	2·82	1·33	0·97	0·63	6·50

Glenlee

Year	April	May	June	July	August	Total
1951	3·27	2·80	2·61	2·20	10·03	20·91
1952	2·83	3·48	2·98	3·63	5·24	18·16
1953	2·88	3·51	2·17	6·52	3·72	18·80
1954	1·67	4·56	4·79	3·97	4·29	19·28
1955	2·72	4·59	3·44	2·71	1·59	15·05

Survival rates amongst transplants and seedlings, often quite high at the end of the first growing season, frequently decreased considerably by the end of the third year, but the decrease was much less between the third and sixth year. These differences were common irrespective of the year of planting. (See Tables 48 and 50).

Effect of Site type on Growth of Transplants and Seedlings

Vegetation type had a great effect upon the amount of weeding required. An attempt was made at Glentrool to compare the difference in weeding costs between transplants and seedlings over the six years, and weeding times were therefore recorded for each plot; but it was found that in a large number of cases the data could not be used. For instance, it was clear that comparison could not be made for plots where the survival rate of seedlings was considerably less than that for transplants. However, where difference in survival between the two types of plants was less than 10 per cent, it was estimated that the cost of weeding seedlings was approximately one and a half times that for transplants. The smaller and less bushy seedlings took longer to overcome the competition of grass vegetation than the more sturdy transplants. The necessity for early weeding did not arise at Fetteresso, where the heather took much longer to recolonize the plough ridges than did the grass at Glentrool.

At Glentrool, transplant survival rate at six years averaged between 80 per cent and 90 per cent for all species on all vegetation types. Survival rate of pine seedlings was low but Scots pine did best on the grass/bracken/*Calluna* slopes (72 per cent). On the same type Japanese larch had its lowest survival rate (62 per cent); its survival rate also averaged 80 per cent on grass with *Molinia.* Sitka spruce seedling survival rate also averaged 80 per cent on the better *Molinia* types, but fell to between 40 per cent and 60 per cent on the poor bog types.

On the heaths at Fetteresso, where the difference between the three vegetation types was less marked than between the types at Glentrool, seedling survival rate at three years averaged 56 per cent for all species. Japanese larch was the poorest with an average of 44 per cent and Sitka spruce best at 64 per cent. The average for transplants of all species at Fetteresso was 81 per cent.

Elevation

At Glentrool, where elevation ranged from about 250 feet to near 1,200 feet, its effect on both transplants and seedlings was to cause a reduction in survival rate for the pines, particularly Scots pine. In contrast, the other species tended to show better survival rates for seedlings (and in some cases transplants) at the higher elevations. The reason for this surprising result is probably the lesser weed competition at the upper sites. Rate of growth of all species decreased with increase in elevation.

At Fetteresso, where the difference in elevation between plots was seldom more than 300 ft., comparisons were limited, but Scots pine seedlings and Japanese larch transplants and seedlings had lower survival rates at the higher elevation, while with Lodgepole pine and Sitka spruce there was little difference.

Depth of Peat

Depth of peat had little general effect at either of the two forests. Results, frequently offset by other site factors, e.g. elevation and vegetation differences, are difficult to interpret, but making a general comparison between shallow (under 12 inches) and deep peat (over 12 inches), there was little difference in survival rate, or height growth. Only on the very deep peat (over 30 inches) at Glentrool did the Sitka spruce seedling survival rate drop to the low value of 42 per cent, while at the same forest the small number of Norway spruce plots averaged 60 per cent on *deep*, as compared with 50 per cent on *shallow* peat.

Again at Glentrool, Scots pine transplants and seedlings were four to five times taller on shallow peat with a grass/bracken/heather vegetation than they were on deep peat.

Damage by Game, Rodents and Climatic Agencies

A large number of plots of both transplants and seedlings were damaged by deer, hares, voles and occasionally by blackgame (*Tetrao tetrix*), particularly at the higher elevations; the pines more so than the spruces or larch. Because the damage appeared to be sporadic and to affect transplants and seedlings equally, it was not taken out of the assessments. No appreciable damage by late and early frost or from severe exposure was reported from either of the two forests. Reports from Fetteresso mentioned that heavier losses in the 1954 and 1955 planting may have been due to the long drought during the summer of 1955.

Summary of Results

Survival

Survival rates of *pine transplants* averaged around 75 per cent to 80 per cent; whereas the survival rates of *pine seedlings* averaged 55 to 65 per cent.

Japanese larch transplants had survival rates in the region of 75 to 80 per cent, but seedling plots were variable, being about 70 per cent to 75 per cent at Glentrool and falling to near 40 per cent at Fetteresso.

The survival rate of Norway spruce at Glentrool averaged about 90 per cent for transplants; seedling plots varied somewhat, the average was about 55 per cent.

Sitka spruce transplants had higher survival rates than the pines or larch. Nearly all plots were around 90 per cent at Fetteresso and over this figure at Glentrool. Seedling survival rate was much more variable, ranging from under 20 per cent on the less favourable to over 90 per cent on some of the better sites, but with an average of 65 per cent at both forests.

Height Growth

Height growth of seedlings at Glentrool, at the end of six years, averaged between half and three-quarters that of transplants for Norway spruce and Sitka spruce. The other three species showed smaller differences between seedlings and transplants, and in some plots seedlings of Lodgepole pine and Japanese larch were actually taller than transplants. This was possibly attributable, in part, to provenance differences.

Weeding

The amount of weeding necessary for seedlings on the grass vegetation at Glentrool was approximately one and a half times that required for transplants.

Damage by Animals, Birds and Weather

There was no evidence to suggest that seedlings were more liable to be attacked by animals or birds, or to be worse damaged by climatic agencies than transplants, but where damage did occur seedlings were less likely to recover than transplants.

Table 48

GLENTROOL EXPERIMENT 8, 1951

Mean Survival Rates of all Plots at First, Third and Sixth Years and Height at Six Years

Percentages

	Scots pine		Lodgepole pine		Japanese larch		Norway spruce		Sitka spruce		Grand Mean	
	T	S	T	S	T	S	T	S	T	S	T	S
1st year survival	96	84	91	78	98	88	96	84	98	86	96	84
3rd year survival	89	66	80	68	94	73	90	63	95	71	90	70
6th year survival	78	56	79	66	87	71	87	57	91	66	86	64
Mean height at 6 years (feet)	2·3	1·9	3·4	3·1	6·1	5·2	3·0	2·0	3·9	2·8	—	—

Notes. T = Transplants.
S = Seedlings.
Mean of all planting years.

Table 49

GLENTROOL EXPERIMENT 8, 1951

Mean Survival Rates of all Plots by Site Types at First, Third and Sixth Years and Height at Six Years

Percentages

Depth of peat	Elevation feet above sea level	Year of Survival and Height (ft.) Assessment	Scots pine								Lodgepole pine						Japanese larch					
			B Molinia—Grasses		D Molinia—Tricho-phorum—Calluna—Erio-phorum—Sphagnum		F Grass—Bracken—Calluna		G Molinia—Calluna—slopes		B Molinia—Grasses		D Molinia—Tricho-phorum—Calluna—Erio-phorum—Sphagnum		E Erio-phorum—Tricho-phorum—Sphagnum—Erica tetralix—Calluna		B Molinia—Grasses		F Grass—Bracken—Calluna		G Molinia—Calluna slopes	
			T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S
I under 12 ins.	under 500	1st year surv.					88	77	98	82									97	79	96	80
		3rd year surv.					87	74	96	73									93	64	93	69
		6th year surv.					87	72	77	64									92	62	63	68
		6th year ht.					5·2	4·0	1·1	1·2									8·2	6·1	2·9	4·4
	500–800	1st year surv.	98	92							87	68					100	98				
		3rd year surv.	81	56							80	61					99	87				
		6th year surv.	74	46							80	58					99	86				
		6th year ht.	1·6	1·4							3·4	2·8					6·4	4·0				
	800–1,200	1st year surv.							95	76											99	94
		3rd year surv.							89	53											90	86
		6th year surv.							78	36											87	79
		6th year ht.							1·8	1·4											4·4	4·8
II 12–30 ins.	500–800	1st year surv.											88	68								
		3rd year surv.											66	52								
		6th year surv.											62	47								
		6th year ht.											2·6	2·7								
	800–1,200	1st year surv.			99	95																
		3rd year surv.			90	75																
		6th year surv.			75	61																
		6th year ht.			1·9	1·4																
III over 30 ins.	under 500	1st year surv.											89	87	92	81						
		3rd year surv.											86	82	79	64						
		6th year surv.											85	79	78	64						
		6th year ht.											2·7	1·4	4·8	5·3						
	500–800	1st year surv.													95	86						
		3rd year surv.													90	81						
		6th year surv.													89	79						
		6th year ht.													3·8	3·3						

Notes: T = Transplants.
S = Seedlings.
Mean of all planting years.

Table 49—*continued*

Percentages

Depth of Peat	Elevation (ft.)	Year of Survival and Height (ft.) Assessment	Norway spruce						Sitka spruce							
			A Molinia		C Molinia—Juncus		D Molinia—Trichophorum—Calluna—Eriophorum—Sphagnum		A Molinia		B Molinia Grasses		D Molinia—Trichophorum—Calluna—Eriophorum—Sphagnum		E Eriophorum—Trichophorum—Sphagnum—Erica tetralix	
			T	S	T	S	T	S	T	S	T	S	T	S	T	S
I under 12 ins.	under 500	1st year surv.			93	76										
		3rd year surv.			91	51										
		6th year surv.			87	46										
		6th year ht.			3·2	2·2										
	500–800	1st year surv.			96	73					99	88				
		3rd year surv.			89	57					92	64				
		6th year surv.			88	54					92	62				
		6th year ht.			3·2	2·0					4·5	2·8				
II 12–30 ins.	under 500	1st year surv.					99	97	98	94						
		3rd year surv.					86	60	98	91						
		6th year surv.					83	53	98	91						
		6th year ht.					4·1	2·5	4·5	3·4						
	500–800	1st year surv.	97	87	97	89			99	83	99	96	100	92		
		3rd year surv.	91	74	92	73			97	79	97	91	98	86		
		6th year surv.	89	68	88	62			97	78	97	91	98	86		
		6th year ht.	2·2	1·5	2·3	1·7			4·3	3·9	4·9	3·9	3·9	3·0		
	800–1,200	1st year surv.							92	78	98	95	99	91		
		3rd year surv.							91	74	92	88	98	87		
		6th year surv.							90	72	92	82	97	83		
		6th year ht.							3·5	2·6	2·5	2·0	4·2	2·5		
III 30 ins. +	under 500	1st year surv.											98	77	97	65
		3rd year surv.											96	66	96	44
		6th year surv.											95	61	93	43
		6th year ht.											4·3	3·2	4·1	2·8
	500–800	1st year surv.											98	90	99	87
		3rd year surv.											86	44	94	65
		6th year surv.											53	13	92	55
		6th year ht.											2·2	1·5	3·2	2·0
	800–1,200	1st year surv.													93	48
		3rd year surv.													91	46
		6th year surv.													91	42
		6th year ht.													3·1	2·0

Notes: T = Transplants.
S = Seedlings.
Mean of all planting years.

Table 50

FETTERESSO EXPERIMENT 3, P. 51

Mean survival Rates of all Plots at First and Third Years

Percentages

	Scots pine		Lodgepole pine		Japanese larch		Sitka spruce		Grand Mean	
	T	S	T	S	T	S	T	S	T	S
1st year survival	89	67	87	66	89	64	95	78	90	68
3rd year survival	80	56	77	56	77	44	90	64	81	56

Notes. T = Transplants.
S = Seedlings.
Mean of all planting years.

Table 51

FETTERESSO EXPERIMENT 3, P. 51

Mean Survival Rates of all Plots by Site Types at First and Third Years

Percentages

Depth of peat	Elevation (feet)	Year of Survival Assessment	Scots pine						Lodgepole pine						Japanese larch				Sitka spruce					
			A Calluna		B Calluna—Tricho-phorum		C Tricho-phorum—Calluna—Erio-phorum—Erica tetralix		A Calluna		B Calluna—Tricho-phorum		C Tricho-phorum—Calluna—Erio-phorum—Erica tetralix		A Calluna		B Calluna—Tricho-phorum		A Calluna		B Calluna—Tricho-phorum		C Tricho-phorum—Calluna—Erio-phorum—Erica tetralix	
			T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S
I under 6 ins.	600–800	1st year	90	69	89	78			82	55					92	69	93	75	99	75				
		3rd year	79	57	88	69			79	36					75	48	87	63	97	44				
	800–900	1st year	89	70					98	42					92	54								
		3rd year	82	60					—	—					92	36								
II 6–12 ins.	600–800	1st year	86	67					86	70					94	73			93	82				
		3rd year	78	56					77	59					79	49			90	70				
	800–900	1st year	91	59	80	52			91	54	72	78			82	58	52	34	98	91	94	84		
		3rd year	81	40	73	45			84	39	62	70			76	54	44	16	95	77	89	71		
III 12–24 ins.	600–800	1st year	94	63					92	86			78	38	92	51			99	70			83	46
		3rd year	74	62					84	73			74	33	87	33			92	50			74	26
	800–900	1st year	88	75	92	65			85	74	87	69							98	92	90	74		
		3rd year	83	58	80	52			82	63	78	56							96	83	88	66		
IV over 24 ins.	600–800	1st year					98	86					97	86									99	95
		3rd year					92	72					94	71									98	92
	800–900	1st year			94	74	89	65			95	52	83	58									93	45
		3rd year			90	52	80	49			—	—	69	48									88	31

Notes: T = Transplants.
S = Seedlings.
Mean of all planting years.

Discussion

The evidence from this large-scale trial of one-year seedlings is not so much that their performance (survival value and early height growth) is *generally poorer* than that of transplants (though it usually is so), but that it has been *very much less reliable*. Some of the better performances recorded would almost certainly be regarded as successful, economically speaking, even taking into account increased costs of planting and weeding. These trials however confirm the general opinion that the use of one-year seedlings is too hazardous for general practice. The development of a suitable type of one-year seedling for the more favourable sites is plainly not an impossibility, though in the search for a cheaper plant the undercut two-year seedling seems at the moment the more promising line.

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TRIAL PLANTATIONS AT HIGH ELEVATIONS

By S. A. NEUSTEIN

Introduction

Many plantations made under the normal afforestation programme have been extended to high elevations. The oldest of these suffer from deficiencies in silvicultural technique (e.g. they are unploughed and/or unmanured), and good records of establishment success are rare. In 1958 a general instruction was issued formalising the establishment of high elevation trial plantations. The siting of such plantations would remain the responsibility of the local forest (Conservancy) staff, and Research Branch would give advice where required, and maintain records of site and crop and make periodic assessments of growth. These plantations are generally larger than five acres in extent, lie well above the current local planting limit, ranging from 800 to 2,400 feet in elevation; the choice of species has been based on local experience of those most likely to succeed. Appropriate modern establishment techniques have been used.

46 such trial plantations have been recorded. All except one have been planted since 1941, and all but eight are in Scotland—approximately half in East Scotland. The small group of trial plots at high elevations in Wales fall into a somewhat different category, since they contain other experimental work, and are not dealt with here. In late summer and autumn of 1963 all plantations over four years of age (30 sites) were visited by Research staff and a general report made on the growth and condition of the trees. Table 52 gives the distribution, elevation range and main species of the plantations.

All plots at the time of inspection had had one growing season since the severe winter of 1962/63. All but three plantations were established on ploughed ground. Most were manured with phosphates at normal rates (1½ to 2 ounces of ground mineral phosphate per plant). Over twenty species were represented, but as can be seen from Table 52 Lodgepole pine and Sitka spruce were the main constituents of most of the plantations.

Initial survival rate was reasonable in all plots, and at the time of inspection only two plantations gave doubts about their capacity to produce fully stocked woodland.

The inspection reports were of a general nature, without detailed assessments. Heights were described by ranges, and exposure symptoms and conditions were described qualitatively. However, graphs have been drawn to show the relation between the growth of Lodgepole pine, Scots pine, Sitka spruce and various site factors. Firstly, for Lodgepole pine, mean annual height growth was plotted against elevation, aspect and vegetation type. An attempt was made to estimate exposure by summing at each site the angles to the surrounding horizon, and mean annual height growth was plotted against this total. However, none of the above site factors showed an obvious correlation with the condition of the Lodgepole pine, but it was noteworthy that several of the plantations showing the best growth are on the worst vegetation type, i.e. *Trichophorum/Calluna;* this, however, is clearly confounded with depth of peat. Even when provenances of Lodgepole pine were distinguished, no clear pattern was discernible. There is, however, much other experimental evidence on the differences in exposure resistance of Lodgepole pine due to provenance variation. Needle retention of

Table 52

DISTRIBUTION, ELEVATION AND MAIN SPECIES OF PLANTATIONS

Conservancy and Forest	Elevation (feet)	Planting year	Main Species
North Scotland Conservancy			
Morangie	950	52	Lodgepole pine.
Morangie	1,000	52	Lodgepole pine.
East Scotland Conservancy			
Black Craig	1,100–1,270	59	Hybrid larch.
Black Craig	1,300	60	Japanese larch.
Newtyle, Plot 1	1,010	54	Lodgepole pine.
Newtyle, Plot 2	930	55	Lodgepole pine.
Newtyle, Plot 3	950	54	Lodgepole pine.
Drumtochty	1,350–1,400	56	Scots pine; Europen larch; Birch; Sitka spruce; Lodgepole pine.
Drumtochty	1,300–1,350	56	Scots pine; European larch; Birch.
Pitfichie	1,500	55	Lodgepole pine.
Allean	1,200–1,440	49–50	Scots pine; Sitka spruce.
Allean	1,200–1,440	49–50	Lodgepole pine.
Clashindarroch	1,050	55	Lodgepole pine; Sitka spruce.
Clashindarroch	1,300	58	Lodgepole pine.
Clashindarroch	1,320	56	Lodgepole pine.
Elchies	1,010	56	Lodgepole pine.
Fonab	1,070–1,300	58	Scots pine; Japanese larch.
Fonab	1,070–1,300	59	Scots pine; Japanese larch; Sitka spruce.
Glenlivet	1,450–1,600	59	Lodgepole pine; Sitka spruce.
Glenlivet	1,750–1,800	54	European larch; Scots pine; Japanese larch; Lodgepole pine; Norway spruce; Sitka spruce; Noble fir; Douglas fir.
Glenlivet	1,620	59	Lodgepole pine.
Glenlivet	1,560	56	Lodgepole pine.
Dallas	1,050	51	Lodgepole pine; Sitka spruce.
Rosarie	1,000–1,150	58	Lodgepole pine.
Glen Isla	1,520	53	Lodgepole pine; Japanese larch; Maritime pine.
South Scotland Conservancy			
Glen Trool	800–1,000	49	Sitka spruce.
Glen Trool	1,250–1,500	52	Sitka spruce.
Glen Trool	1,700–1,750	59	Sitka spruce; Lodgepole pine.
Ae	1,500	58	Lodgepole pine; Sitka spruce.
Ae	1,400–1,500	58	Lodgepole pine; Sitka spruce.
North West England Conservancy			
Thornthwaite	1,650–1,750	53 & 57	Lodgepole pine; Maritime pine; Engelmann spruce; White spruce.

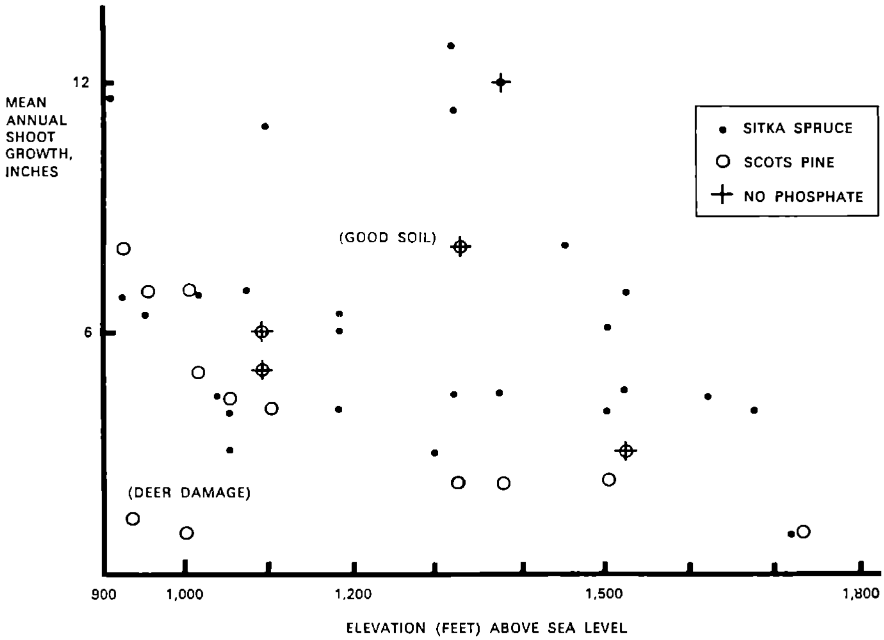

FIGURE 10. Mean annual shoot growth of Sitka spruce and Scots pine, relative to elevation.

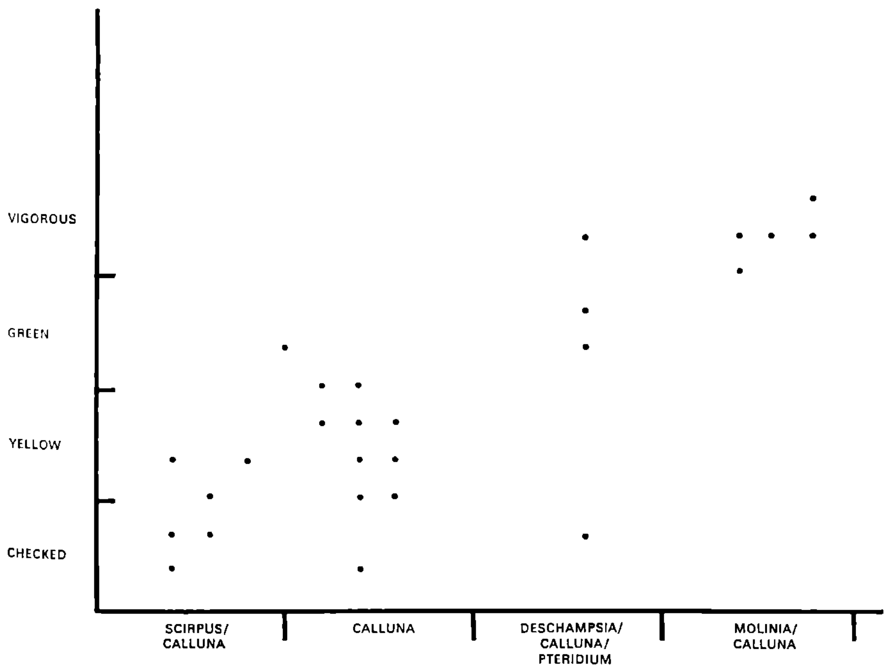

FIGURE 11. Condition of Sitka spruce in relation to vegetation type.

Lodgepole pine showed a slight correlation with elevation but was also much confused by provenance differences. No clear pattern was discernible when different provenances were distinguished in the graphs.

Mean annual shoot growth of Scots pine (Fig. 10) shows a clear correlation with altitude, and on the ground its inferiority to Lodgepole pine is particularly obvious at higher elevations. However, comparisons between species are not really valid as in most instances the species are not on similar ground.

For Sitka spruce, Fig. 11 illustrates the over-riding effect of vegetation on early growth. This completely swamps any direct effect of elevation. Nevertheless it is encouraging to note the frequent good growth of Sitka spruce on the better vegetation types at considerable elevations and in severe exposures.

Some tentative conclusions may therefore be drawn from this first assessment of recent high-elevation plantations in Northern Britain.

1. Using modern techniques we have probably not yet reached an altitudinal limit for the initial establishment of Lodgepole pine and Sitka spruce. It is, of course, not until the trees get taller that the full effect of exposure at these altitudes will make itself felt, and some of these sites may well prove to be sub-marginal as economic forestry subjects.
2. Without a far better knowledge of the exact environmental conditions pertaining to each site, it is probably unprofitable to make comparisons between growth at equal altitudes between regions. The aim and object of a trial plantation is strictly a local one.

DIFFERENCES IN PHENOLOGY OF SITKA SPRUCE PROVENANCES

By R. LINES and A. F. MITCHELL

Introduction

The dates on which Sitka spruce flush in the spring and form terminal buds at the end of the growing season determine their susceptibility to frost damage and their period of shoot extension. Few studies have been made of the seasonal growth of Sitka spruce, though other species have been examined in great detail (Kozlowski 1964, Mitchell 1965). In 1958, twelve provenances of Sitka spruce covering the range from Alaska, 63½°N, to Oregon, 43°N, were sown in three nursery experiments, and subsequently planted at thirteen sites in Great Britain and two in the Republic of Ireland to form a comprehensive trial of this species. The nursery stage was reported by Aldhous (1962). Small provenance demonstration plots were planted in 1959 at Newton, Morayshire, Lat. 57°35′N; Bush, Midlothian, Lat. 55°45′N and Wykeham, Allerston Forest, Yorkshire, Lat. 54°15′N. Also at Alice Holt, Hampshire, Lat. 51°15′N in 1960. The provenances are listed in Table 53.

Description and Assessments

These demonstrations were laid down with the idea of studying the phenological differences between the provenances at sites convenient for frequent observations, and they were therefore planted in nurseries adjacent to a Research Forester's office. The plants were 1 + 0 seedlings (1 + 1 transplants at Alice Holt), selected as approximately the mean size for each provenance, and all those used in the Northern demonstrations came from the same nursery experiment (Benmore). They were planted in twelve rows of six plants per provenance at 2 feet spacing, with a datum peg beside each tree, and the soil was kept weed free throughout the three years of observations. Plate 12 shows the Wykeham trial in 1962. It should be noted that although the provenances were intended to be planted in latitudinal order, the Juneau one is misplaced, as it should fall between Cordova and Sitka.

The progress of flushing was recorded as one of four stages reached on the particular date, using standard photographs as a guide (see Plates 2–5). These stages are:

1. Winter state;
2. Buds swollen, but not yet burst.
3. Buds burst and showing individual needles,
4. Buds fully flushed.

It was assessed at weekly intervals during the 1960 and 1961 growing seasons on both lateral and terminal buds. It was omitted in 1959, as it was believed that transplanting might have affected the inherent pattern of growth.

Periodic growth measurements were made by measuring the height of each plant to the shoot tip, at approximately weekly intervals from the commencement of extension growth until three successive measurements showed no further increase. Measurements were made through the 1959, 1960 and 1961 growing seasons, recording heights to the nearest 1/10th of an inch. A slightly different scheme was followed at Alice Holt and separate comments are made on this site below.

Table 53

PROVENANCE OF SITKA SPRUCE

SEED ORIGINS REPRESENTED

Forestry Commission Identity No.	Centre of Collection	Province or State	Latitude (°N)	Rainfall (inches)	Mean Annual Temp. (°C)
				From nearest Met. Station	
57(7985)1	Cordova	Alaska	60½	25	3
56(798)500	Lawing	Alaska	60*	25	3
56(7987)1	Juneau	Alaska	58½	60	5
57(7986)1	Sitka	Alaska	57	80	7
57(7114)1	Terrace	British Columbia	54½	50	7
57(7111)2	Skidegate, Q.C. Isles	British Columbia	53	55	9
57(7116)500	San Juan River, Vancouver Is.	British Columbia	48½	60	10
57(7116)3	Sooke, Vancouver Is.	British Columbia	48½	60	10
57(7971)1	Forks, Olympic Peninsula	Washington	48	115	10
57(7972)2	Hoquiam	Washington	47	62	10
57(7951)4	Jewell	Oregon	46	69	10
57(7952)1	North Bend	Oregon	43	52	11

Note: *Though slightly to the south of Cordova, Lawing is four degrees to the west, and near the limit of the species, which followed the retreating ice along the coast from British Columbia.

Results

Flushing

In 1960 flushing took place earliest at Bush, followed closely by Newton, whilst at Wykeham it occurred about a week later. In 1961, the same general pattern was found, but at each nursery the trees flushed about a fortnight earlier than in the previous year. These differences were almost certainly due to the exceptionally warm weather of February and March 1961, as compared with the cool early spring of 1960 (see Table 54), since April and May temperatures were higher in 1960 than in 1961.

In all provenances, the lateral buds flushed before the terminal buds, usually the first buds to flush being those just below the leading shoot, or on the leader below the terminal bud. There was a difference of about one week between the date when the *lateral* buds reached Stage 3, and the date when the *terminal* bud reached this stage.

Table 54

MONTHLY TEMPERATURE AND RAINFALL AT THE DEMONSTRATION AREAS

Mean Air Temperature °C

		Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
Silpho Moor	1959	3·9	5·8	8·0	10·3	13·4	15·7	16·0	13·8	11·2
Wykeham, (Allerston Forest)	1960	2·5	3·8	7·5	10·8	14·1	13·3	13·4	11·7	9·2
	1961	4·8	7·6	7·7	8·9	13·6	13·0	13·7	13·5	9·5
Kinloss (Newton)	1959	3·9	6·6	7·7	10·7	13·4	15·2	16·1	13·4	11·2
	1960	2·3	5·4	8·6	11·3	14·2	13·7	13·1	11·2	9·0
	1961	5·7	8·4	7·9	9·3	12·7	13·3	13·7	13·1	9·8
Bush	1959	3·5	5·7	7·3	9·8	12·4	14·5	15·2	12·5	10·4
	1960	1·8	4·6	8·0	11·1	14·0	(13·4)	(13·4)	11·4	8·8
	1961	5·1	7·6	7·5	9·3	11·8	12·7	13·0	12·7	9·2

Total Monthly Rainfall Ins.

		Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
Silpho Moor	1959	0·48	1·71	3·11	0·83	1·78	2·46	0·54	0·40	2·68
Wykeham, (Allerston Forest)	1960	2·78	2·06	0·93	1·44	0·82	4·25	3·39	3·19	11·10
	1961	1·30	0·91	2·30	2·64	1·99	3·11	2·11	2·13	5·02
Kinloss (Newton)	1959	0·44	1·15	1·83	0·74	2·19	1·74	0·90	0·73	2·81
	1960	1·98	0·81	1·28	0·26	4·22	2·30	6·61	2·01	2·30
	1961	1·40	0·90	0·70	0·74	1·63	2·38	3·25	1·83	2·70
Bush	1959	0·42	0·75	1·78	0·52	1·69	3·01	0·41	0·55	2·62
	1960	2·71	1·58	1·17	1·17	1·25	3·17	4·25	1·60	2·98
	1961	2·40	2·46	2·36	1·22	1·16	3·07	4·10	2·48	4·97

There was considerable variation in date of flushing *within* all provenances, and this (coupled with the small number of plants) made it difficult to compare provenance means. For example, at Wykeham in 1961, while all provenances had some trees in Stage 2 for lateral buds by 17th March, a few of the 'Lawing' trees had begun to show swollen buds as early as 8th March; but other trees in this provenance were still in Stage 2 a month later. The southern provenances tended to complete their flushing period sooner than those from further north; for instance it took 59 days from the first bud swelling on the first tree to the fully flushed state on all trees in the Lawing and Cordova provenances, whereas in the provenances from latitude 53°N and lower the comparable period was only 46 days. These however are the extremes and an individual tree usually took only a fortnight to three weeks to pass from Stage 1 to Stage 4. The main exceptions were in far northern provenances, in which some individuals showed swollen buds a month before they began to burst. Table 55 shows a typical set of data on flushing.

Height growth

The pattern of growth during the growing season also showed wide variation between individuals within a provenance, but latitude of origin had here a clear over-riding effect. The Alaskan provenances made a rapid early burst of growth in May, at which time their rate of increment was just as fast as that of the southern provenances, but by the end of June the most northerly Alaskan ones had virtually ceased height growth. The two southerly Alaskan provenances (from Sitka and Juneau), together with that from Terrace, continued to grow slowly but steadily until the beginning of September. The southernmost provenance, from North Bend, grew quite fast in May, slowed down in June, and then made its most rapid growth in July, August and into the early part of September. Figure 13 shows the kind of variation found between the height growth of different individuals of two provenances, and Figure 12 shows the mean height growth of all trees in each provenance at Wykeham at approximately weekly intervals during 1960. The growth pattern was similar at the other two sites in this and also in the 1959 and 1961 growing seasons, with minor variations, due most probably to individual tree variation, since the sample size (6 plants) was very small to be representative of the provenance.

The date on which growth ceases is important, and large differences in the time of terminal bud formation were noted in the transplant lines with these provenances, both at Benmore and at Fleet (see Aldhous, 1962). Table 56 gives the dates when height growth ceased in 1960 and in 1961 at Newton, Bush and Wykeham; Table 57 gives the mean date for the two seasons observations at Alice Holt. Growth ceased earlier in 1961 than in 1960, probably due to the cool period in September and October 1961. Figure 14 shows these dates in relation to the latitude of the provenances, and it will be seen that, comparing nursery sites, growth terminated earliest at the most southerly demonstration (Alice Holt). Comparing provenances, growth ceased first on the northern ones, showing a roughly clinal relationship with latitude at each site. This pattern of behaviour suggests a photoperiodic mechanism, climatic factors plainly offering no explanation. Some provenances (e.g. Sitka) show a very wide variation in date of growth cessation at the different sites, while others (e.g. Lawing; San Juan River) are relatively restricted in the range of dates.

Because the Alice Holt demonstration was planted a year later than the three northern ones, and then assessed on slightly different lines, it is best to consider the results separately. It was assessed annually for flushing from 1960 until 1964. During 1960 and 1961 there was little difference among the provenances in the start of growth. They were nearly all at Stage 3 by 1st or 2nd May, thus not showing the same difference between these years as was noted in the north. Again in 1963 and 1964 there were no striking differences between the flushing times of the different provenances, but in 1962 some of the northern provenances (especially Lawing and Terrace) were well in advance of the southern provenances, of which Forks was exceptionally late flushing. This last provenance was one of the last to flush every year at Alice Holt.

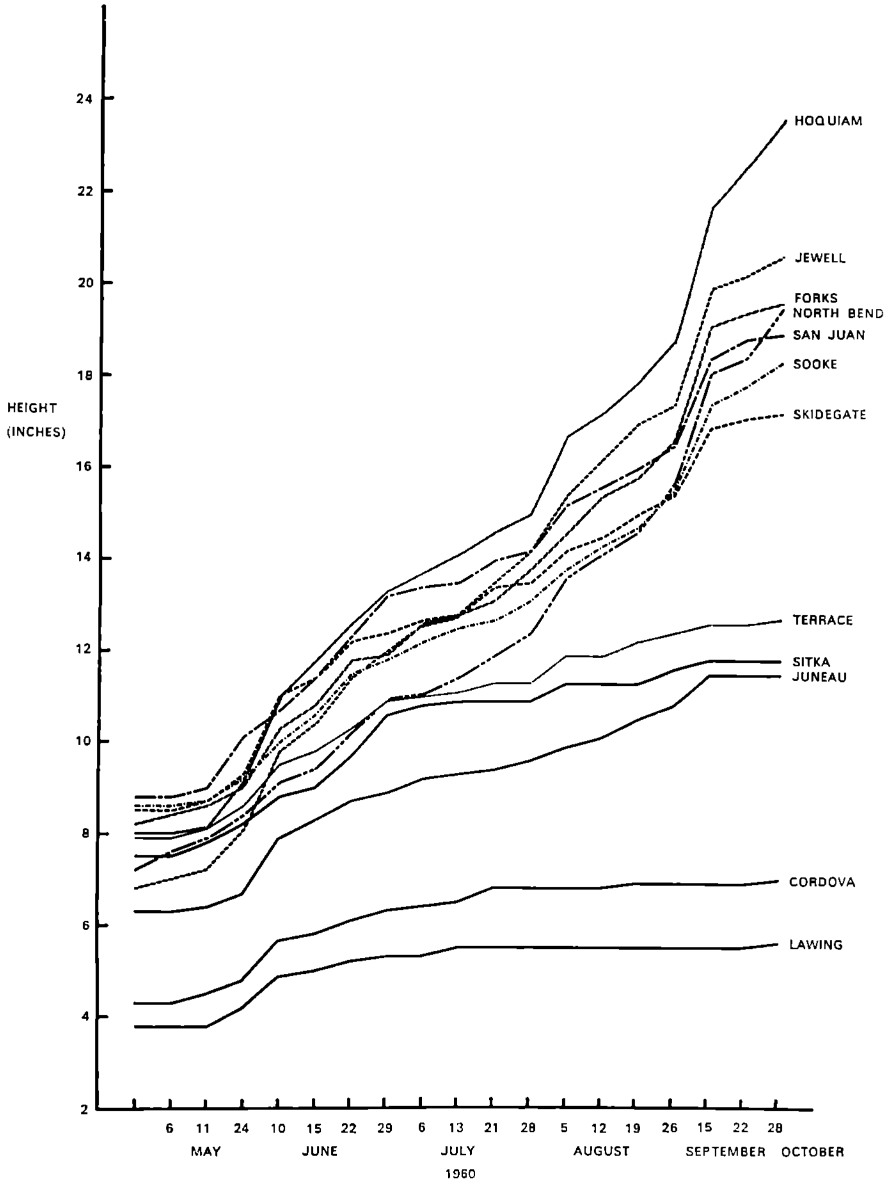

FIGURE 12. Provenance of Sitka spruce. Height growth throughout the season. Wykeham Nursery, Allerston Forest.

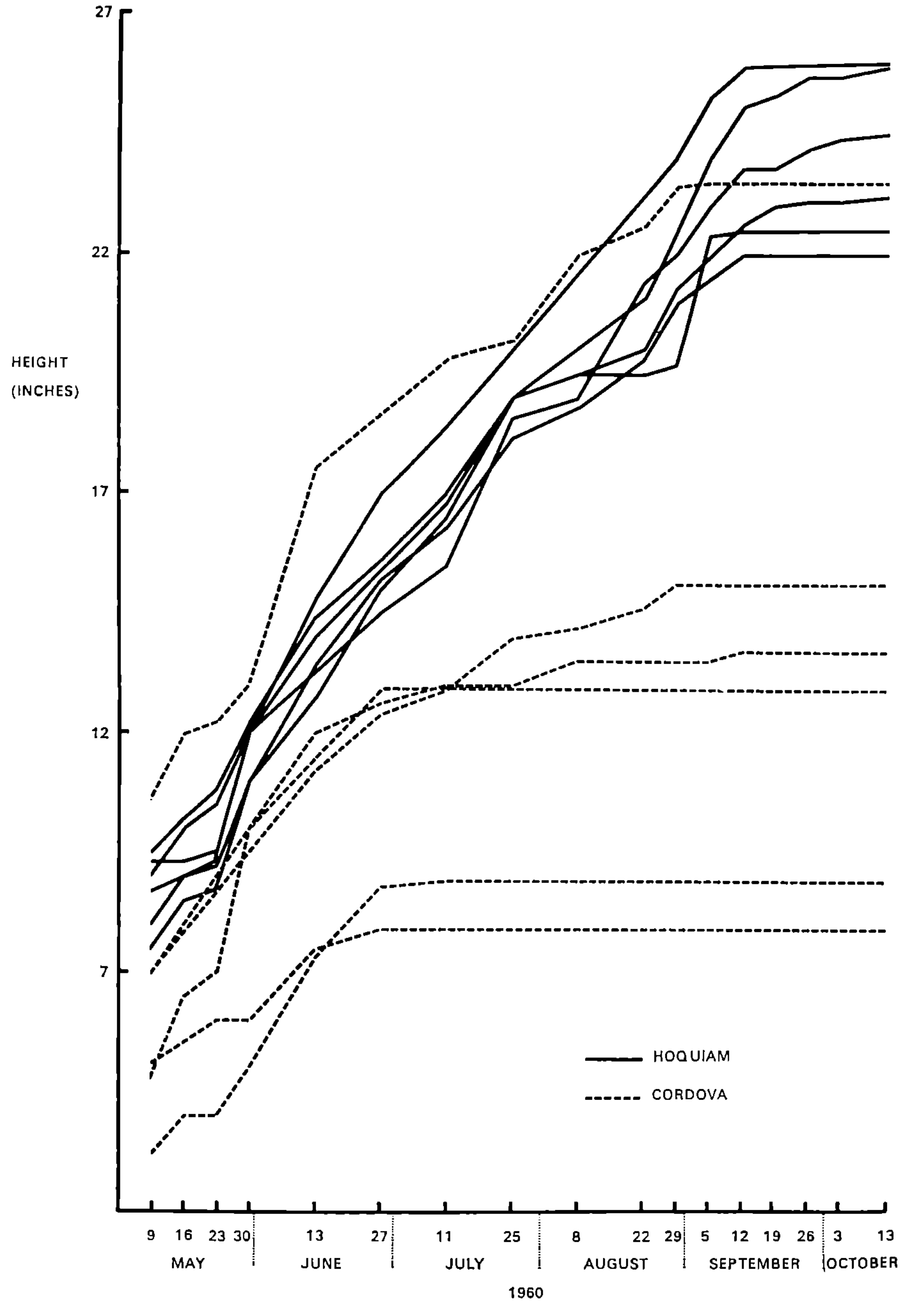

FIGURE 13. Provenance of Sitka spruce. Variation in height growth of individuals of Hoquiam (Washington) and Cordova (Alaska) provenance. Wykeham Nursery, Allerston Forest.

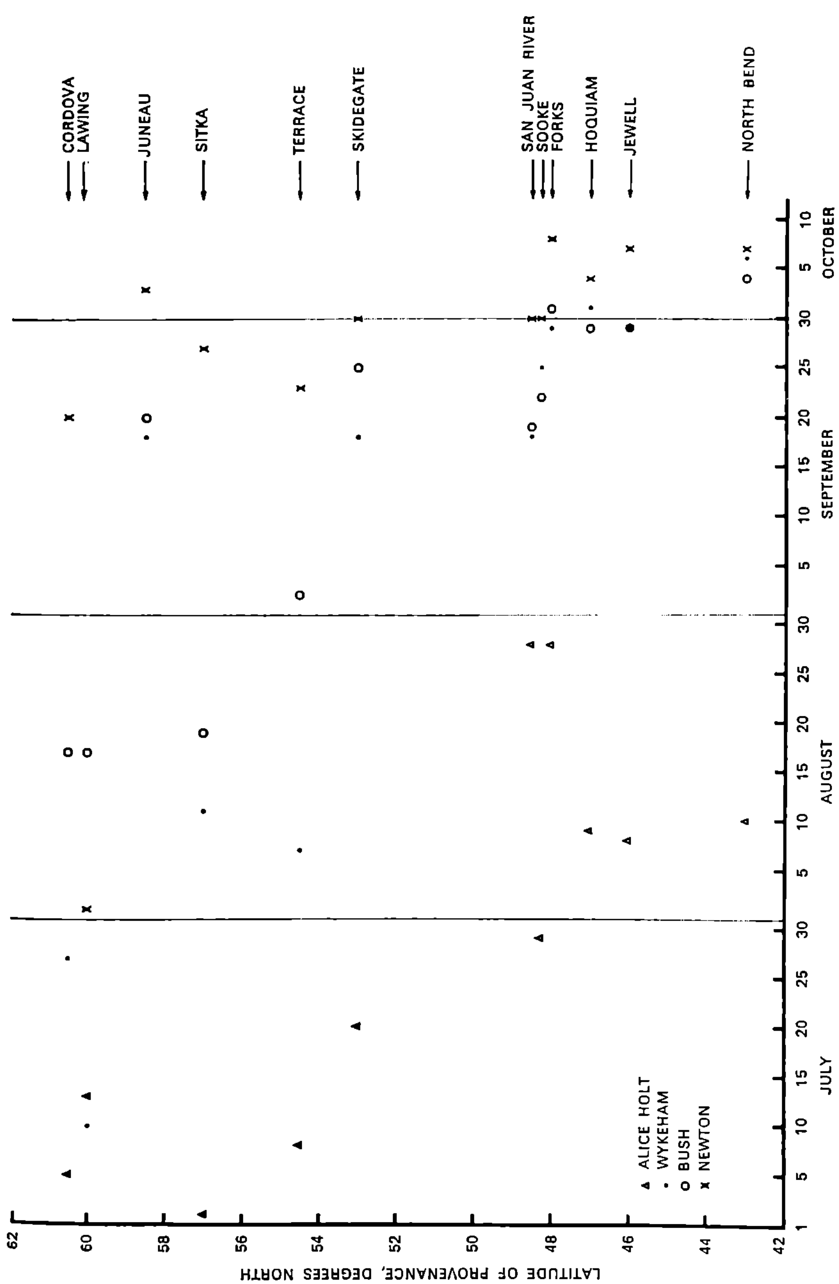

FIGURE 14. Provenance of Sitka spruce. Mean dates of cessation of height growth in different nurseries.

Table 55

STAGES OF FLUSHING OF SITKA SPRUCE PROVENANCES, NEWTON, 1961

Mean Flushing Stage—Terminal Buds

Date	Cordova	Lawing	Juneau	Sitka	Terrace	Skidegate	San Juan	Sooke	Forks	Hoquiam	Jewell	North Bend
4.4.60	1	1	1	1	1	1	1	1	1	1	1	1
14.4.60	1	2	1	1	2	2	2	2	2	2	2	2
19.4.60	2	2	2	2	2	3	2	2	2	3	2	2
22.4.60	2	2	2	2	3	3	3	2	2	3	2	2
27.4.60	2	3	2	2	3	3	3	3	3	3	3	2
29.4.60	2	3	2	2	3	3	3	3	3	3	3	3
3.5.60	4	4	3	4	4	4	4	4	4	4	4	4
11.5.60	4	4	4	4	4	4	4	4	4	4	4	4
13.5.60	4	4	4	4	4	4	4	4	4	4	4	4

Notes: (A) 1. Buds in winter state.
2. Buds swollen, but not yet open.
3. Buds burst, showing individual needles.
4. Buds fully flushed.

See also Plates 2 to 5.

(B) The horizontal lines indicate approximately the dates of completion of flushing.

Table 55—*continued*

Mean Flushing Stage—~~Terminal~~ Lateral Buds

Date	Cordova	Lawing	Juneau	Sitka	Terrace	Skidegate	San Juan	Sooke	Forks	Hoquiam	Jewell	North Bend
4.4.60	1	1	1	1	1	1	1	1	1	1	1	1
14.4.60	2	2	1	2	2	2	2	2	2	2	2	2
19.4.60	2	2	2	2	2	2	2	2	2	2	2	2
22.4.60	2	2	2	2	2	2	2	2	2	2	2	2
27.4.60	2	2	2	2	2	3	3	2	2	3	3	2
29.4.60	2	3	2	2	3	3	3	3	2	3	3	2
3.5.60	3	4	3	3	3	4	4	3	4	4	4	3
11.5.60	3	4	3	4	4	4	4	4	4	4	4	4
13.5.60	4	4	4	4	4	4	4	4	4	4	4	4

Notes: (A) 1. Buds in winter state.
2. Buds swollen, but not yet open.
3. Buds burst, showing individual needles.
4. Buds fully flushed.

See also Plates 2 to 5.

(B) The horizontal lines indicate approximately the dates of completion of flushing.

Table 56

DATE OF CESSATION OF GROWTH OF VARIOUS PROVENANCES OF SITKA SPRUCE (ALL PLANTS) IN 1960 AND 1961 AT NEWTON, BUSH AND WYKEHAM

Provenance	Newton			Bush			Wykeham (Allerston Forest)		
	1960	1961	Mean	1960	1961	Mean	1960	1961	Mean
Cordova	21/9	19/9	20/9	12/9	24/7	17/8	19/8	6/7	27/7
Lawing	30/8	4/7	1/8	12/9	24/7	17/8	13/7	6/7	10/7
Juneau	11/10	28/9	4/10	30/9	11/9	20/9	15/9	21/9	18/9
Sitka	27/9	28/9	27/9	15/9	24/7	19/8	15/9	20/7	11/8
Terrace	18/10	29/8	23/9	15/9	21/8	2/9	15/9	27/7	7/8
Skidegate	11/10	19/9	30/9	8/10	11/9	25/9	29/9	7/9	18/9
San Juan	11/10	19/9	30/9	3/10	7/9	19/9	29/9	7/9	18/9
Sooke	11/10	19/9	30/9	8/10	7/9	22/9	6/10	15/9	25/9
Forks	18/10	28/9	8/10	13/10	21/9	2/10	29/9	29/9	29/9
Hoquiam	11/10	28/9	4/10	13/10	14/9	29/9	13/10	21/9	1/10
Jewell	11/10	3/10	7/10	13/10	14/9	29/9	6/10	21/9	29/9
North Bend	11/10	3/10	7/10	13/10	24/9	4/10	13/10	29/9	6/10

Note. As there was no height assessment at Wykeham between 22/9/60 and 28/10/60, extrapolated dates of growth cessation have been used, based on the amount of growth made between these assessments.

Table 57

DATE OF GROWTH CESSATION IN 1960, 1961 OF VARIOUS PROVENANCES OF SITKA SPRUCE AT ALICE HOLT

Provenance	Mean date of 1960 and 1961	Daylength at Alice Holt on this date. Hours	Equivalent date with this daylength at seed origin
Cordova	5th July	16·6	8th August
Lawing	13th July	16·3	11th August
Sitka	2nd July	16·7	22nd July
Terrace	8th July	16·6	17th July
Skidegate	20th July	16·1	20th July
San Juan	29th July	15·7	15th July
Sooke	28th August	13·8	22nd August
Forks	28th August	13·8	21st August
Hoquiam	9th August	15·1	23rd July
Jewell	8th August	15·1	18th July
North Bend	10th August	15·0	10th July

Note. The end-of-growth data suggest, if back-derivation from dates here to daylength at origin is valid, that they stop growth at similar times there regardless of latitude, but the western-edge trees keep growing longest. The effect of daylength here causes northern provenances to stop earliest but stopping is inconsistent with latitude with Sooke and Forks.

The date of cessation of height growth at the end of the growing season was recorded in 1960 and 1961 at Alice Holt, and the mean of these years is shown in Table 57.

Discussion

Flushing and growth cessation are controlled by three different mechanisms, photoperiodism, thermoperiodism and an endogenous growth rhythm (Vaartaja 1962). These mechanisms operate to different degrees in different species, that of most importance in controlling flushing usually being the increase in temperature in spring (Kozlowski, 1964). For example, *Larix sibirica* usually flushes so early in the spring in Britain that it is frosted each year (Macdonald et al, 1957). Northern provenances of Scots pine flush earlier than those from southern regions when grown in middle latitudes (Dietrichson, 1964), and this has also been noted in Scotland. Kozlowski also notes various other species which show variation in flushing with provenance, though in others the differences were small in relation to individual variation. The results found for Sitka spruce in these demonstrations, confirmed by a large amount of previous observational evidence, make it clear that flushing differences between provenances are small, and of little practical importance in view of the irregular occurrence of spring frosts. No appreciable damage from spring frosts was noted at any of the sites during the three years of the study, despite the fact that temperatures below freezing were recorded during the flushing period on several occasions. It should however be noted that spring frost damage is less likely to occur to trees in cultivated ground than to trees growing in grass, presumably due to the greater ease of heat transfer from bare soil.

Various methods have been suggested for determining the end of the growth period in conifers. For example, Robak (1962) used the appearance of terminal buds from within their cover of needles to determine the time of growth cessation in Norway spruce. Dietrichson (1964) considered that in Norway spruce the wood anatomy of a cross section of the stem gave a better indication of the stage reached at the end of the season, as he was able to show autumn tissue damage on trees which had not fully hardened off in Norway. There was a close relationship between lignification, cessation of growth and hidden frost damage. Anic (1961) used the same method described here, measuring the height weekly, while Robak's method is similar to the one used with these provenances at Benmore and Fleet (Aldhous, 1962).

It seems certain that the very large differences in date of growth cessation, as between different provenances of Sitka spruce, must be a result of photoperiodic control, since the most northerly ones ceased growth at a time when other factors were still favourable. The fact that growth ceased earliest at the most southerly site, and latest at the more northerly one, reinforces this conclusion and suggests that photoperiod is an even more important control with Sitka spruce than it is with Norway spruce. Working with Norway spruce, Dietrichson found that in the International series of experiments in Norway, growth ceased earliest at the most northerly site, and draws the conclusion that 'the practical importance of photoperiodicity is moderate compared with other environmental factors'.

The contrast between Britain, where even the southern provenances of Sitka spruce were able to harden off sufficiently before winter frosts occurred, and West Norway (at 60°N), where 'no provenance (of Norway spruce) was able to form fully uncovered terminal buds before onset of winter' (Robak, 1962) is very marked. However, the fact that serious frost damage did not occur in these trials does not mean that southern provenances can always be planted with impunity in Britain, since in certain of the experiments planted in 1960/1961 severe damage was recorded in the exceptional winter of 1962/63, especially to southern provenances.

In any future studies of this type, at least 30 trees of each provenance should form a treatment plot. Since one is interested in the behaviour of the majority of trees in the population rather than in that of the extremes, the modal or median values would be more useful expressions than the arithmetic mean value.

SUMMARY

Small unreplicated demonstrations were planted in 1959 and 1960 with twelve provenances of Sitka spruce (*Picea sitchensis* (Bong.) Carr.), ranging from Alaska to Oregon, over a range of latitude from 60½° to 43° North. These demonstrations were at four sites at latitudes from 51°N to 57½°N. They were assessed each year for date of flushing, and their height growth was measured at weekly intervals during the 1959/1961 growing seasons. Date of flushing varied more between individual trees than between provenances; the latter differences were small, but the northern provenances tended to flush over a longer period than did the southern ones. The growth pattern also showed considerable variation within a provenance, but the most striking feature was the early cessation of growth on the provenances from northern Alaska, which stopped growing in mid-summer when the southern provenances had completed only half of their annual height growth. Photoperiod or critical daylength is suggested as the cause of growth cessation, as it was also found that the average date when the provenances stopped growing was related to latitude of the experimental site; the provenances continued to grow for the longest period at the most northerly site.

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THE PERIOD OF OVIPOSITION BY THE DOUGLAS FIR SEED WASP [Megastigmus spermotrophus]

By J. T. STOAKLEY

A possible method of controlling the Douglas fir Seed Wasp (*Megastigmus spermotrophus*) is to spray the tree crowns and susceptible cones with an insecticide just before the start of oviposition to kill the adults, either during mating or while first ovipositing. Experiments in North America have shown that emergence of adults and mating continue over about the same period as oviposition although some days in advance (Johnson and Winjum 1960). The insecticide used should be effective over most of the period of oviposition, or if that is not possible, a second application will be required. Hence the choice of insecticide and the decisions on date (or dates) of application will depend upon reliable knowledge of the date of the commencement of oviposition and the period over which it extends.

Hussey (1954) has described the stage of development of Douglas fir cones during which they are susceptible to oviposition in Britain, and has observed that the period of susceptibility lasts from two to three weeks. Johnson and Winjum (1960) determined, in one experiment, the periods of oviposition of six insect species (including the Douglas fir Seed Wasp) which attack Douglas fir cones and seed in North America. They enclosed shoots bearing female flower buds in bags made of 32-mesh plastic screen material, then exposed each for some days during the period of cone development so that when the cones were nearing maturity all had been exposed in succession. Later they used a variation of this method for studying the period of oviposition by Douglas fir Cone Midges (*Contarinia oregonensis* and *C. washingtonensis*). (Johnson 1963).

In 1962 an attempt was made to determine the period of attack by the Douglas fir Seed Wasp on two trees, A and B, in the New Forest, following Johnson and Winjum's simple procedure of exposing groups of cones in succession. The results were unsatisfactory, mainly because the exposures made proved to be insufficient in number or duration to cover fully the period of oviposition, on these particular trees. On tree A, oviposition appeared to start between 1st and 4th June and to continue beyond 19th June. On Tree B, there were indications that oviposition began about 29th May and continued for some time after 1st July.

In 1964, the period of oviposition was studied on a single tree in an avenue of Douglas fir at Whangeri Fruit Farm, Rake, near Liss, Hants. (by kind permission of the manager, Mr. C. E. T. Cooper). The experiment covered a period well in excess of that expected for oviposition. Forty shoots bearing groups of cones were selected in all parts of the upper half of the crown and numbered. Thirty-six shoots were enclosed in bags made of fine-mesh stabilized polythene material. They were exposed to oviposition in succession for three or four days during the period of the experiment, two shoots being exposed on each occasion. The order in which the shoots were exposed was determined by random numbers. Two shoots were kept enclosed for the whole period of the experiment i.e. from 20th May, when the bags were first put on, until 17th July, when bags were removed. The four remaining numbered shoots were left

Table 58

APPROXIMATE PERIOD OF OVIPOSITION BY DOUGLAS FIR SEED WASP ON A TREE NEAR LISS, HANTS, 1964

Wed. 20 May	
	X
	X
Fri. 22 May	
	X
	X
	X
	X
Tues. 26 May	
	X
	X
	X
Fri. 29 May	
	X
	X
	X
	X
Tues. 2 June	
	O
	O
	O
Fri. 5 June	
	O
	O
	O
	O
Tues. 9 June	
	O
	O
	O
Fri. 12 June	
	O
	O
	O
	O
Tues. 16 June	
	O
	O
	O
Fri. 19 June	
	O
	O
	O
	O
Tues. 23 June	
	O
	O
	O
Fri. 26 June	
	O
	O
	O
	O
Tues. 30 June	

X = Exposed cones not infested.
O = Exposed cones infested.

Table continues opposite

Table 58—*continued*

Tues. 30 June	
	X X X
Fri. 3 July	
	X X X X
Tues. 7 July	
	X X X
Fri. 10 July	
	X X X X
Tues. 14 July	

X = Exposed cones not infested.
O = Exposed cones infested.

unenclosed during the whole period of the experiment. After the final removal of the bags, the cones were left on the tree to develop in the normal way until they were collected on 13th September.

A temporary scaffolding tower was erected around the tree with platforms at three levels to provide access during the period of bagging and exposure. In the autumn the cones were collected with the aid of a Simon hydraulic platform (Seal *et al.* 1965) as this was cheaper than leaving the scaffolding in position.

All seed was extracted from each cone individually, and the numbers of sound and infested seed were assessed by radiography. The presence or absence of infestation in each group of cones is shown in Table 58 where the symbols XXX or XXXX represent an exposure without infestation, according to the number of days of the exposure, and 000 or 0000 similarly represent an exposure with infestation of seed.

During the experiment, three groups of cones failed to develop due to the shoots being partly broken. Two groups of cones were not fully developed, but nevertheless could be assessed. Also, after one group of cones had been picked, the number was found to include an extra cone which could not have been enclosed, so this group was discarded. In consequence of these accidents the effective end of the experiment was 14th July, and not 17th July. The cone assessments are summarised in Table 59.

It will be seen from the tables that oviposition extended over the period 2nd–30th June. However, the exposures were not well replicated and the numbers of potentially sound seed, that is, seed at risk of infestation, were small. Considering all of the 84 cones which were assessed, the mean number of potentially sound seed per cone was 3·9. By comparison, a survey of infestation in the same season, based on samples of cones (generally 25) from 23 trees from all parts of Britain, showed a weighted mean of 15·7 potentially sound seed per cone. Hence it cannot be established statistically that the results show the full period of oviposition. Nevertheless they give a useful indication of the period of oviposition for a single tree in a particular season.

Table 59

SUMMARY OF ASSESSMENT OF SOUND AND INFESTED SEEDS IN INDIVIDUAL CONES

Dates of Exposure	Shoot Nos.	No. of cones with potentially sound seed	No. of cones infested	Total sound seed	Total infested seed	Total potentially sound seed	No. of cones with no potentially sound seed
20–22 May	1 & 28	2	—	7	—	7	2
22–26 May	5 & 10	3	—	9	—	9	1
26–29 May	4 & 24	3	—	18	—	18	1
29 May–2 June	13	2	—	7	—	7	—
2– 5 June	19	2	1	4	1	5	—
5– 9 June	11 & 3	5	2	9	3	12	—
9–12 June	7 & 14	5	4	22	5	27	—
12–16 June	2 & 27	4	2	13	10	23	—
16–19 June	21 & 29	5	2	6	14	20	—
19–23 June	25 & 33	3	3	11	15	26	—
23–26 June	6 & 12	5	2	9	2	11	—
26–30 June	15 & 18	6	1	16	3	19	1
30 June–3 July	23 & 36	4	—	11	—	11	—
3– 7 July	16 & 35	3	—	9	—	9	—
7–10 July	8 & 34	4	—	6	—	6	—
10–14 July	17 & 30	6	—	29	—	29	—
Cones enclosed whole period	22 & 26	8	—	27	—	27	1
Cones exposed whole period	37, 38, 39 & 40	8	8	19	43	62	—

According to Hussey (1954) Douglas fir cones, when first susceptible to oviposition, have green ovuliferous scales; during the period of susceptibility, a reddish-brown coloration spreads from the base of the scales and, by the time this has reached all but the apical fringe of the scales, the cones will have become too tough for successful oviposition. In this investigation, it was observed that the spreading of the reddish-brown coloration occurred later on *bagged* cones than on *unbagged* ones in similar situations on the tree. It was also noted that there was great variation in degree of browning, at any one time, between individual unbagged cones and between different parts of the same cone. Most browning occurred with full exposure to light. It is not known whether these variations are of any significance with respect to susceptibility to oviposition.

Adult female Seed Wasps were seen on the tree only while ovipositing. No adult males were observed. Females were first seen on 19th June. Several were also observed on 23rd June and 25th June. On 26th June only one was found after careful searching of all accessible cones. None was found after another careful search on 30th June and none was seen later.

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STUDIES ON TIT AND PINE LOOPER POPULATIONS AT CULBIN FOREST, MORAYSHIRE

By MYLES CROOKE

Forestry Department, University of Aberdeen

Introduction

In recent years Pine looper moth (*Bupalus piniarius* L.) has caused considerable damage in some British pine forests or has threatened to do so (Crooke 1959, Bevan 1961), and in both situations extensive applications of insecticides have been made in efforts to achieve control. These happenings have focussed attention upon this insect and in particular upon the intriguing problem of why, with an indigenous insect, infestations have occurred in the last few years when none have been recorded before this time. Thus the epidemiology of *B. piniarius* is receiving close attention from Forestry Commission research workers (Bevan 1962, 1963) and a special study is being made of some aspects of natural control (Davies 1962). This latter work is concentrated mainly upon a study of the parasites of *B. piniarius;* but some investigation, from which so far no results have been published, is also being carried out on the effect of bird predation. This work is being conducted at Cannock Chase Forest, Staffordshire, and its objects (Forestry Commission Entomology Section Experiment 271/ENT/1/62, unpublished working plan) are to determine:—

'(1) Whether provision of bird nest boxes increases the bird population,

(2) The number of nest boxes which can be successfully colonised per unit area,

(3) The effect of size of 'boxed area' upon degree of colonisation,

(4) The effect of bird boxing on the *Bupalus piniarius* population'.

Some parallel studies, considering only points (1) and (4) of the above, were initiated by me at Culbin Forest, Morayshire, in the Autumn of 1961, with the encouragement and generous financial support of the Forestry Commission. This report summarises the results of three breeding seasons' observations, in 1962, 1963, and 1964.

The original outline plan of operations was based upon:—

(1) Selecting two sizable (c. 200 acres each) study plots in Culbin Forest which were broadly similar in terms of site and crop composition.

(2) Carrying out such measures, mainly the provision of artificial nest-boxes, in one of these plots as might be anticipated to increase the breeding population of tits (*Parus* spp.) therein, as compared with the unboxed control plot.

(3) Estimating concurrently the densities of tit and Pine looper populations inhabiting each of the two study plots.

(4) Comparing the population indices so collected, to ascertain whether or not enhanced tit numbers during the breeding season produced any significant depression of Pine looper moth densities.

In the event, the main practical difficulty encountered in following this programme has been that of accurately censusing the numbers of breeding pairs of tits in the two plots. The procedures adopted, and their shortcomings, will be described in subsequent sections of this report, along with the presentation of other results.

Field Studies at Culbin

(a) The Study Plots

The study plots were selected in October 1961. Plot 1 has a total area of 202 acres and is comprised of seven compartments, numbers 134, 135, 136, 137, 138, 146, and 147. The crop is predominantly of Scots pine planted in 1930 and 1931, with, in compartment 134, 10 acres of Lodgepole pine planted in 1930. The growth of the Scots pine has been relatively uniform and in general only small numbers of birch are present as an understorey.

Plot 2 has a total area of 197 acres and is comprised of eight compartments, numbers 112, 113, 114, 115, 119, 120, 121 and 122. The crop is again predominantly of Scots pine but with a fair admixture of Corsican pine and with a little Norway spruce, Maritime pine, and Lodgepole pine. Almost all of these stands were planted in 1924 and 1925, so that Plot 2 is older than Plot 1, but the rate of growth has been slower in Plot 2 than in Plot 1, and in terms of top height the two plots are currently broadly similar. There are, however, much greater variations in rates of growth in Plot 2 than there are in Plot 1, and irregular areas of stunted trees are interspersed amongst more vigorous crops. Consequently there are many more 'edges' and this, coupled with the facts that there is a fair amount of broom (*Sarothamnus scoparius*) in the rides, and a wider variety of tree species present, probably makes Plot 2 the slightly richer habitat for bird life of two rather inclement areas. In order not to exaggerate any differences in tit densities that might be achieved by the provision of nest-boxes and other measures, Plot 1 was, therefore, selected as the area where the increase in tit numbers would be attempted.

(b) Pine Looper Densities

All data on the densities of Pine looper pupae in the two plots have been obtained by the usual method of collection from soil quadrats during the period January to March (Forestry Commission 1959).

In the main block of Culbin Forest, covering some 3,500 acres, it had been noticeable during the winter of 1953/54, when the pine looper density was high, that mean pupal counts in different compartments showed remarkably little scatter. The mean counts of 77 of the 112 compartments sampled fell within the range of 5 to 20 pupae per square yard when the forest mean was 12·5 pupae per square yard (Crooke 1959). More generally, it is known that changes and oscillations in pine looper numbers typically occur simultaneously and sympathetically over considerable forest areas. Obviously, local differences in the habitat will affect the precise population density that is reached, but nevertheless general trends do occur. The annual pine looper pupal survey in Britain frequently shows not only that sample compartments in any single forest produce similar counts, but also that forests in any region often yield comparable returns. It would not, therefore, be unexpected to find that the mean looper populations in two study plots chosen to be broadly similar in crop and site conditions, in such relatively homogeneous environment as that of Culbin, would closely approximate each other from year to year. Table 60 demonstrates that this was in fact the case during the period from the infestation in 1953/54 until 1960/61, the year prior to the commencement of the main studies dealt with in this report. All figures given are based on five square-yard samples per compartment: the 1954 figures are the means of all compartments in the plots: figures for subsequent years are for compartments 136/137 and 138 (144 and 154 old numbers) representing Plot 1 and compartment 112 (33 old number) representing Plot 2.

Table 60

PUPAL COUNTS IN STUDY PLOTS, 1954–61

Year (Jan.–Mar.)	Pupae per square yard	
	Plot 1	Plot 2
1954	13·5	15·2
1955	0·0	0·2
1956	0·0	0·2
1957	0·0	0·0
1958	0·0	0·0
1959	0·0	0·0
1960	1·6	0·6
1961	3·4	1·6

Since the start of the present investigation all compartments in both study plots have been sampled for pupae each winter. In 1962, five quarter-square-yard quadrats were examined per transect, there being eight transects in Plot 1 and six in Plot 2. In 1963 and subsequent years the sampling was intensified to ten quarter-square-yard quadrats per transect. Table 61 details the results of this sampling.

As will be seen from Table 61, the pupal counts in the two study plots have been closely similar during the winters covered by the present study.

(c) **Tit Densities**

(i) **Mapping Territories.** The plotting of the positions of singing males and the subsequent mapping of the location and extent of territories, based upon the grouping of positions so registered, is a well known technique for estimating the number of breeding pairs of birds on a given area. Tinbergen (1960) describes his procedure quite briefly:

'The density of the birds was deduced from the number of occupied territories in April. These were counted during early morning song. The observations took place during 1½ hours per day, from one hour before sunrise onwards. In this time, three to five 'rounds' were made in a certain part of the wood, about 12 hectares (30 acres) in size.

The observer cycled along the paths between the blocks. At each round, the singing birds were plotted on a separate map. A special symbol was used for males which had been heard simultaneously. Displacements of one and the same male were also recorded. Both kinds of information are important.

This procedure was repeated at intervals of about one week, about four complete counts being made in each part of the wood. Eventually a survey chart was drawn in which all observations on one species were combined. Fig. 6 shows that the different territories can easily be recognised on such charts.'

Table 61

PUPAL COUNTS IN STUDY PLOTS, 1962–64

Year	Plot 1		Plot mean pupae/sq. yd.	Plot 2		Plot mean pupae/sq. yd.
	Cpts.	Pupae/ sq. yd.		Cpts.	Pupae/ sq. yd.	
1962	134	3·2	3·5	112	0·0	4·3
	135	2·4		114	3·2	
	136/147	3·2		115/120	4·0	
	147	4·0		121/113	7·2	
	146	5·6		122	4·0	
	137/146	3·2		119	7·2	
	137	3·2				
	138	2·4				
1963	134	0·4	0·2	112	0·0	0·13
	135	0·4		114	0·4	
	136/147	0·0		115/120	0·0	
	147	0·0		121/113	0·0	
	146	0·0		122	0·0	
	137/146	0·4		119	0·4	
	137	0·4				
	138	0·0				
1964	134	0·4	0·25	112	0·0	0·07
	135	0·0		114	0·0	
	136/147	0·0		115/120	0·4	
	147	0·4		121/113	0·0	
	146	0·0		122	0·0	
	137/146	0·0		119	0·0	
	137	0·4				
	138	0·8				
1965	134	0·0	0·50	112	0·0	0·33
	135	0·4		114	0·8	
	137/146	0·0		115/120	0·8	
	147	0·0		121/113	0·0	
	146	2·0		122	0·0	
	147/136	0·8		119	0·4	
	137	0·4				
	138	0·4				

Gibb (1960) is also brief: 'The breeding population of tits and Goldcrests at Bacon's Strip was measured by plotting the pairs on a large-scale map. The whole area was traversed at least twice (once in 1954) each spring for this purpose, and further visits were made to check doubtful pairs. Pairs on the boundary were counted or not, according to whether the nest was inside or outside the area; and if the nest was not found, by whether the birds were seen more often inside or outside the area. If no clear decision could be reached, only one bird instead of the pair was included in the census; but this rarely happened.'

At Culbin, in the interior of the pine plantations where the study plots are sited, there are only two species of tits which breed in the absence of nest-boxes.

These are the Coal tit *Parus ater* and the Crested tit *P. cristatus*. Because of this restricted species list, and because of the apparent simplicity of the method of defining territories from song registrations, it appeared at the beginning of the investigation that the determination of the numbers of breeding pairs would be easily achieved. This was not to prove the case.

In 1962 in the period from 26th April to 6th June fifteen morning spells of observation, each lasting about two hours, were spent in Plot 1, and twelve spells of similar duration in Plot 2. On any one date the two spells of recording lasted from approximately 0400 to 0600 hours and 0830 to 1030 hours GMT (All times in this report are given GMT, Greenwich Mean Time), and covered about 50 acres. It proved to be easy to hear Coal tit song at distances of up to fully one hundred yards, and from this to locate the cock bird precisely. In contrast, in the case of the Crested tit, no true song was ever identified and they were registered only at close range when giving their alarm calls. Only five such contacts with Crested tits were made in each plot, and this number of registrations is, of course, too small to give any indication of the location or size of occupied territories. Therefore, apart from saying that the general impression gained during field work was that Crested tits were appreciably rarer than Coal tits, Crested tits are not further considered in this section of the report.

For the Coal tit, the observation periods yielded twenty-five registrations in Plot 1 and the same number in Plot 2. The positions of these are shown on Plates 13 and 16 along with an interpretation of location and extent of the territories they were considered to represent. It will be seen from the maps that there were thought to be four occupied Coal tit territories in Plot 1, and three in Plot 2; but it will be appreciated that the interpretation was difficult because of the few registrations and, in particular, because of the paucity of the valuable simultaneous registrations.

In 1963, song recording was concentrated in Plot 1 and inspections were made on 5th, 9th and 25th April, on 9th, 17th, 23rd, 24th and 31st May, and on 6th June. At each visit the collection of song registrations was undertaken at the same time as the inspection of nest-boxes. These latter had been sited along equidistantly-spaced transects, traversing the study plot at 107 yard intervals, so that each inspection covered the whole of the plot.

These rounds took an average of four hours to complete and were usually made from 0800 to 1200 hours; it was not considered necessary to synchronise them with the dawn chorus, since results in 1962 had not suggested any great difference in song intensity between the earlier and later morning hours. (In 1962, in fact, thirty registrations were made in a total of 25 hours 22 minutes observation during the earlier rounds, as opposed to twenty registrations during 25 hours 50 minutes during the later rounds.) In 1963, thirty four registrations were made; these are shown on Plate 14 along with the interpretation of the location and size of the territories which were then thought to total six in number.

In Plot 2 in 1963 it was possible only to make a few random observations. These gave too few registrations for plotting, but suggested that Coal tit activity was at about the same level as in Plot 1.

In 1964, it was decided to intensify the effort on collecting song registrations in Plot 1, in an attempt to produce a more comprehensive account of conditions there. Recording was carried out, therefore, not only during the nest-box inspection rounds as in 1963, but also by an assistant employed full time for this purpose. During the period from April 20th until singing faded out in early

June, this man observed in the plot for five days per week from 0630 to 1430 hours. The combined result of his and my observations yielded a total of 84 registrations. These, along with the interpretation of territorial limits based on them, are shown on Plate 15. The assessment of the breeding population is 17–18 pairs of Coal tits when one-half is reckoned for each territory with a substantial part of its area outside the boundary.

In studying the four maps produced by this method of plotting song-points, it is quite clear that the data for 1962 and 1963 are inadequate to allow of any reliable delineation of Coal tit territories and thus of any accurate estimate of the number of breeding pairs being made. Only in Plot 1 in 1964, when the number of hours spent on observation was much increased over the time devoted to this subject in 1962 and 1963, is it possible to indicate the territorial boundaries with fair certainty (Plate 15). But even in this case, in those parts of the study area where fewer pairs occurred, the interpretation of the position must still be regarded as tentative.

In comparing the Culbin studies with those carried out by Tinbergen and by Gibb, it is clear that those authors obtained satisfactory results for a relatively smaller expenditure of effort. Tinbergen had to spend only about six hours per thirty acres to obtain ample registrations to allow easy recognition of territories. Gibb (*pers. comm.*) could map territories over a considerable area by standing at one point and recording positions of singing males for as short a time as twenty to thirty minutes; a further visit lasting about the same time was made to clear up doubtful points, and to permit of an accurate interpretation of the situation. This contrast suggests either that there were gross differences in density of the Coal tit populations at Culbin as compared with those observed in the Netherlands and at Thetford and/or that there were major differences in singing frequencies per cock in those different localities.

The former explanation does not appear tenable. The population density of Coal tits in Plot 1 at Culbin in 1964 was 8·75 pairs per 100 acres; it was probably of the same order there in 1962 and 1963.

Tinbergen does not publish Coal tit breeding density figures, but the single map with which he illustrates his census technique shows nine Coal tit territories on his study area in 1954—i.e. 5·63 pairs per 100 acres. Gibb records breeding densities in different study areas in different years, ranging from 4·59 to 26·97 pairs per 100 acres. Thus the Culbin density appreciably exceeds the Dutch one which presented no difficulty of interpretation, and it falls within the range of Thetford densities which similarly allowed of rapid and easy territory estimation.

The hypothesis that there was a real difference in the singing frequency of the male Coal tits at Culbin as compared with those in the other situations seems more feasible. One measure of this difference is simply the comparison of the number of registrations per unit time. Tinbergen recorded forty-five registrations in approximately six hours (i.e. about 7·5 song records per hour) and illustrates on one map a situation where six separate Coal tit cocks were heard in twelve minutes. At Culbin 50 records were obtained in approximately 51 hours in 1962 and thirty-four records in approximately thirty-six hours in 1963—i.e. about one song record per hour.

Another measure of song frequency differences, and one which reflects the relative ease of territory indentification, is the percentage occurrence of registrations simultaneously involving two or more males in the total number of registrations. Of the total number of 168 registrations made at Culbin only 18

(11 per cent) involved more than one bird. In Tinbergen's mapping, referred to above, 26 out of a total of 45 registrations are multiple ones: this is equivalent to 58 per cent. The contrast between these data strongly suggests a behavioural difference on the part of the male Coal tits in the two localities. There are no comparable data available in Gibbs report, but his populations would seem to have behaved much as did the Dutch birds.

The results in the years 1962–64 clearly demonstrate that close estimation of the number of breeding pairs of Coal tits in the study plots at Culbin can be achieved only if considerable lengths of time are spent on field observation. In this respect the writer's experience corresponds much more closely to that of Kenneth Williamson than to that of either Tinbergen or Gibb. Williamson has written (*pers. comm.*) 'In our census work (in woodland) we have found that sufficient registrations of song and other territorial activity for a reasonable assessment of the population require something of the order of 15–18 visits during the season to an area of approximately 50 acres'. On this basis, which in view of my recent experiences at Culbin seems quite realistic for this situation, censusing of the two study plots would require between 240 and 432 hours field time if the duration of each 'visit' is of two to three hours. These observations must be concentrated into a fairly short season of about six weeks and necessarily demand that the observer be employed full-time during this period on this single aspect of the study.

(ii) **Location of Nests.** For the purpose of estimating breeding densities of tits, one obvious alternative to territory mapping is the counting of nests. Many workers, in areas where artificial nest-boxes are provided, use the number of pairs of tits nesting in boxes as the figure for breeding density, since tits are reputed much to prefer boxes to natural sites. Gibb (1963) has referred to this by saying 'Effectively all the Great tits (*Parus major*), Blue tits (*P. caeruleus*) and Coal tits (*P. ater*) present at Mousehall and Cranwich bred in the nest-boxes, so that the breeding population was taken from the numbers occupied'.

At Culbin, estimation of breeding populations based on nest finding raises two main questions:—(1) In areas bountifully supplied with nest-boxes do virtually all breeding Coal tits occupy these boxes? (2) If this is not so, or in areas without nest-boxes, is it practicable to find all or a very high proportion of natural nests?

Boxed Areas. The records for Plot 1 in 1963 and 1964, when respectively 100 and 200 nest-boxes were available in the plot, show that only a proportion of the Coal tits used the boxes for nesting. In 1963 six nests occurred in boxes and four were found in natural sites. In 1964, five nests were in boxes and five were found in the ground: furthermore, mapping of territories suggests that there were another seven or eight natural nests in the plot. It is clear, therefore, that at Culbin it would be quite misleading to take the number of pairs of coal tits nesting in boxes as the number of breeding pairs inhabiting the area which had been provided with boxes.

Natural Nests. As soon as it became apparent early in the investigation that estimation of breeding densities by mapping of territories was going to be a laborious procedure, nest counting was considered as an alternative. In 1963 a search for natural nests was carried out during inspection rounds of nest-boxes in Plot 1, and four such nests were found; at that time I considered it unlikely that any appreciable number of natural nests had been overlooked. The situation became clearer in 1964 when more time was spent in searching and when five natural nests were found. At that time I believed that no natural nest had been missed, but the independent cross-check provided by the mapping of territories disclosed the probable presence of seven or eight which had gone undetected. From this it is clear that no confidence can be placed in nest finding as a reliable or quick method of estimating Coal tit breeding densities.

(iii) **Family Parties.** A third method of estimating coal tit breeding densities, by counting family parties shortly after the young had left the nest, was attempted in 1962 and 1963. At this time of year these family groups are very noisy and can be readily located as they feed in the pine crowns.

In 1962 a line of seven observers walked through half of Plot 1, and two-thirds of Plot 2, and counted the number of family groups encountered. Three such groups were found in Plot 1 and four in Plot 2. Translated to figures for the whole extent of the plots, these indicate counts of six broods in each plot.

In 1963 the whole of both plots were similarly surveyed by a team of seven observers. Eleven family parties were located in Plot 1 and eight in Plot 2.

Since nothing is known about the range and rate of movement from the nest or mobility of these family groups, it is difficult to know what significance to attach to these figures. Certainly this technique gave estimates of density above those yielded by the first interpretations of territorial extent. These latter are known to have been in error, and to have provided underestimates of density, so that the figures given by family counting are at least less poor assessments of the true position; but how closely they approach the true figure remains undetermined.

In 1964 an effort was made to discover something about the range and rate of movement of family parties from their nest sites. Four broods of Coal tits in Plot 1 were marked with brightly coloured dyes on their cheek and nape patches, shortly before they left the nest; and two of these broods were additionally marked with coloured leg rings.

The dyes used were Edicol Supra Amaranth AS (ICI, cherry red), Edicol Supra Amaranth Blue EGS (ICI, blue), and Tetrazene (Gurr) plus Edicol Supra Green BS (ICI, green). The first two dyes produced good deep colours when applied to the feathers previously moistened with absolute alcohol, but the last produced a pale effect difficult to differentiate from the normal lemon of the head patches and so it was abandoned.

A lookout was maintained for these marked broods from 10th June until 17th July. During this period, 118 contacts were made with Coal tit families in Plot 1, but only one of these was with a marked brood. In this particular case the family was seen at a distance of 315 yards from the nest in which it had been reared. This result suggests either that marked broods occurred very sparsely amongst a large population of unmarked broods (it is known, in fact, that in the plot itself two-ninths of the broods were marked), or that these parties quickly move considerable distances away from their rearing positions and remain away from them. Neither of these explanations seems probable or convincing.

(iv) **The Effect of Providing Nest boxes.** It is widely accepted that the provision of artificial nest-boxes in woodland increases the breeding densities of hole-nesting bird species. For example, a Dutch report (Anon. 1948), considering conditions in pure Scots pine plantations, states that the titmouse population in a wood unprovided with nest-boxes was about two-thirds as dense as in another wood furnished with boxes. Mackenzie (1952) is firmly of the opinion that hole-breeders can be increased by supplying them with artificial nest sites in British plantations, whilst in Czechoslovakia Tichy (1963) goes as far as to say that in predominantly pine crops the population of hole-nesting birds can be increased almost four-fold by providing nest-boxes.

Whilst it may be true in a general sense that nest-boxing, especially in intensively managed forests where natural holes in trees are deficient, can increase the densities of hole-breeders, it seems much less probable that, in the particular case of the Coal tit, numbers can be stimulated by this method. At Culbin, as elsewhere, the Coal tit normally nests in holes in the ground, and these are in superabundant supply. Thus availability of nest sites does not exert a restraining influence on breeding density. Similarly, in the case of the Crested tit at Culbin, factors other than the presence of breeding sites appears to limit breeding density. This species breeds typically in an excavation in the rotting stem of birch or pine, and there appears to be more than a sufficiency of these present to accommodate the rather low numbers of Crested tits present. The situation at Culbin is thus similar to that recorded by Tinbergen (1949) who found that in pine woods the provision of nest-boxes increases the numbers of Great and Blue tits but not of Coal or Crested tits, which nest in the ground and in rotting stumps, respectively.

At the time of writing this report there are three hundred John Gibb type (Cohen 1961) nest-boxes in Plot 1 at Culbin. One hundred of these were put out in September 1962, and further batches of one hundred each in January 1964 and January 1965. Coal tits have used some of these boxes since the 1963 breeding season, but as has been shown on page 196 only a small proportion of the breeding population occupied nest-boxes. This is at variance with Lack's (1955) experience that in conifer plantations most Coal tits nested in boxes if these were present. Further, there is no evidence whatsoever to suggest that the overall breeding density of Coal tits in Plot 1 at Culbin has been affected by the presence of nest-boxes. This accords with the view of Gibb and Betts (1963) who have written 'Coal tits . . . were about equally dense 'without boxes' at Bacon's Strip or 'with boxes,' as at Mousehall and Cranwich.'

One effect of boxing at Culbin has been to introduce into Plot 1 the Blue tit as a breeding species. Normally, Blue tits do not nest deeply within the main block of pine plantations at Culbin, but two broods were reared in boxes in the plot in 1964 and there is continuing present evidence of their occupation of this area.

Conclusion

The results presented in the previous section disclose that the objectives set in the original plan have not been met. The main failure has been in developing a reasonably simple and accurate census method for determining the breeding densities of the tit species inhabiting the study plots. In fact, for only one species in one year, in one of the two plots (the Coal tit in 1964 in Plot 1), has an acceptably accurate estimation of breeding density been made. This means, of course, that it has not been possible to compare the tit densities of the two plots for different years as had at first been planned, but general considerations strongly suggest that the provision of nest-boxes in one plot has not increased the numbers of the most common species, the Coal tit, breeding therein as compared with the unboxed control plot. The presence of boxes in the plot has, however, allowed the Blue tit to establish itself there as a breeding species.

The work to date has nevertheless shown that it would in future be feasible to ascertain Coal tit breeding densities in the study areas. It would be quite impracticable to attempt this by searching for nests, but it could be done by mapping territories if a sufficient amount of field time could be devoted to this at the critical time of year.

Summary

1. Two study areas in pine plantations at Culbin Forest, Morayshire, have been used for the attempted measurement of Pine looper moth (*Bupalus piniarius* L.) and tits (*Parus* spp.) densities during the period 1962–64. One of the study areas was provided with nest-boxes with the object of increasing the number of breeding pairs of tits therein, as compared with the unboxed area.
2. Pine looper moth numbers in the two plots have been closely similar during the period 1962–64.
3. Technical difficulties were encountered in counting the number of breeding pairs of Coal tits (*P. ater*), the most numerous tit species in the plots. It is possible to count them by mapping territories, but this requires the expenditure of a much greater time on field observations than has been necessary in previous similar studies in England and the Netherlands.
4. It is not practicable at this stage to determine the number of breeding pairs of Coal tits either by nest finding or by locating family groups off the nest.
5. Crested tits (*P. cristatus*) occur in small numbers in the study areas.
6. The provision of artificial nest-boxes in one of the plots
   (a) has not increased the number of Coal tits nesting therein, as compared with the unboxed plot;
   (b) has attracted only a small proportion of the Coal tits in the plot to the boxes;
   (c) has allowed the Blue tit (*P. caeruleus*) to establish itself as a breeding species in the plot.
7. The original objectives of the investigation—*viz.* the comparison of tit numbers in the boxed and unboxed plots, and measurement of the tit predation effect on pine looper numbers—have not yet been met.

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THE INFLUENCE OF GEOMORPHIC SHELTER ON EXPOSURE TO WIND IN NORTHERN BRITAIN

By R. HOWELL and S. A. NEUSTEIN

Exposure is recognised as one of the main factors limiting tree growth, particularly in the northern and upland areas of Great Britain. It has usually been assessed subjectively by foresters by judging the influence of local topographic features on the regional flow of wind, i.e. by making a visual assessment of what meteorologists call 'geomorphic shelter'. Because of the increasing importance in the afforestation programme of exposure-limited sites, it is desirable to find a convenient objective measure of exposure. The rate of tatter of unhemmed flags has been shown to provide a reasonably good measure over a period of two or three years, during which the site is visited bimonthly (Lines and Howell 1963), but there is an obvious advantage in a measure which can be obtained with no more than a single visit to a site. To find such a measure one may accept flag tatter as the best available method, and try to correlate its observed variation with that of more conveniently obtained substitutes.

In 1960, following a survey of exposed plantations in Morayshire, an unsuccessful attempt was made to express exposure on an objective scale, by measuring on a map the distance between the exposed parts of the plantation and the nearest point of the same or higher elevation in the sixteen principal compass directions. The inability of this system to combine satisfactorily elevation and distance invalidated its use and a further approach has now been tried with more promising results.

In 1962 measurements were taken at the 36 sites in northern Britain (Shetland Islands to Yorkshire) where flags had been exposed for consecutive periods over three years. The angle to the skyline was measured with an Abney level and recorded for each of the sixteen principal compass directions. The distance to the skyline was not measured, but this varied from a few yards just below the brow of a hill, to the distance to the horizon at sea, the assumption being that a small hill near the site could be taken as equivalent to a higher more distant hill subtending the same vertical angles over the same horizontal arc. This method was suggested by a measure found in America to be related to wind-run (Blust and de Cooke, 1960). It seemed advisable, however, to admit the possibility that the shelter value of any feature would depend on its direction, the most effective direction for shelter probably being that of the prevailing wind. This possibility can be tested by fitting to the tatter data an equation designed to estimate the direction in which the flags were most sensitive, by assuming that the sensitivity in a given direction will be some sinusoidal function of the compass reading for that direction.

The height of the skyline of a site thus measured is an inverse measure of its local relative altitude, large skyline angles implying a relatively sheltered site. Combining this expression of relative altitude with the height of the site above sea-level, in the same equation for the flag-tatter data, should give a better estimate of tatter over a wide range of sites.

The calculation of the coefficients in equations on this basis resulted in about half of the variation in flag-tatter being accounted for. The results showed there was no statistically significant effect dependent on the *direction* of the geomorphic shelter. There was also a suggestion that the effect of height above sea-level might vary between the regions over which the flag-sites were distributed.

The most obvious major groups of sites are those separated by the Scottish lowlands, into a northern and a southern group. The northern group included 22 sites ranging in altitude from 100 feet above sea-level to 1,350 feet but with an average altitude of about 500 feet. Average skyline angles for these sites varied from 0° to 8°. The southern group consisted of 14 sites with altitudes ranging from 500 feet above sea-level to 1,800 feet, with an average of about 1,100 feet; their average skyline angles varied from 1° to 5°. The northern sites were thus characterized by a wider range of relative shelter, while the southern sites were generally at higher elevations.

Treating the data of the two groups separately, in the northern region tatter of the flags was found to be significantly influenced by the skyline angle, being slightly more sensitive to exposure from the east, while the influence of height above sea-level was insignificant. In the southern region, height above sea-level alone accounted for about 60 per cent of the variation in tatter, and the skyline angle had no apparent effect. Bearing in mind the ranges of relative and absolute altitude in the two groups, a result like this was perhaps to be expected, but this grouping of the sites also gave a much better fit to the data, and this has been taken as implying that other regional or local factors modify the influence of the skyline angle and altitude of the site. Unless such factors can be determined and measured, the exposure of a given site is better estimated in terms of its skyline angle and altitude, using an equation based on data from a limited region. It must be admitted, however, that so far the combination of skyline angles and altitude in regression equations has not been shown to be markedly superior to more subjective methods of assessing exposure over widely scattered sites.

The most common requirement for an estimate of exposure in British forestry arises when a comparison is wanted between an area being considered for planting, and one nearby for which at least some idea of the effects of exposure on its tree crop has already been obtained. Except in the north of Scotland, it is uncommon to find that no area carrying a crop is available, within a few miles, for comparison. Some attention has also been paid therefore to more local investigations of the relationship between flag tatter and the skyline.

At three forests skyline angles were measured at sites where flags had been established, the flags being within a few miles of one another. This was done at Clashindarroch, Glenlivet and Inchnacardoch; where groups of flags had been exposed over a period of three years. At Clashindarroch there were six sites at nearly equal altitude (1,350 feet), but varying in mean skyline angle from 0° to 4°. At Glenlivet nine sites ranged in altitude from 1,200 feet to 2,040 feet, and in mean skyline angle from 2° to 8°. For ten sites at Inchnacardoch, the ranges were from 840 feet to 1,300 feet and from 1·5° to 6°.

For the Clashindarroch flags (which were sited in two groups on two hills approximately eight miles apart), where the differences in altitude were negligible, there was a very close linear relation between tatter and mean skyline angle, which explained over 97 per cent of the variation in tatter. For the flags at Glenlivet (sited in two groups on hills seven miles apart) both altitude and skyline angle contributed to explain 78 per cent of the variation in tatter, while at Inchnacardoch (where flags were sited on one hillside), despite the considerable variation in altitude, only skyline angle contributed appreciably (45 per cent) to explaining the variation in tatter.

The regression equations for tatter at the three forests were:

$$\text{For Clashindarroch } T = 2{\cdot}037 - 0{\cdot}30\,X$$
$$\text{For Glenlivet } T = 0{\cdot}450 - 0{\cdot}12\,X + 1{\cdot}05H$$
$$\text{For Inchnacardoch } T = 1{\cdot}380 - 0{\cdot}14\,X$$

where: T is the area of flag lost in square inches per day,
X is the mean skyline angle in degrees,
H is the altitude above sea-level in thousands of feet.

Comparing these equations, it appears that the effect of mean skyline angle is about the same at Glenlivet as at Inchnacardoch, but that it is much more pronounced at Clashindarroch.

A consideration of the aspects of the flag stations at each forest does not shed further light on the differences in the relation between tatter and skyline angle, for at each of these forests the aspect was either open, or else close to the general directions East, South or South-west. It appears therefore that, within a given locality, a simple measurement of the surrounding skyline does aid the appreciation of exposure. There are however, as noted above, still some anomalies which are to be further investigated, as data from other sites where replicated flag experiments have been sited become available, and the use of skyline angles in the characterization of a site for afforestation cannot yet be recommended.

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THE SOIL AND WINDTHROW SURVEY OF NEWCASTLETON FOREST, ROXBURGHSHIRE

By D. G. PYATT

Following the survey of Clocaenog Forest, Denbighshire, described in the *Report on Forest Research, 1964*, in which soils conducive to windthrow were satisfactorily delineated on a map, the soils and wind damage to date were mapped in detail at a scale of 6 in. to 1 mile at Newcastleton Forest (7,754 ac.). Conditions in the Scottish Border region were found to be rather different from those in North Wales, and over 87 per cent of the forest soils appeared more or less uniformly conducive to instability.

Tree-pulling work conducted by A. I. Fraser (described in Part I of this *Report*, page 44) confirmed that trees on brown earths and peaty podzols were deeply rooted and relatively stable, and that trees on surface-water gleys, peaty gleys and deep peats were shallowly rooted and relatively unstable. Rooting depths are given in Table 62.

Table 62

AVERAGE ROOTING DEPTHS ON DIFFERENT SOIL TYPES

(inches)

Brown earths	44
Peaty podzols	26
Surface-water gleys	20
Peaty gleys	17
Deep peat	20

The wind damage survey recorded 144 acres of windthrow in 80 separate areas, each greater than 0·1 ac. Site and crop characteristics were recorded for each area; these included soil type, elevation, topographical position (upper, middle or lower slopes), aspect, slope, direction of wind apparently causing damage, crop top height, rooting depth and species. The main findings are summarised in Tables 63 and 64.

Table 63

AREAS OF WINDTHROW ON DIFFERENT SOIL TYPES

(acres)

Brown earths	0·3
Peaty podzols	0·3
Surface-water gleys	74·0
Peaty gleys	69·2
Deep peats	0·2

Note. Very few crops on deep peats had reached the susceptible top height of about 35 ft.

Table 64

WINDTHROW ON DIFFERENT TOPOGRAPHICAL POSITIONS AND AVERAGE TOP HEIGHTS OF CROPS THROWN

Position	Area	Top height
Upper slopes	104·3 acres	41 ft.
Middle slopes	34·2 acres	49 ft.
Lower slopes	5·5 acres	53 ft.

Although 99·9 per cent of the damage was in Sitka spruce and 0·1 per cent in Norway spruce, this was not considered particularly significant as the former species has grown faster and has therefore produced susceptible crops earlier; also the latter species is almost wholly confined to lower slope sites. The tree-pulling work did not reveal significant differences between the measured resistance to over-turning of the two species, on comparable soils.

The results of the wind damage survey, particularly those given in Table 64, indicated that a topographic zonation of the forest super-imposed on the soil map would produce a useful windthrow forecasting map. Three zones were adopted, the lowest (most sheltered) zone also included areas of deeply rooted soils irrespective of their location. Wherever possible zone boundaries were made to follow compartment or sub-compartment boundaries, to facilitate subsequent computations of acreages. In the upper, 'red' zone crops appear to become susceptible to windthrow at a top height of about 35 feet, and by 50 feet they appear likely either to be completely thrown or so badly damaged as to be only fit for clear-felling. In the intervening 'white' zone, crops become susceptible at 45 feet and appear likely to be thrown by 60 feet. In the lowest, 'green' zone some crops become susceptible at 55 feet but most may be expected to exceed 70 feet before serious windthrow occurs.

Using working plan crop assessment data, areas of crops which have already exceeded their respective susceptible heights in each zone were calculated, and defined as 'at risk'. Further calculations were made to predict future windthrow, allowing for recruitment of crops to the 'at risk' stages. This method was not considered very precise however, as the proportion of the area at risk which has been thrown at any one time depends on the number of years the various parts of the area have been at risk, and at present little is known about the progression of damage through such crops.

A rather more satisfactory prediction is probably obtained by comparing the area which has reached its 'final' predicted top height (50 feet in red zone, 60 feet in white and say 80 feet in green) at the present time, with that expected in the future. The results of these various computations are given in Table 65.

Table 65

AREAS AT RISK AND REACHING THEIR 'FINAL' HEIGHTS

(acres)

	As at 30.9.65	Recruitment in 5 years, to 30.9.70
Areas at risk	1,412	732
Areas reaching 'final' heights	62	390

The very tentative forecast is therefore made, that at Newcastleton Forest windthrow will increase over the next five years to about six times its present extent; or in other words that the average annual area thrown will rise from about 25 acres to about 150 acres.

It will be most instructive to watch the extension of wind damage at Newcastleton in the three zones, if indeed it does occur. No doubt within a few years improvements will be made to the predictive method, but it is felt that the soil/topographic exposure map is a useful first approximation to the solution of this most important problem.

A REVIEW OF FLOWER INDUCTION EXPERIMENTS AND TRIALS 1948–63

By R. FAULKNER

Almost forty flower induction experiments were established by the Section during this period of fifteen years. Most of them were concerned with the effects of different types and rates of fertilizers on female flower and cone production in seed stands or clonal seed orchards. Other investigations have been made on the effects of stem girdling, root pruning, disbudding and shoot pruning on flowering. This paper briefly summarises the results obtained from these experiments. During the period J. D. Matthews produced a valuable review on the factors affecting the production of seed in forest trees. This was published in 1963 in *Forestry Abstracts* Vol. 24 No. 1.

Experiments in Seed Stands and Forest Plantations

Alice Holt Experiment, 1948: Girdling

The first experiment on flower induction was carried out on twenty-two-year-old Corsican pine growing in Alice Holt Forest, Hants., in 1948. Full details of this work were published by Holmes and Matthews (1951). The main conclusions were:

(i) Girdling the stems of trees at breast height by means of two ¼-inch wide half-girdles, on opposite sides of the stem and spaced either two inches or six inches apart; or by constriction with a ⅜ ins. wide metal band; all increased cone production in the second season after application.

(ii) Trees with the largest girths and crowns produced the largest numbers of cones.

(iii) Stem girdling was more effective than constriction by stem bands, particularly when applied in May as opposed to September or January.

Sherwood Experiment, 1952: Girdling and Fertilizers

An experiment established at Sherwood Forest, Notts., in 1952 extended the earlier work by combining stem girdling with fertilizer applications. A twenty-six-year-old Corsican pine plantation, with tree girths ranging from fifteen to twenty-one inches, was chosen for the experiment, which included applications of nitrogen, applied as 'Nitrochalk', a granulated mixture of lime and ammonium nitrate (containing 15·5 per cent N); phosphorus, as ground mineral phosphate (30 per cent soluble P_2O_5); and potash, as muriate of potash (60 per cent K_2O)—all applied at 5 cwt. per acre. In addition bracken and rideside trimmings were applied as a mulch at approximately ten tons per acre, while a Control received neither fertilizers nor mulch. All treatments were applied both singly and in factorial combination. The treatment plot size was 0·07 acres, and half the trees in each plot were girdled by making two half girdles, ¼ inch wide, two inches apart and one foot above ground level. The trees in each plot were grouped into two-inch girth classes for the girdling treatments and assessment purposes. The treatments were laid out in four randomized blocks.

In August 1952—the year before treatment, which was not a good seed year for Corsican pine, the mean number of cones per tree was four. In 1954, the crop year following treatment, the mean number of cones per tree for all treatments was 1·5 and ranged from 0·91 for the plots treated with phosphate to 2·02 for those treated with nitrogen. Control plots had an average of 1·88 cones per tree. Girdling treatments highly significantly (1 per cent level) increased the number of cones per tree from 0·95 to 2·09. As might be expected, standard deviations were high and the experimental precision was low. 1954 was a poor seed year for Corsican pine in the Midlands and the results from this experiment suggest that fertilizer and girdling treatments cannot be relied upon to improve substantially a Corsican pine cone crop in a poor seed year.

Torrie Experiment, 1959: Root-pruning, Girdling, Shoot-pruning and Fertilisers

An experiment in 1959 on Scots pine at Torrie Forest, Stirling, was established to determine whether root-pruning, shoot-pruning, or N, P and K fertilizer treatments, applied singly or in factorial combination, would stimulate male or female flower production, or both, in a seven-year-old crop which had not yet reached the age of regular male and female flower production. All the treatments were applied in April to single trees; each tree was selected for similarity in height and girth and given full crown release.

The treatments were:

(a) Root pruning to a depth of nine inches in a complete circle two feet in diameter around the base of the tree.

(b) Root pruning to a depth of nine inches in a semi-circle of six inches radius.

(c) Girdling either by inverting a ¼-inch wide band, or by removing two ⅛-inch wide half-circles of tissue two inches apart and on opposite sides of the stem.

(d) Shoot pruning, removal of half the length of all 1958 terminal and lateral shoots in the 4th, 5th and 6th whorls of branches from the top of the tree.

(e) Fertilizers, nitrogen, phosphorus and potassium applied respectively as 'Nitrochalk' (15·5 per cent N), superphosphate (18 per cent soluble P_2O_5) and sulphate of potash (48 per cent K_2O), either singly or in combination, and at rates equivalent to 3·75 ounces or 1·25 ounces of N, P_2O_5 and K_2O per tree.

The experimental design consisted of a ⅓ replicate of a 3^5 factorial with twenty seven plots of three blocks each, each plot split by the two level shoot pruning treatment. The total number of male and female strobili were recorded for each tree during May 1960 and 1961.

In May 1961, fourteen of the trees with the inverted girdle had either broken at that point, or were almost dead; this precluded full statistical analysis of the data. Furthermore both the incidence and amount of flowering varied greatly between trees, suggesting either a large variation between trees in their response to certain treatments, or a faulty or variable experimental field technique; the latter appearing especially likely for the inverted bands of tissue. As a result only a few generalisations can be drawn from the data.

In 1960 only four trees out of 162 produced any male flowers; 103 trees out of 162 bore female flowers. Shoot pruning significantly increased the number of female flowers, when compared with the unpruned controls. The heaviest dressing of phosphate also significantly stimulated female flowering.

In 1961, twenty-two of the remaining 148 trees produced male flowers, while six trees produced female flowers. Girdling was undoubtedly the most effective treatment in stimulating flowers of both sexes. Root pruning and fertilizer treatments were fairly consistently ineffective. No treatment other than the severest girdling showed any indication of being either harmful to the tree or inhibiting to flowering.

Drumtochty Experiment, 1958: Girdling and Drought

In 1958, an experiment was carried out on a four-year-old *Picea omorika* seed plantation at Drumtochty, Kincardineshire, in which a stem-girdling treatment removing two half-circular three-quarter-inch-wide bands of tissue, was compared with three treatments designed to create different degrees of artificial drought, plus a control. A randomised block design was used, with five blocks and single-tree treatment plots. The artificial drought conditions were obtained by anchoring sheets of black polythene 4 feet by 4 feet, 4 feet by 6 feet, or 6 feet by 6 feet in size, on the ground and around the butt of the trees. A nine-inch-wide strip of polythene was placed vertically into the soil on the top and side edges of the slope, to prevent surface seepage of water. The black polythene effectively killed all vegetation near the plants, and the removal of competition, together with the mulching effect, resulted in greatly improved growth of the treated trees. From visual observations of soil conditions it seems likely that this treatment failed to induce any very significant moisture stress. During the period 1959–61 none of the treated trees or controls produced flowers.

Grizedale and Alice Holt Experiments, 1960: Root-pruning and Girdling

Two similar experiments to estimate the effects, on both male and female flower production, of factorial combinations of root-pruning and stem-girdling treatments were established in 1960 at Grizedale, Lancashire, and at Alice Holt, on nine-year-old *Picea omorika* trees which ranged in height between nine and thirteen feet. The treatments were:

(a) Root-pruning to a depth of nine inches in a circle of either two, four or six feet diameter around the trees.
(b) Stem girdles at 25, 50 or 75 per cent of the tree height using two half girdles two inches apart and either ¼ inch or ½ inch wide.
(c) Non-girdled control trees were also included.

The design was a 3^3 factorial in one complete replication with the highest-order interaction partly confounded with blocks. Single-tree plots were used.

At Grizedale, none of the trees had flowered before the experiment began in 1960, and only five out of the total of twenty-seven trees produced any flowers in 1961; no tree flowered in 1962. Thus no conclusions can be drawn from the data, other than the observation that girdling does not always stimulate flowering.

At Alice Holt, where the trees were eleven to fifteen feet tall, eleven trees had a small number of female flowers, and one bore male flowers, in the year before treatments were applied. In 1961, twenty-one trees bore female flowers and twenty-four bore male flowers. In 1962 and 1963 all the trees but one bore both female and male flowers. The main effects of the treatments are presented in Table 66. A logarithmic transformation of the data was used for statistical analysis purposes.

There was a consistent increase in male flowering from 1961 onwards, whereas female flower production rose to a peak in 1962 and dropped to below the 1961

Table 66

ACTUAL MEAN NUMBERS OF MALE AND FEMALE FLOWERS PER TREE BY TREATMENTS AND YEARS

(Alice Holt Expt. 5/60)

Treatment	Male strobili			Female strobili		
	1961	1962	1963	1961	1962	1963
No girdle	47	63	90	67	61	25
2, $\frac{1}{4}$-in. wide semi-circular girdles	70	150	200	40	131	32
2, $\frac{1}{2}$-in. wide semi-circular girdles	10	85	152	26	70	34
Girdles applied at 25% of tree height	36	96	90	53	125	22
Girdles applied at 50% of tree height	22	67	150	51	60	33
Girdles applied at 75% of tree height	69	135	202	29	77	36
Root pruning in a circle 2 ft. from the tree	11	88	79	62	103	35
Root pruning in a circle 4 ft. from the tree	62	80	146	61	80	29
Root pruning in a circle 6 ft. from the tree	54	130	217	10	79	27
Annual Total	127	298	442	133	262	91

level in 1963. The $\frac{1}{2}$-inch girdling treatments significantly (at the 5 per cent level) increased the production of female flowers in 1962, in comparison with ungirdled trees, and the number of flowers in the $\frac{1}{4}$-inch girdling treatment was highly significantly (at the 1 per cent level) greater than in either the control or the $\frac{1}{2}$-inch girdling treatment. Trees girdled at one quarter of their height produced significantly more female flowers in 1962 than did those girdled mid-way, or three-quarters of the way, up the stem. Girdles made at three-quarters of the tree height doubled the 1962 crop of male flowers, in comparison with those placed at half the tree height, and half as many again as those with girdles one quarter of the way up the stem. The severest root-pruning treatments favoured female flower production in 1961 and 1962, whereas in all years severe root-pruning reduced the crop of male flowers.

Twelve Experiments in 1962 on Fertilizer Treatments (Table 67)

In 1962, a group of experiments involving six coniferous species, growing on twenty-three forest sites, compared the effects of combined N, P and K fertilizers, at four different rates of application, with an unfertilized control. The fertilizers were applied to rideside trees of similar height and girth, specially selected for their long crowns and southerly exposure, and showing indications of having flowered in previous years. The fertilizer treatments were:—

(0) No fertilizer

(1) 2 oz. 'Nitrochalk' (21 per cent N) and 2 oz. of a commercial 0:1:2 fertilizer (20 per cent P_2O_5: 20 per cent K_2O)

(2) 3 oz. 'Nitrochalk' (21 per cent N) and 2 oz. of a commercial 0:1:2 fertilizer (20 per cent P_2O_5: 20 per cent K_2O)

(3) 4 oz. 'Nitrochalk' (21 per cent N) and 4 oz. of a commercial 0:1:2 fertilizer (20 per cent P_2O_5: 20 per cent K_2O)

(4) 6 oz. 'Nitrochalk' (21 per cent N) and 6 oz. of a commercial 0:1:2 fertilizer (20 per cent P_2O_5: 20 per cent K_2O)

Each treatment plot contained five neighbouring trees, and consisted of a twelve-feet wide strip extending to six feet on each side of the trees. A group of five treatment plots at each forest constituted one 'block' of the experiment.

Only the cone crop data for Scots pine, Japanese larch and Douglas fir was analysed and this is presented in Table 67. The cone crop for Corsican and Lodgepole pine and Sitka spruce was either too similar for all treatments, or else the crops were altogether too poor to permit valid conclusions to be drawn.

Because Scots pine flowers take eighteen months to mature, the crop data was collected in 1964. The figures show that flowering responses had been achieved to one or more of the fertilizer application treatments, at all four forests.

The 1963 Japanese larch cone crop showed that larch had responded well to the two intermediate rates of fertilizer at Gwydyr and Eggesford forests, but at Dartington the cone increases attributable to fertilizers were not significant (at the 5 per cent level). At Grizedale the entire crop was too poor to permit useful conclusions to be drawn, but the 1964 data indicated that the heaviest fertilizer rate had produced a massive boost to cone production. This result was also repeated at Eggesford, but not at Dartington.

In 1963 and 1964 the heaviest rate of fertilizer greatly improved the cone crop on Douglas fir at the New Forest and Thetford. The third heaviest application at Thornthwaite forest provided the biggest flowering response in 1963, and in 1964 a similar result was observed at Thetford.

In 1964 the linear effects of those treatments which were analysed showed significant increases in cone crops, of 20 per cent for Scots pine, 50 per cent for Douglas fir and 67 per cent for Japanese larch, per ounce of 'Nitrochalk' and 0:1:2 fertilizer.

Experiments in Clonal Seed Orchards

This part of the paper is concerned with treatments applied to grafted plants consisting of scionwood grafted on to seedling rootstocks. No experiments have been done on rooted cuttings.

Alice Holt Experiment, 1958: Disbudding

In 1958 a number of four-year-old grafts of Scots pine of Clone No. 730, growing at Alice Holt, were used to demonstrate the effects of disbudding treatments on the production of male flowers. Two treatments were applied in early April—namely:

(i) Removal of all terminal buds.

(ii) Removal of all terminal and lateral buds.

(iii) One third of the plants were left untreated.

Grafts which had all the buds removed produced on average two clusters of male strobili, in contrast to the controls and those plants which had only the terminal buds removed, which plants were barren.

Drumtochty Experiment, 1962: Fertilizers

During 1962 a detailed experiment to determine the effects of different rates of N P K fertilizers on the production of female strobili in a ten-year-old Scots

Table 67

Data for the 1962 Flower Induction Experiments on Scots Pine, Japanese Larch and Douglas Fir

Species	Forest or locality	Expt. No.	Year of crop	Treatment No. Total No. of cones per 5 trees					Transformed data log (X + 1)						Mean Ht.	Mean Girth	Elev.	Soil type
				0	1	2	3	4	0	1	2	3	4	SE±	(ft.)	(ins.)	(ft.)	
SCOTS PINE	Culbin	23/62	64	16	29	19	142	84	1·23	1·48	1·30	2·16	1·93	1964 0·14	33	24	30	Sand
	Roseisle	7/62	64	194	290	177	308	265	2·29	2·46	2·25	2·49	2·42		24	16	30	Sand
	Devilla	18/62	64	59	45	35	135	346	1·78	1·66	1·56	2·13	0·84		32	20	200	Sandy podzol
	Wykeham	97/62	64	18	17	22	6	38	1·28	1·26	1·36	0·84	1·59		32	20	600	Sandy podzol
JAPANESE LARCH	Grizedale	8/62	63	4	0	0	30	40	0·60	0·00	0·00	0·47	1·60		26	17	525	Sandy loam
			64	0	3	27	3	287	0·00	0·60	1·45	0·60	2·46					
	Gwydyr	20/62	63	397	71	1,008	844	18	2·60	1·86	3·00	2·93	1·26	1963 0·33	68	40	200	Heavy clay loam
			64	—	—	—	—	—	—	—	—	—	—					
	Dartington, Devon	2/62	63	320	490	275	650	660	2·51	2·69	2·47	2·81	2·82	1964 0·32	36	22	500	Shaly loam
			64	0	19	5	0	4	0·00	1·30	0·78	0·00	0·70					
	Eggesford	4/62	63	1101	2,790	583	191	380	3·04	3·45	2·77	2·28	2·59		41	19	425	Sandy loam
			64	22	14	21	29	267	1·36	1·18	1·34	1·48	2·43					
DOUGLAS FIR	Thornthwaite	4/62	63	80	0	31	210	0	1·91	0·00	1·51	1·32	0·00		63	38	450	Sandy loam
			64	0	0	0	0	0	0·00	0·00	0·00	0·00	0·00					
	Thetford	76/62	63	112	20	480	84	114	2·05	0·32	2·68	1·93	2·06	1963 0·30	61	43	150	Sandy loam
			64	26	8	6	103	95	1·43	0·95	0·85	2·08	1·98					
	New	116/62	63	0	5	0	0	521	0·00	0·78	0·00	0·00	2·72	1964 0·48	86	57	200	Sandy loam
			64	0	26	0	0	130	0·00	1·43	0·00	0·00	2·12					
	Dean	86/62	63	0	0	0	40	2	0·00	0·00	0·00	1·61	0·48		65	43	350	Medium loam
			64	0	0	0	25	30	0·00	0·00	0·00	1·42	1·49					

Table 68

FOLIAGE ANALYSIS DATA. SCOTS PINE CLONE 362

(Drumtochty 7 P.53 Extn. 62)

N P K Treatment Rate	Dry weight per needle mgm.			% N			% P			% K			% Mg			% Ca		
	62	63	64	62	63	64	62	63	64	62	63	64	62	63	64	62	63	64
0	43·6	32·0	34·0	9·2	4·6	6·4	0·89	0·59	0·75	3·3	2·3	2·8	0·48	0·38	0·51	1·3	0·9	1·0
1	37·4	32·6	38·6	7·1	4·6	6·3	0·77	0·68	0·81	2·8	2·6	2·9	0·37	0·36	0·42	1·4	1·3	1·4
1½	34·6	39·2	39·8	6·7	5·6	5·3	0·64	0·74	0·75	2·3	2·7	2·2	0·33	0·43	0·36	1·2	1·4	1·0
2	41·8	52·2	36·6	8·4	8·3	6·0	0·75	0·94	0·81	2·3	3·9	2·8	0·50	0·42	0·51	1·2	1·5	0·9

pine orchard was laid down at Drumtochty (Expt. 7P. 53 Extn. 62). The treatments were:

(0) Untreated control;

(1) 118 lb. N; 49 lb. P, 93 lb. K, per acre, applied as a mixture of 'Nitrochalk' (21 per cent N) and commercial 0: 1: 2 fertilizer;

(1½) The same fertilizers applied at 1½ times the above rate.

(2) The same fertilizers applied at double rate 1.

The fertilizers were applied over plots of 15 feet × 45 feet during March. Each plot contained three grafted trees and there were six replications of the four treatments. In all, fourteen clones were included in the experiment. At the time of laying out the experiment, it was thought that the plot means would average out the between-clone differences in flowering.

Needle samples were collected from Clone 362 during September 1962, 1963 and 1964 and were analysed for N, P, K, Ca and Mg. The data is presented in Table 68.

In 1963, flower production was not affected to any noticeable degree by any of the treatments. In 1964, counts of female flowers, and measurements of male flowering shoots, were made; they clearly showed that the treatment effects were negligible in comparison to the differences between clones. (See Table 69).

Table 69

MALE AND FEMALE FLOWER PRODUCTION ON GRAFTED SCOTS PINE TREES, AFTER N, P AND K FERTILIZER TREATMENTS APPLIED IN 1962. 1964 DATA

(Drumtochty 7 P.53 Extn. 62)

Clone No.	Control		NPK Treatment Rate 1		1½		2		Means		No. of ramets assessed
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	
290	0	1	—	—	0	22	1	42	0	18	6
292	0	72	112	479	56	415	—	—	16	390	5
296	40	247	25	0	13	98	103	195	52	180	6
298	40	10	1	39	1	207	0	90	10	71	6
362	3	2	11	0	4	10	15	11	5	7	6
366	26	122	0	68	—	—	0	48	11	83	6
368	0	66	0	81	—	—	0	48	0	65	6
280	147	146	2	123	2	71	0	51	99	114	6
281	0	55	289	80	96	209	100	315	65	180	6
282	300	59	502	106	25	68	150	71	265	80	6
283	1	250	0	125	0	175	0	163	0	163	6
477	—	—	3	8	2	36	2	25	2	26	6
478	—	—	1	619	2	382	14	592	6	513	5
479	1	146	1	146	1	74	1	36	11	55	6
Mean	48	91	44	160	45	152	24	128	40	133	—

Note. Male flower measured in inches of male flowering shoot.

Alnwick Experiment, 1963: Removal of Female Flowers

In 1963, six Scots pine clones in a 100-ramet polycross orchard at Alnwick were chosen for an experiment, which was designed to determine the effects, on the flower crop in the following season, of completely removing all female flowers, and also the previous year's conelets. The ramets ranged from 2·3 ft. to 6·6 ft. in height, and they were grouped in pairs, each member of a group being similar in height and root-collar diameter to its neighbour, before applying the flower removal and conelet removal treatments. In all, there were twenty-one paired treatments (i.e. treated graft or grafts in which only the previous year's conelets were removed) with either three or four paired treatments per clone. The grafts were also measured for height, and for root collar diameters, to determine whether cone production seriously restricted the vigour of grafts—as expressed by heights and root collar diameter. Summarised data are presented in Table 70.

Table 70

EFFECTS OF REMOVING FEMALE FLOWERS ON THE FEMALE FLOWER CROP AND THE HEIGHT AND ROOT COLLAR DIAMETER GROWTH IN THE FOLLOWING YEAR

(Alnwick Expt. 1/63)

Factor	Mean per ramet		Difference
	Control	Number of flowers removed 1963	
1963 No. of flowers before removal	12·2	15·2	− 3·0
1964 No. of flowers	47·8	43·5	+ 4·3
Height difference (1964–1963)	2·95 ft.	2·90 ft.	+ 0·05 ft.
Root collar diam. difference (1964–1963)	2·13 cm.	2·08 cm.	+ 0·05 cm.

The indications were that removing female flowers in 1963 did not increase the crop of female flowers in 1964, nor did developing cones draw seriously on carbohydrate reserves and so reduce the vigour of grafts. There may however be long-term effects not revealed by this short-term experiment.

Newton Experiment, 1959–1964: Grass Cutting and Fertilizers

An experiment on methods of managing established seed orchards of larch, which was laid-out in an eight-year-old larch seed orchard at Newton, Morayshire, extended over the period 1959 to 1964. It was designed to test the effects on female flowering (as expressed by counts of ripe cones) of three sets of treatments. These consisted of:

(i) Cutting the grass sward twice, three or six times a year.
(ii) Maintaining three different levels of phosphorus and potassium in the soil.
(iii) Applying annual top dressings of nitrogen at three rates.

Usually the grass cut during the period June to mid August had to be removed to avoid choking the machine during the next cut. At other times the grass was left to rot on the site. The phosphate and potassium fertilizers were applied at rates calculated to provide 8, 16 or 24 milligrams of P_2O_5 or K_2O per 100 grams of soil to a depth of 6 inches (8 mgm. per 100 grams of P_2O_5 and K_2O is regarded as a satisfactory level for forest nursery soils); the rates were calculated on the basis of a detailed soil analysis. Nitrogen was applied as 'Nitrochalk' (21 per cent N) at either 2, 4 or 6 cwts. per acre. The plot size was 0·137 acres and contained either 24 or 32 grafted seed trees of European and Japanese larch. There were 3 blocks, each containing three grass-cutting treatments. Each grass-cutting treatment was split for the three manurial treatments. Because the highest rates of fertilizer applied were at a level likely to prove harmful to the grafts if applied in one dose, it was, for safety, given in three stages during the period 1959/60. In 1962, and again in 1964, further soil analyses of composite samples, to a depth of six inches, indicated that the levels of P and K were actually much lower than prescribed; as a consequence these two elements were again applied during these years, at rates calculated to raise the P_2O_5 and K_2O to the required levels. A foliage analysis was made in the autumns of 1963 and 1964, and an additional soil analysis was made in June 1965 using stratified samples taken at depths of one, three and six inches. The data derived from these soil and foliage analyses are given in Tables 71, 72 and 73.

Table 71

MEAN FIGURES FOR THE SOIL CONTENT OF P_2O_5 AND K_2O IN 1962 AND 1964

(Newton Expt. 9 P.52 Extn. 59)

Treatments	P_2O_5 mgm./100 gms.		K_2O mgm./100 gms.	
	Early 1962	Late 1964	Early 1962	Late 1964
Grass cutting twice per year	7·3	7·2	4·8	4·6
Grass cutting three times per year	6·8	7·1	4·7	5·9
Grass cutting six times per year	6·4	6·6	4·9	8·8
Low level phosphorus and potassium	4·5	4·6	4·0	4·6
Medium level phosphorus and potassium	7·1	7·0	4·0	6·1
Highest level phosphorus and potassium	9·0	9·2	7·0	8·2

In 1962 the soil pH ranged from 4·6 to 5·4; soluble CaO per cent from 0·08 to 0·22; organic matter from 6·0 to 11·0 per cent and MgO from 2·5 to 8·6 mgm./100gm. of soil.

During the whole period of the experiment, each successive cone crop was a virtual failure, and for this reason no cone counts were made. As expected, the fertilizer effects were very pronounced on the grass sward, which responded greatly to the higher rates of fertilizer by growing vigorously—and to the extent that it was often difficult to cut the grass by machine. The soil analyses show how the potash and phosphate in particular becomes concentrated in the upper soil layer where many of the tree feeder roots occur, and where much of the nutrient is presumably recycled by both the trees and the sward. At lower levels (3 inches and below) the nutrient levels are lower than predicted, as a result of phosphate fixation, by leaching, or by the effects of harvesting part of

Table 72

CHEMICAL ANALYSIS OF FOLIAGE (SAMPLES COLLECTED 16TH SEPT. 1963 AND 26TH SEPT. 1964)

Species	Treatment	Needle Dry Wt.		N %		P %		K %		Mg %	
		1963	1964	1963	1964	1963	1964	1963	1964	1963	1964
European larch (3 clones)	Low level NPK	6·9	6·2	2·61	2·69	0·37	0·42	0·69	0·61	0·16	0·20
	Medium level NPK	6·7	5·4	2·66	2·89	0·32	0·33	0·93	0·53	0·15	0·13
	High level NPK	6·5	5·4	3·08	3·00	0·38	0·30	0·90	0·70	0·10	0·15
Japanese larch (4 clones)	Low level NPK	8·5	4·4	3·37	2·95	0·41	0·35	1·11	0·86	0·17	0·10
	Medium level NPK	7·8	4·4	3·24	2·81	0·38	1·31	1·56	0·99	0·12	0·13
	High level NPK	6·6	4·8	2·90	3·12	0·38	0·30	1·64	1·16	0·12	0·13

Table 73

MEAN FIGURES FOR pH AND SOIL CONTENT OF P_2O_5, K_2O, CaO AND MgO FROM TWO TREATMENTS IN JULY 1965

(Newton 9 P.52 Extn. 59)

Treatment	Depth (inches)	pH	Mgm./100 gms. soil			
			P_2O_5	K_2O	MgO	Sol.CaO %
Low level P & K grass cut thiee times per year	1	5·70	7·8	7·3	11·7	0·22
	3	5·40	3·0	6·1	6·6	0·17
	6	5·45	4·1	5·4	4·4	0·18
High level P & K grass cut three times per year	1	5·30	34·2	9·6	9·6	0·23
	3	5·00	12·7	6·1	4·7	0·14
	6	5·00	6·0	6·1	—	0·12

the grass crop. Two grass cuts per year tend to maintain a lower level of available *phosphate* in comparison with three or six cuts, but have the reverse effect on soil *potash.* Increased rates of potash and phosphate do not proportionally increase the soil content of these nutrients, and only the highest rates of application maintained the lowest target level of 8 mgm. per 100 gms. of soil.

The foliar analysis indicated that very high application of N, P and K do not result in correspondingly higher concentrations of these elements in the foliage. In fact there is a strong suggestion that by stimulating a very vigorous grass sward the higher rates may encourage the nutrient uptake in the grasses, at the expense of the trees.

Newton Experiment, 1963: Foliar application of Urea

Nitrogen applied as foliar sprays of urea at different concentrations, was tested for its possible effects on the 1963 flower crops of European and Japanese larch grafts on a sixty-clone seed orchard at Newton, Morayshire. Solutions of 5 lbs., 10 lbs. or 20 lbs. urea, in 100 gallons of water, were sprayed onto the plants (which were 4 feet to 7 feet tall) in mid-July or mid-August 1962, or in mid-March and April or mid-May 1963. Approximately eight fluid ounces of solution were applied per graft, representing 0·005 ozs. N; 0·01 ozs. N; or 0·02 ozs. N; per graft. None of the treatments had any effect on the 1963 or 1964 crop of female flowers. The rates of application are similar to those recommended for apple orchards in England, but may be too low and therefore ineffective for larch. Further investigations, particularly on the effects of repeated applications, are proposed.

Discussion and Summary

The effects of four groups of treatments on flowering and cone production have been studied in the experiments described here. These treatments were: fertilizer applications, root-pruning, complete or partial girdling of the stem, shoot-pruning and disbudding. The experiments were made on a range of tree species, but mainly on Scots pine, Corsican pine, European larch and Japanese larch. The treated trees have been of both seedling origin and also of clones of grafted plants. Treatments were applied on a range of sites and over several years.

The results were very varied and often conflicting, but some general ideas about the effectiveness of several methods of increasing flower production have emerged:

Root-pruning has been tried in three experiments in which it produced conflicting results. It does not appear to be a promising treatment for increasing flowering in either managed seed stands or seed orchards. It was unreliable in its effects on small trees, and it is difficult to apply to large trees.

Partial stem-girdling has been successfully used to increase the flowering of four-year-old Scots pine, ten-year-old *Picea omorika* and twenty-two and twenty-six year-old Corsican pine. The more severe versions of stem girdling, such as inverting a ring of bark tissue, did not succeed and often caused the death of the tree. The advantage of partial stem girdling when carefully applied were: firstly, the response in increased flowering was quick and fairly reliable; secondly, there appeared to be no, or only small, after-effects on the treated trees; thirdly, some positive responses can be seen even in years of poor flowering. Trees that were too young or too small did not respond, whilst amongst those which were large enough, or old enough, to flower the largest trees showed the best response.

Application of Nitrogen, Phosphorus and Potassium. The numerous experiments involving applications of these three major nutrients to raise the nutrient status both of the soil and the seed trees produced conflicting results, but overall they emerged as promising treatments. It appears that all three can have effects leading to increased flowering and complete fertilizers have a general value. However efforts to raise the nutrient levels in the oldest larch seed orchard at Newton, Morayshire, were not successful in the presence of strong grass growth even when the sward was cut up to six times a season. It appears that closer control of the grass growth may be required if the seed trees are to benefit from fertilizers. Applications of nitrogen, phosphorus and potassium did not appreciably increase flowering and seed production in 'off' years.

Shoot-pruning. The limited work which has been done is insufficient to enable anyone to judge the importance of this type of treatment. However the evidence available from three experiments suggests that shoot-pruning and disbudding in pines have promise, but require further detailed investigation.

In all the experiments, two well-recognised but complex groups of factors have been either accentuating or masking the various treatment effects. Two innate factors in the treated seed trees themselves are firstly, their apparent need to achieve a certain size before flowering begins; and secondly, the very large differences between trees in the number of male and female flowers produced and the frequency at which flowering occurs. Interacting with these factors have been the considerable effects of climate and site, and also the level and timing of the treatments which are often crucial to their success.

All the experiments have suffered in some degree from defects of design, layout, and assessment, which have made their analysis and interpretation difficult. Experiments to demonstrate the effects of treatments on flowering and seed production are not easy to design and execute, and the following points are noted to indicate the direction of future work.

Application of fertilizers and shoot-pruning treatments require further study, the first because a relatively high nutrient status appears important for regular heavy flowering, and the second because pruning treatments offer possibilities of controlling the size and shape of seed trees, particularly in seed orchards.

Work can now proceed on a range of seed stands and seed orchards with the object of increasing flower and seed production. One significant lesson learned is that an experimental response may not appear for several years, because of the over-riding effects of climatic factors.

Complex statistical lay-outs may serve a useful role in separating a range of potentially valuable treatments, but these should be replaced as soon as possible by simple more reliable designs. Careful account should always be taken of probable between-tree variation in responses.

REFERENCE

HOLMES, G. D., and MATTHEWS, J. D., 1951. *Girdling or Banding as a Means of Increasing Cone Production in Pine Plantations.* Forest Record No. 12. H.M.S.O., London.

RELATIONSHIP BETWEEN STAFF AND WORK-LOAD IN INDIVIDUAL FOREST UNITS

By J. N. R. JEFFERS

Introduction

This paper summarizes the practical conclusions of an investigation into the relationship between the work load at individual forest units, and the numbers of workers, gangers, assistant foresters, and foresters allocated to those units. The detailed evidence upon which these conclusions are based is contained in a paper by J. N. R. Jeffers and B. E. Seale (*Statistics Section Paper* No. 78) and is not repeated in this paper.

Basic Data

The basic data used in the investigation were derived from a survey carried out in all the territorial Conservancies of the Forestry Commission at the end of 1961. For each of 486 forest units, information was collected on 21 variables, designed to represent the work load of the unit and the numbers of workers and supervisors provided to satisfy that load. Fourteen of the variables were concerned with the work load, the remaining seven being the numbers of workers and supervisors of various grades.

Work Load Variables

The following variables were used to measure the work load in each forest unit:—

(a) Number of separate blocks of forest under 300 acres in area.

(b) Number of separate blocks of forest between 300 and 1,000 acres in area.

(c) Number of separate blocks of forest over 1,000 acres in area.

(d) Area of plantable land in acres.

(e) Area under plantations in acres.

(f) Area still to be planted in acres.

(g) Area of nursery in acres.

(h) Area to be planted in 1962 (i.e. one year later).

(i) Volume of timber sold 'standing', in 1961 (current year), in thousands of hoppus feet.

(j) Volume of timber sold 'felled,' in 1961 (current year), in thousands of hoppus feet.

(k) Volume of timber to be sold 'standing', in 1962 (following year), in thousands of hoppus feet.

(l) Volume of timber to be sold 'felled,' in 1962 (following year), in thousands of hoppus feet.

(m) Estimated volume of timber production in 1970 (i.e. 9 years later), in thousands of hoppus feet.

(n) Estimated volume of timber production in 1975 (i.e. 14 years later), in thousands of hoppus feet.

Staff Variables

The following categories of workers and supervisors were used in the investigation:—

(o) Number of Forest Workers of all grades.
(p) Number of workers of other grades (i.e. not Forest Workers).
(q) Number of Gangers.
(r) Number of Leading Gangers.
(s) Number of Assistant Foresters.
(t) Number of Foresters, at or below the efficiency bar.
(u) Number of Foresters, above the efficiency bar.

(*Note.* At this date an efficiency bar governed the progress of supervisory Foresters, up their salary scale).

Practical Conclusions

The practical conclusions derived from the investigation may be summarized as follows:—

(1) The fourteen variables used in this study may be conveniently expressed as five independent factors of the work load in individual forest units. These factors are:—
   (a) The general size of the unit, as expressed by such variables as the area of plantable land, the area under plantations, and the estimates of future timber production.
   (b) The area of active planting, as expressed by such variables as the area still to be planted and the area to be planted in the next Forest Year.
   (c) The volume of timber to be sold 'standing.'
   (d) The degree of 'scatter' of the unit, as expressed by the number of blocks of less than 300 acres.
   (e) The area of nursery.

(2) The correlations between the numbers of workers, Gangers, Assistant Foresters, and Foresters are very high, and suggest that a good balance has been kept between the numbers in each grade. The numbers of Leading Gangers, however, suggest that this grade has been used in widely differing ways in differing parts of the organization, and that some clear direction is necessary as to the functions and numbers of men in this grade.

(3) A general index of the numbers of workers and supervisors in the various grades is related to the size of the unit, the 'scatter' of the unit, and the area of nursery.

(4) The numbers of Forest Workers and of Gangers are related to the size of the unit, the degree of 'scatter' of the unit, and the area of nursery.

(5) The number of workers of 'other grades' (i.e. not Forest Workers) is related to the size of the unit and the area of nursery.

(6) The number of Leading Gangers is related to the size of the unit, the volume of timber to be sold standing, and the area of nursery.

(7) The number of Assistant Foresters is related to all factors of the work load, i.e. to the size of the unit, the area of active planting, the volume of standing thinnings, the degree of scatter of the unit, and the area of nursery.

Table 74

QUANTITIES USED FOR RELATING STAFF TO WORK LOAD

	Quantities for calculating numbers of:—						
	Forest Workers	Other workers	Gangers	Leading Gangers	Assistant Foresters	Foresters (below bar)	Foresters (above bar)
Basic number	2·67	0	0·346	0·011	0·181	0·215	0·297
Number per block less than 300 acres	0·323	0·001	0·009	0	0·014	0	0·017
Number per thousand acres of plantable area	2·109	0·512	0·168	0·007	0·121	0·057	0·092
Number per acre of nursery	0·392	0·060	0·030	0·004	0·009	0·008	0·005
Number per 100 acres of land to be planted each year	0·861	0·104	0·170	0	−0·017	0·062	−0·029
Number per 10,000 hoppus feet to be sold 'standing'	0·214	0·083	0·016	0·003	0·011	0	0·002
Number per 10,000 hoppus feet to be sold 'felled'	0·745	0·085	0·060	0·002	0·010	0	0·050
Proportion of variability accounted for	70·2	49·3	53·9	8·3	39·6	20·4	45·4

Notes. (A) For a unit with one block of less than 300 acres, a total plantable area of 10,622 acres, a nursery of 37 acres, an annual planting programme of 225 acres, and an estimated timber production of 40 and 191 thousand Hoppus feet for standing and felled sales respectively, the number of Forest Workers required would be calculated as:—

$$2{\cdot}67 + (1 \times 0{\cdot}323) + (10{,}622 \times 0{\cdot}002109) + (37 \times 0{\cdot}392) + (225 \times 0{\cdot}00861) + (40 \times 0{\cdot}0214) + (191 \times 0{\cdot}0745)$$
$$= 2{\cdot}67 + 0{\cdot}32 + 22{\cdot}40 + 14{\cdot}50 + 1{\cdot}94 + 0{\cdot}86 + 14{\cdot}23 = 56{\cdot}92 \text{ or } 57 \text{ Forest Workers.}$$

(B) A unit with 10 blocks of less than 300 acres, a total plantable area of 878 acres, no nursery or timber production, but an annual planting programme of 22 acres, however, would have an estimated number of Forest Workers of:—

$$2{\cdot}67 + (10 \times 0{\cdot}323) + (878 \times 0{\cdot}002109) + (22 \times 0{\cdot}00861)$$
$$= 2{\cdot}67 + 3{\cdot}23 + 1{\cdot}85 + 0{\cdot}02 = 7{\cdot}77 \text{ or } 8 \text{ Forest Workers.}$$

(8) The number of Foresters at or below the efficiency bar is related to the size of the unit, the area of active planting, and the area of nursery.

(9) The number of Foresters above the efficiency bar is related to the size of the unit, the area of active planting, and the degree of scatter of the unit.

Practical Implications

These conclusions suggest that the relationship between the number of workers and their supervisors, and the factors of the work load in individual forest units, is less complex than is frequently represented. Useful estimates of the numbers of workers, gangers, assistant foresters, and foresters can in fact be derived from a relatively small number of variables of the work load, either for the purposes of complementing, or for forecasting the numbers of staff likely to be required in the various grades. The one exception to this is the grade of Leading Ganger, which appears to have been used in an anomalous way in various parts of the organisation. For practical purposes, the area of plantable land, the area of land to be planted in the coming Forest Year, the number of blocks of less than 300 acres, the area of nursery, and the volume of timber to be sold would serve as basic work load variables.

Estimating Equations

Practical equations for estimating the numbers of workers, gangers, assistant foresters, and foresters are given in the table below, based on data for England, Wales and Scotland. At the present time, there is no evidence to suggest that separate equations for the individual Conservancies, (or for the three territorial Directorates, England, Scotland and Wales, which existed in 1961) would give improved estimates. See Table 74.

Calculations of a similar kind provide estimates of the numbers of staff of other grades. It may be noticed that for the Assistant Foresters and Foresters above the efficiency bar, increases in the size of the planting area slightly reduce the demand on the supervisors time.

Future Work

It is suggested that the estimates provided by the equations of section 7 above should be explored further. Two possible extensions of the investigation are:—

(1) comparison of the complements estimated from the equations with actual complements, with particular emphasis upon those units in which there is a marked divergence.

(2) forecasting of the future staff requirements of forest units under various assumptions about future rates of planting, and timber production, and about the relative volumes of timber sold standing and felled.

The equations derived from the present investigation may also provide the basic relationships for more complex studies of the allocation of staff resources, based on techniques of mathematical programming.

Addendum

After the present paper had been completed, it was suggested that it would be of interest to consider the relationship between the total number of industrial workers, i.e. Forest Workers, other workers, Gangers, and Leading Gangers, and the work load variables, and between the total number of supervisors, i.e. Assistant Foresters and Foresters, and the work load variables. This addition therefore considers these relationships. (See Table 75).

Table 75

CORRELATIONS BETWEEN NUMBERS OF WORKERS AND SUPERVISORS AND WORK LOAD VARIABLES

	Coefficient of correlation	
	Workers	Supervisors
Number of blocks under 300 acres	0·203**	0·213**
Total plantable area	0·742**	0·774**
Area of nursery	0·383**	0·256**
Area planted in 1962	0·469**	0·480**
'Standing' sales volume	0·303**	0·314**
'Felled' sales volume	0·552**	0·522**

Note. ** Implies highly significant.

There were significant correlations between the total number of workers, and the total numbers of supervisors, and all of the work load variables considered in this paper.

Table 76

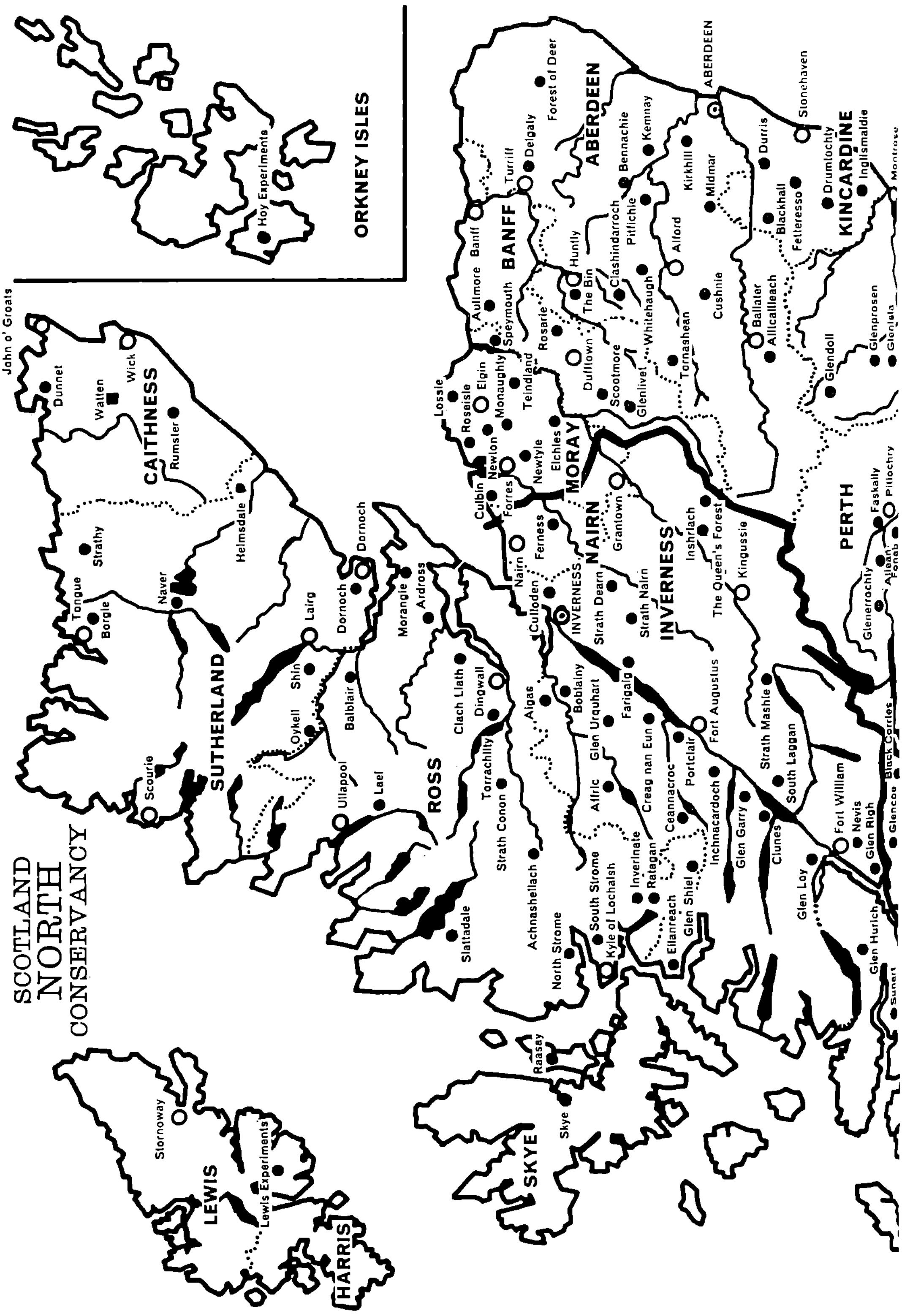
ESTIMATING EQUATIONS

	Quantities for calculating numbers of:—	
Basic number	Workers	Supervisors
	3·04	0·69
Number per block less than 300 acres	0·333	0·029
Number per thousand acres of plantable area	2·808	0·265
Number per acre of nursery	0·485	0·022
Number per 100 acres of land to be planted	1·096	0·022
Number per 10,000 hoppus feet to be sold 'standing'	0·316	0·024
Number per 10,000 hoppus feet to be sold 'felled'	0·889	0·058
Percentage of variability accounted for	74·8	71·5

The two estimating equations (Table 76) accounted for about 75 and 72 per cent of the variability in the numbers of workers and supervisors respectively.

SUMMARY

This note summarizes the practical conclusions of an investigation into the relationship between the work load at individual forest units, and the numbers of workers, gangers, assistant foresters, and foresters allocated to those units. The detailed evidence upon which these conclusions are based is contained in *Statistics Section Paper* No. 78, and is not repeated in this note.



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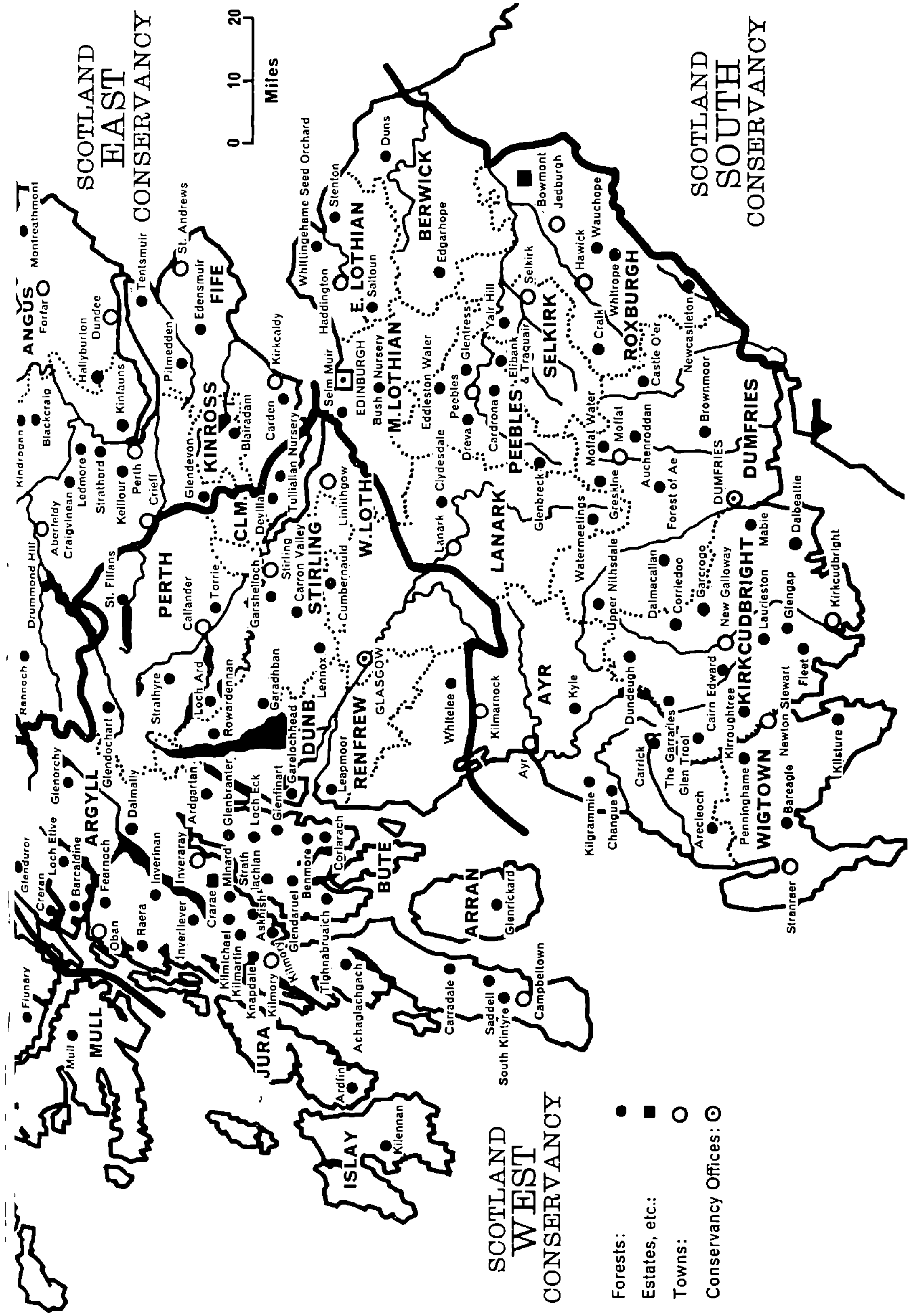
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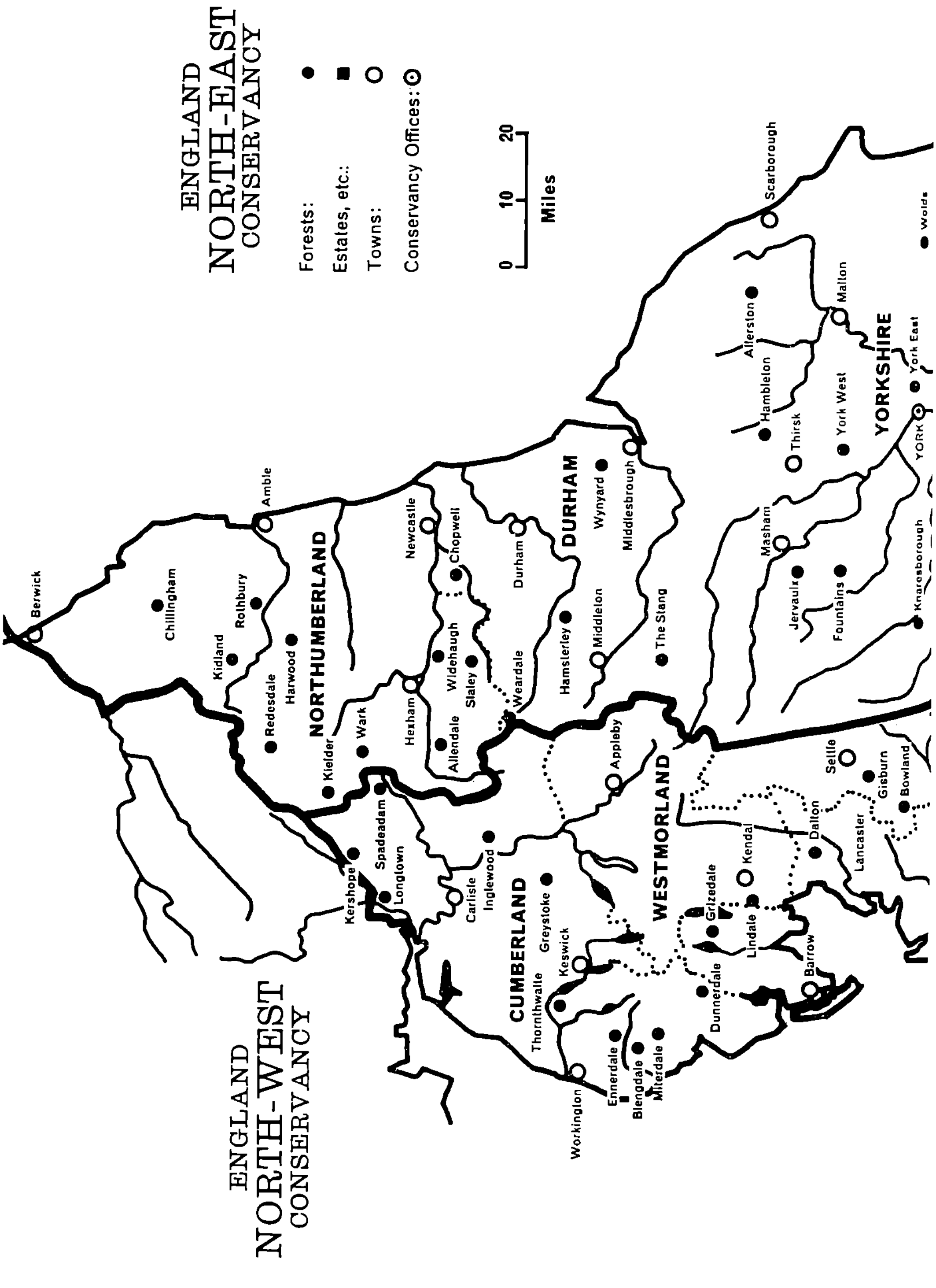
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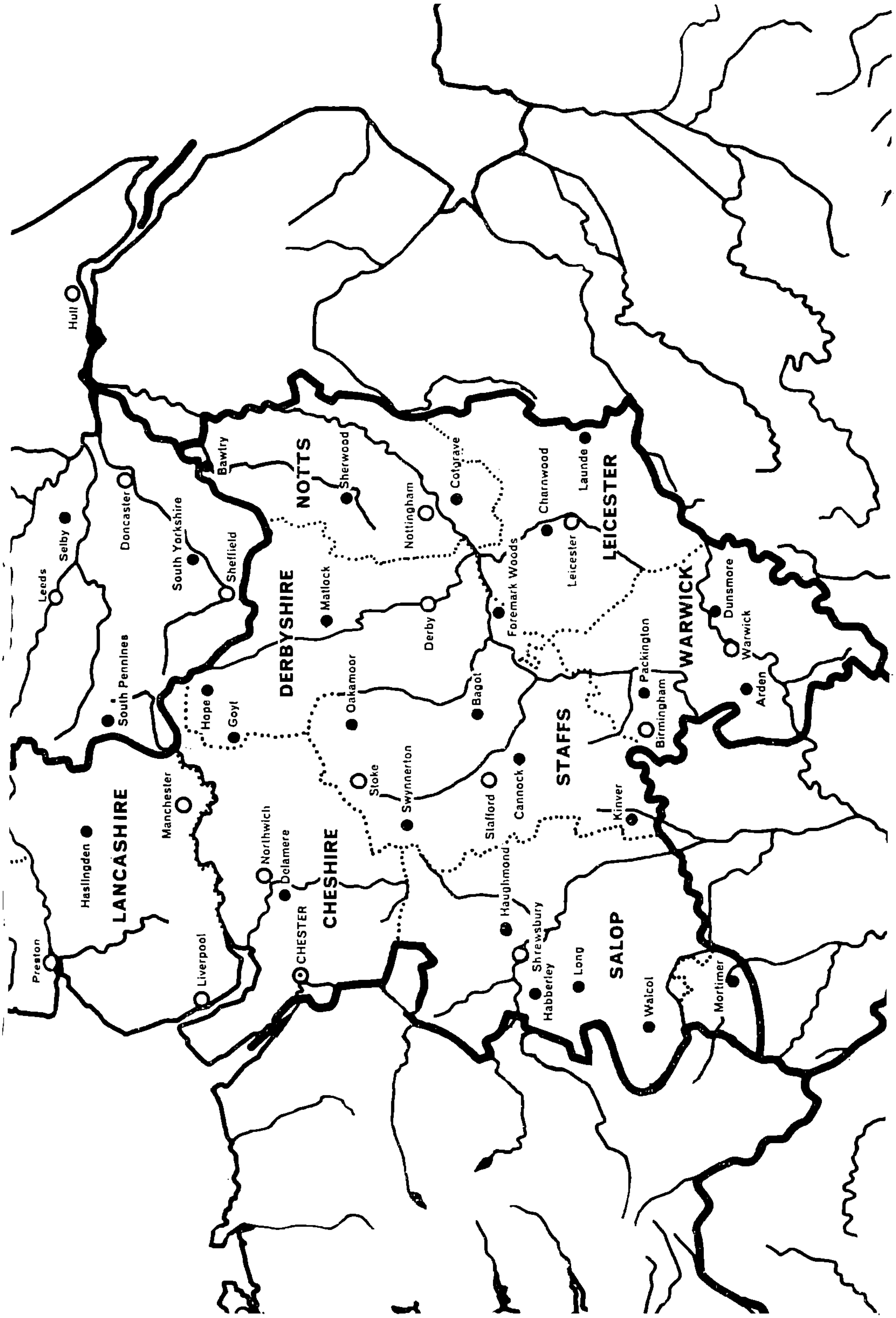
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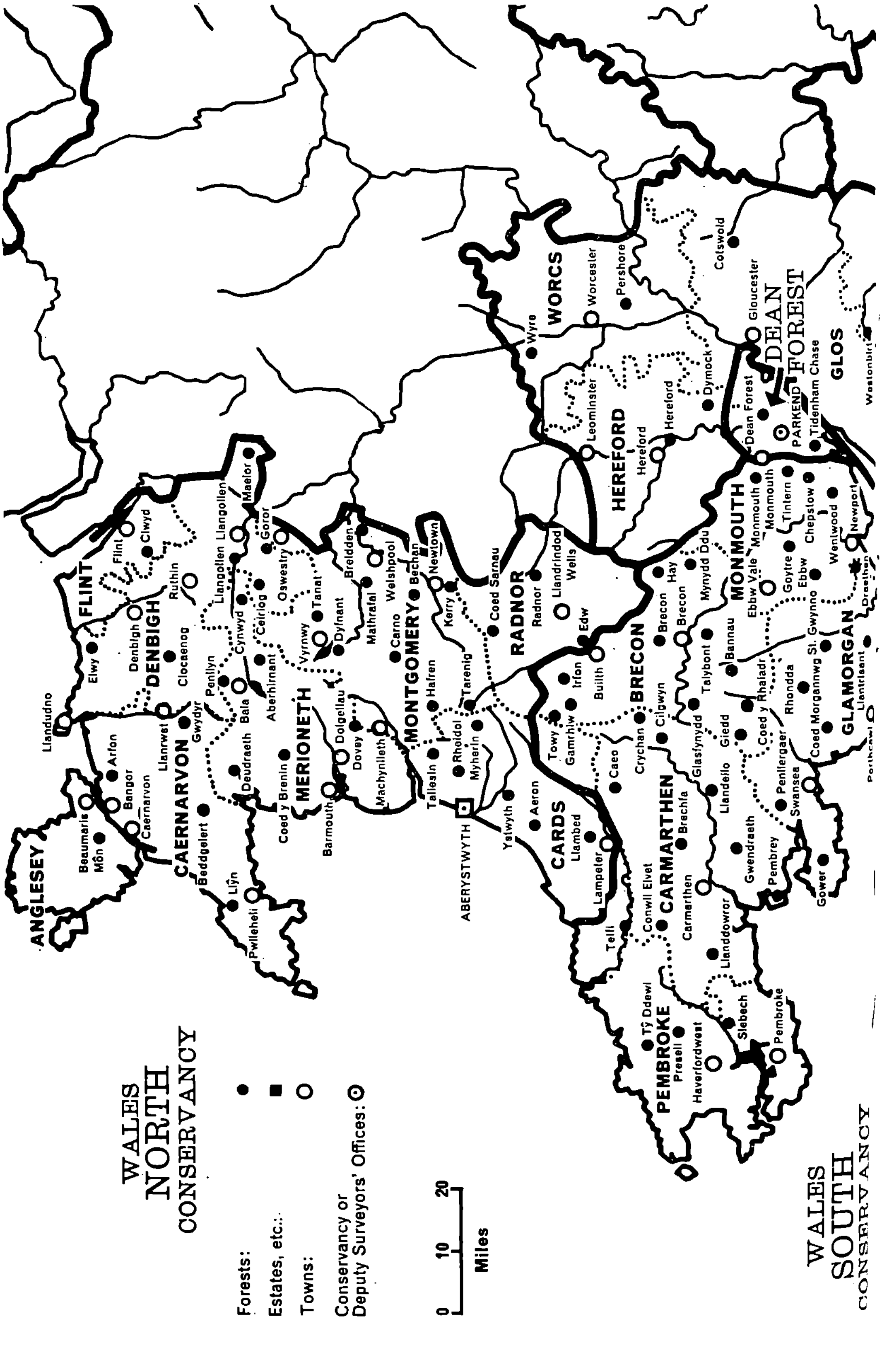
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Llanrwst
Gwydyr
Beddgelert
Llŷn
Pwllheli
Elwy
Denbigh
Clocaenog
Ruthin
Flint
Clwyd
Llangollen
Maelor
Goror
Oswestry
Ceiriog
Cynwyd
Penllyn
Bala
Aberhirnant
Deudraeth
Coed y Brenin
Dolgellau
Dovey
Machynlleth
Barmouth
Vyrnwy
Dyfnant
Tanat
Mathrafal
Breidden
Welshpool
Carno
Bechan
Newtown
Kerry
Coed Sarnau
Hafren
Tarenig
Rheidol
Myherin
Taliesin
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Ystwyth
Aeron
Llambed
Lampeter
Towy
Gamrhiw
Irfon
Builth
Edw
Radnor
Llandrindod Wells
Caeo
Crychan
Cilgwyn
Brecon
Hay
Mynydd Ddu
Talybont
Bannau
Glasfynydd
Giedd
Llandeilo
Brechfa
Carmarthen
Conwil Elvet
Telli
Llanddowror
Gwendraeth
Pembrey
Penllergaer
Swansea
Gower
Coed y Rhaiadr
Rhondda
Coed Morgannwg
St. Gwynno
Llantrisant
Ebbw Vale
Ebbw
Goytre
Wentwood
Newport
Chepstow
Tintern
Monmouth
Tŷ Ddewi
Preseli
Haverfordwest
Slebech
Pembroke
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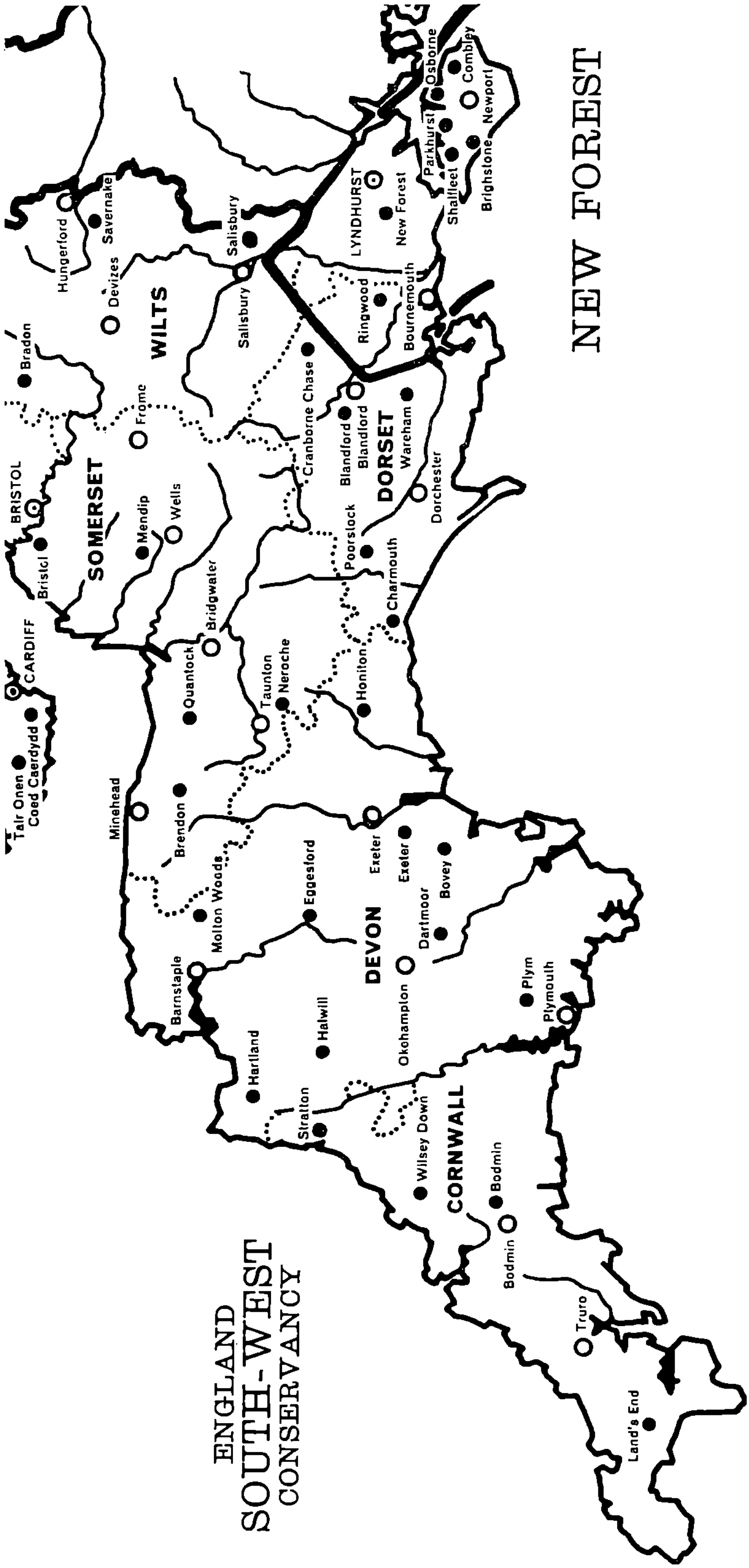
Dean Forest
Tidenham Chase
Gloucester
Cotswold
Worcester
Pershore
Wyre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Bournemouth
Parkhurst
Osborne
Combley
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Brighstone
Shalfleet
Bradon
Frome
Cranborne Chase
Blandford
Blandford
DORSET
Wareham
Dorchester
BRISTOL
Bristol
SOMERSET
Mendip
Wells
Poorstock
Charmouth
Bridgwater
CARDIFF
Quantock
Taunton
Neroche
Honiton
Tair Onen
Coed Caerdydd
Minehead
Brendon
Exeter
Exeter
Bovey
Molton Woods
Eggesford
DEVON
Dartmoor
Barnstaple
Okehampton
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Plym
Plymouth
Hartland
Stratton
Wilsey Down
CORNWALL
Bodmin
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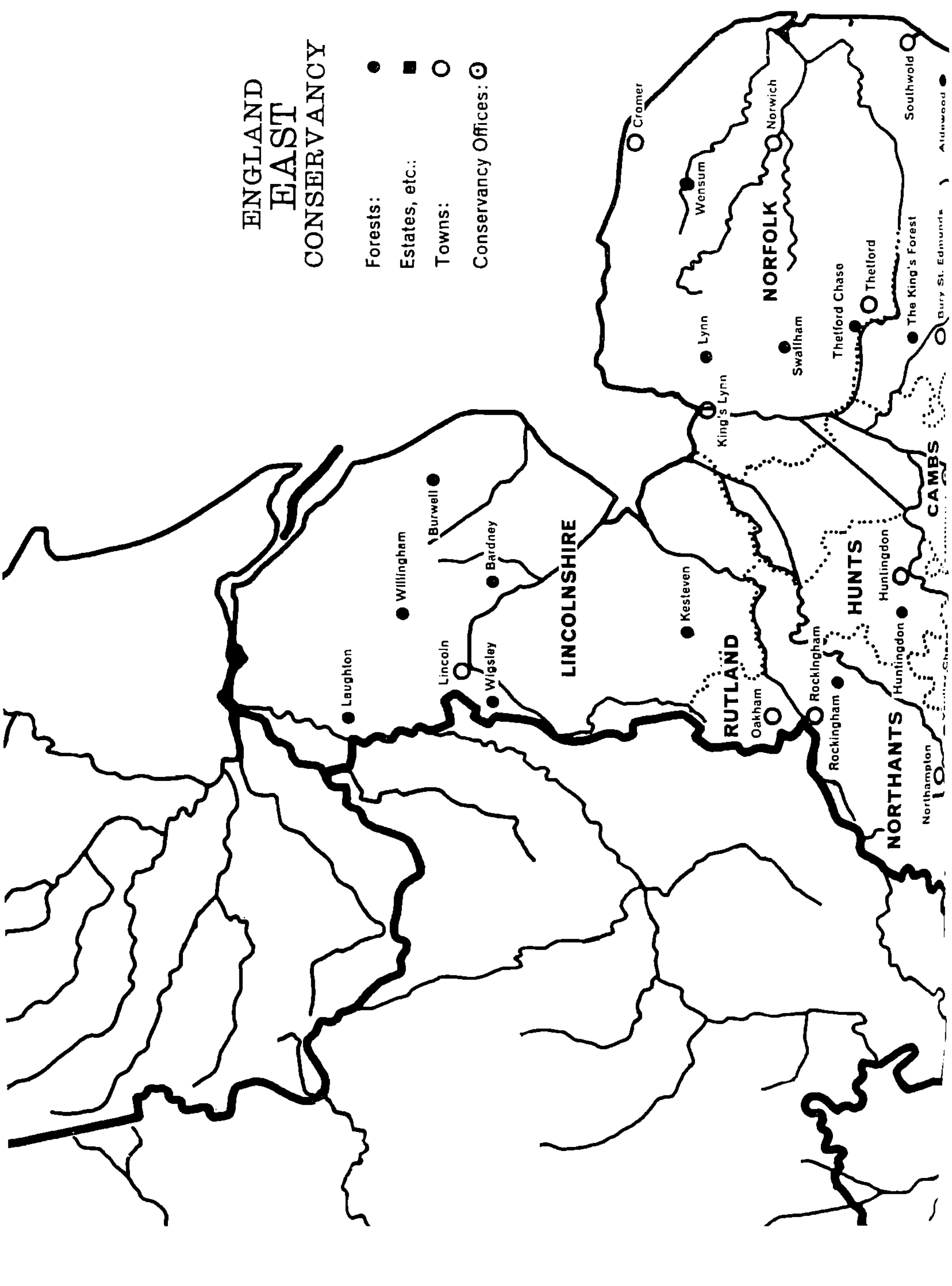
Land's End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The King's Forest
Lynn
Swaffham
King's Lynn
CAMBS
HUNTS
Huntingdon
Huntingdon
LINCOLNSHIRE
Burwell
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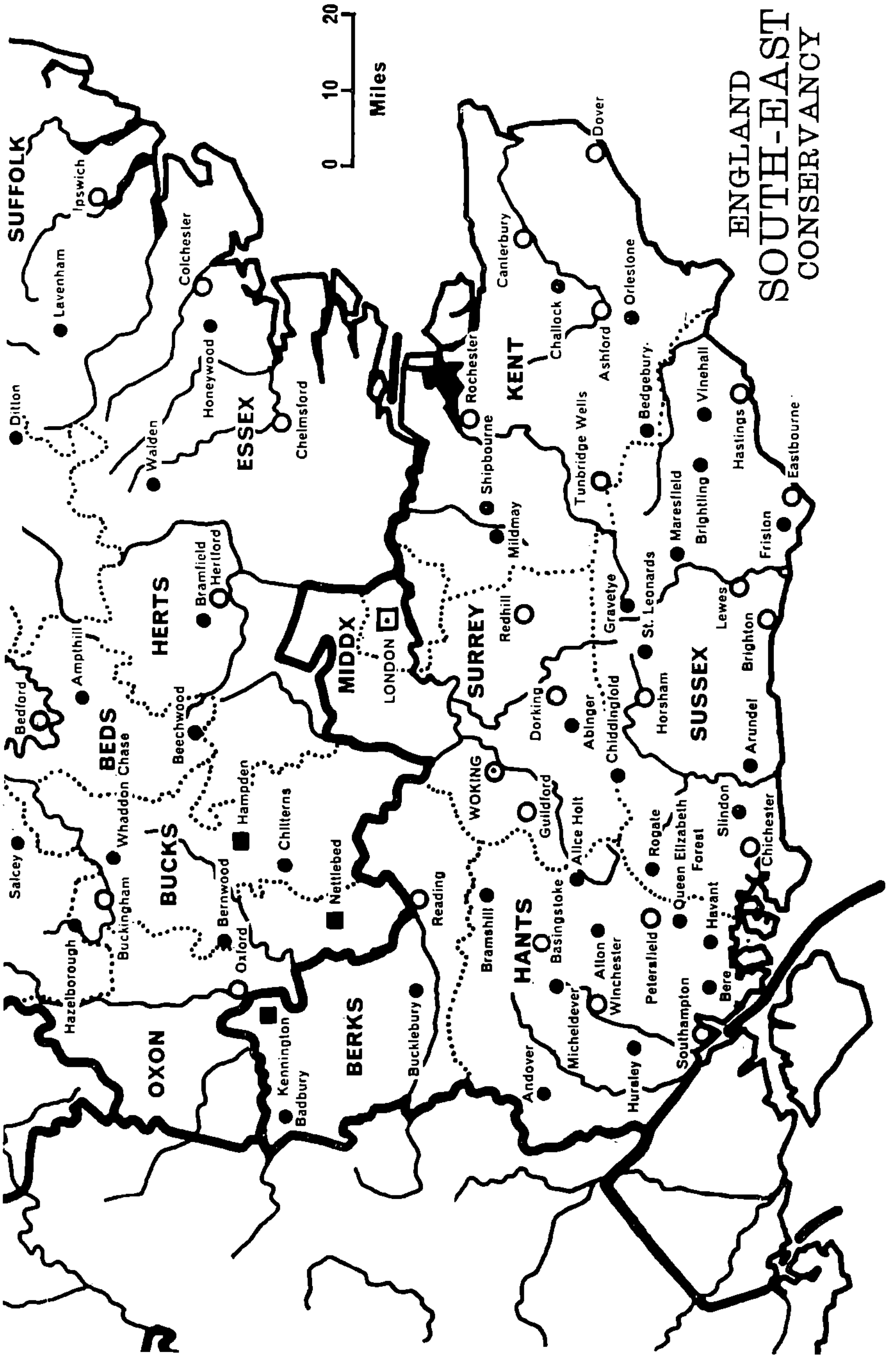
Bardney
Kesteven
Lincoln
Wigsley
Laughton
RUTLAND
Oakham
Rockingham
Rockingham
NORTHANTS
Northampton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HANTS
Ipswich
Lavenham
Colchester
Dillon
Walden
Honeywood
Chelmsford
Rochester
Shipbourne
Canterbury
Challock
Ashford
Dover
Orlestone
Tunbridge Wells
Bedgebury
Vinehall
Hastings
Eastbourne
Friston
Brightling
Maresfield
Mildmay
Redhill
Gravetye
St. Leonards
Lewes
Brighton
Horsham
Dorking
Abinger
Chiddingfold
Arundel
Slindon
Chichester
LONDON
WOKING
Guildford
Alice Holt
Rogate
Queen Elizabeth Forest
Havant
Petersfield
Bere
Southampton
Hursley
Winchester
Alton
Basingstoke
Bramshill
Micheldever
Andover
Reading
Bucklebury
Kennington
Badbury
Oxford
Bernwood
Nettlebed
Chilterns
Hampden
Beechwood
Whaddon Chase
Buckingham
Hazelborough
Salcey
Bedford
Ampthill
Bramfield
Hertford

APPENDIX I

Main Experimental Projects and Localities

The list is not comprehensive. It is a preliminary guide to those who may wish to see experimental work on any particular subject or subjects. The omission of a subject from the list does not mean that no work on it has been done, as some important projects are omitted because experimental work on them is not yet informative. The forests or estates concerned are shown on the maps.

NURSERY EXPERIMENTS

Benmore Nursery, near Dunoon (Argyll)
Bramshill Nursery (Hampshire)
Bush Nursery, near Edinburgh
Fleet Nursery, Gatehouse of Fleet (Kirkcudbright)
Inchnacardoch Nursery, near Fort Augustus (Inverness)
Kennington Nursery, near Oxford
Newton Nursery, near Elgin (Moray)
Sugar Hill Nursery, Wareham Forest (Dorset)
Tulliallan Nursery, near Alloa (Fife)

AFFORESTATION EXPERIMENTS ON PEAT

Achnashellach Forest (Western Ross)
Beddgelert Forest (Caernarvon)
Clocaenog Forest (Denbigh)
Inchnacardoch Forest (Inverness)
Kielder Forest (Northumberland)
Naver Forest (Sutherland)
Strathy Forest (Sutherland)
Watten (Caithness) in conjunction with Department of Agriculture and Fisheries for Scotland
Wauchope Forest (Roxburgh)

AFFORESTATION EXPERIMENTS ON HEATHLAND

Allerston Forest, Harwood Dale (Yorkshire)
Allerston Forest, Wykeham and Broxa (Yorkshire)
Clashindarroch (Aberdeenshire)
Inshriach Forest (Inverness)
Land's End Forest, Croft Pascoe (Cornwall)
Millbuie Forest (Ross)
Taliesin Forest (Cardigan)
Teindland Forest (Moray)
Wareham Forest (Dorset)

FOREST NUTRITION

Allerston Forest, Broxa (Yorkshire)
Arecleoch Forest (Argyllshire)
Clocaenog Forest (Denbigh)
Culbin Forest (Moray)
Exeter Forest (Devon)
Inchnacardoch Forest (Inverness)
Selm Muir (Mid and West Lothian)
Shin Forest (Sutherland)
Tarenig Forest (Cardigan)
Teindland Forest (Moray)
Wareham Forest (Dorset)
Wilsey Down Forest (Cornwall)

SOIL MOISTURE STUDIES

Aldewood Forest (Suffolk)
Bernwood Forest (Oxfordshire)
Bramshill Forest (Hampshire)
Inchnacardoch Forest (Inverness)
New Forest (Hampshire)
Queen Elizabeth Forest (Hampshire)
Swaffham Forest (Norfolk)

PROVENANCE EXPERIMENTS

Scots pine:	Findon Forest (Easter Ross) Thetford Chase (Norfolk)
Lodgepole pine:	Achnashellach Forest (Wester Ross) Allerston Forest, Wykeham (Yorkshire) Brendon Forest (Somerset) Ceiriog Forest (Denbigh) Clocaenog Forest (Denbigh) Forest of Deer (Aberdeen) Millbuie Forest (Easter Ross) New Forest (Hampshire) Taliesin Forest (Cardigan)
European larch:	Coed-y-Brenin (Merioneth) Mortimer Forest (Herefordshire) Savernake Forest (Wiltshire)
European and Japanese larches:	Clashindarroch Forest (Aberdeen) Drummond Hill Forest (Perth) Fetteresso Forest (Kincardine) Lael Forest (Wester Ross)
Douglas fir:	Glentress Forest (Peebles) Land's End Forest, St. Clement (Cornwall) Lynn Forest, Shouldham (Norfolk) Mortimer Forest (Shropshire)
Norway and Sitka spruces:	Newcastleton Forest (Roxburgh) The Bin Forest (Aberdeen)
Sitka spruce:	Clocaenog Forest (Denbigh) Coed Morgannwg (Glamorgan) Glendaruel Forest (Argyll) Kielder Forest (Northumberland) Mynydd Ddu Forest (Monmouth) Radnor Forest (Radnor) Ratagan Forest (Wester Ross) Taliesin Forest (Cardigan) Wark Forest (Northumberland) Wilsey Down Forest (Cornwall)
Western hemlock:	Brecon Forest (Brecon) Brendon Forest (Somerset) Clocaenog Forest (Denbigh) New Forest (Hampshire) Rheidol Forest (Cardigan) Thetford Chase (Norfolk) Wareham Forest (Dorset)
Western Red cedar:	Alice Holt Forest (Hampshire) New Forest (Hampshire) Radnor Forest (Radnor) Thetford Chase (Norfolk)
Beech:	Queen Elizabeth Forest (Hampshire) Savernake Forest (Wiltshire)

CONVERSION OF COPPICE

Alice Holt Forest, Marelands (Hampshire)
Cranborne Chase (Dorset)
Forest of Dean, Penyard and Flaxley (Herefordshire and Gloucestershire)
Hursley Forest (Hampshire)

PLANTING EXPERIMENTS ON CHALK DOWNLANDS

Friston Forest (Sussex)
Queen Elizabeth Forest (Hampshire)

CULTURE OF OAK

Tintern Forest, Crumbland Wood (Monmouth)
Dymock Forest (Gloucestershire and Hereford)
Forest of Dean (Gloucestershire and Hereford)

DRAINAGE EXPERIMENTS

Bernwood Forest (Oxford and Buckinghamshire)
Forest of Ae (Dumfries)
Halwill Forest (Devon)
Kielder Forest (Northumberland)
Lennox Forest (Stirlingshire)
Loch Ard Forest, Flanders Moss (Stirling)
Orlestone Forest (Kent)
Towy Forest (Cardiganshire)

POPLAR TRIALS AND SILVICULTURAL EXPERIMENTS

Bedgebury Forest (Kent)
Blandford Forest (Dorset)
Cannock Chase (Staffordshire)
Creran Forest (Argyll)
Dyfnant Forest (Montgomery)
Forest of Dean (Gloucestershire)
Greskine Forest (Dumfries-shire)
Lynn Forest, Gaywood (Norfolk)
Quantock Forest (Somerset)
Rogate Forest (Hampshire)
South Yorkshire Forest
Stenton Forest (East Lothian)
Wentwood Forest (Monmouthshire)
Wynyard Forest (Durham)
Yardley Chase (Bedfordshire and Northamptonshire)

ARBORETA

National Pinetum, Bedgebury (Kent)
Westonbirt Arboretum (Gloucestershire)
Whittingehame (East Lothian)

MAJOR COLLECTIONS OF SPECIES PLOTS

Crarae, near Minard (Argyll)
Kilmun, Benmore Forest (Argyll)
Bedgebury Forest (Kent)
Brechfa Forest (Carmarthen)
Thetford Chase (Norfolk and Suffolk)

SPECIES COMPARISONS IN RELATION TO SPECIAL SITES

Achnashellach (Wester Ross)
Aldewood Forest (Suffolk)
Beddgelert Forest (Caernarvon)
Bodmin Forest (Cornwall)
Brendon Forest (Somerset)
Brownmoor (Dumfries)
Caeo Forest (Carmarthen)
Cairn Edward Forest (Kirkcudbright)

Clashindarroch (Aberdeen)
Coed Morgannwg (Glamorgan)
Dovey Forest (Merioneth and Montgomery)
Forest of Ae (Dumfries)
Forest of Dean (Gloucestershire)
Garadhban Forest (Stirling)
Glentress Forest (Peebles)
Glentrool Forest (Kirkcudbright)
Glen Urquhart Forest (Inverness)
Gwydyr Forest (Caernarvon)
Inchnacardoch Forest (Inverness)
Kielder Forest (Northumberland)
Kirroughtree Forest (Kirkcudbright)
Land's End Forest (Cornwall)
Micheldever Forest (Hampshire)
Mynydd Ddu (Brecon and Monmouth)
Naver Forest (Sutherland)
New Forest (Hampshire)
Pembrey Forest (Carmarthen)
Rockingham Forest (Northamptonshire)
Rosedale, Allerston Forest (Yorkshire)
Teindland Forest (Moray)
Thetford Chase (Norfolk)
Tintern Forest (Monmouth)
Wareham Forest (Dorset)
Wykeham, Allerston Forest (Yorkshire)

RE-AFFORESTATION EXPERIMENTS

Culloden Forest (Inverness)
Drumtochty Forest (Kincardine)
Forest of Ae (Dumfries)
Kielder Forest (Northumberland)
Lennox Forest (Stirling)
Newcastleton Forest (Roxburgh)
Thetford Chase (Norfolk and Suffolk)
Michaelston, Coed Morgannwg (Glamorgan)
Radnor Forest (Radnorshire)

MENSURATION

The following are experiments in which permanent sample plots are used as assessment units and which are of interest for growth and yield studies. Replicated experiments are marked with an asterisk (*).

SPACING

Scots pine:	Thetford Chase (Suffolk and Norfolk) Roseisle Forest (Moray) Tintern Forest (Monmouthshire) Ebbw Forest (Monmouthshire)
Corsican pine:	Aldewood Forest (Suffolk)
European larch:	Mortimer Forest (Hereford) Forest of Dean (Gloucestershire) Radnor Forest (Radnor) Fleet Forest (Kirkcudbright)
Japanese larch:	Bodmin Forest (Cornwall) Dalbeattie Forest (Kirkcudbright) Drumtochty Forest (Kincardine) Rheola, Coed Morgannwg (Glamorgan) Crychan Forest (Brecon) Ebbw Forest (Glamorgan) Caeo Forest (Carmarthen) Brechfa Forest (Carmarthen)

Norway spruce:	Monaughty Forest (Moray) Clocaenog Forest (Denbigh, Merioneth) Kerry Forest (Montgomery) Rheola, Coed Morgannwg (Glamorgan)
Sitka spruce:	Allerston Forest (Yorkshire) Brecon Forest (Brecon) Rheola, Coed Morgannwg (Glamorgan) Gwydyr Forest (Caernarvon) Clocaenog Forest (Denbigh, Merioneth)
Douglas fir:	Allerston Forest (Yorkshire) Ystwyth Forest (Cardigan) Brechfa Forest (Carmarthen)

THINNING

Scots pine:	Aldewood Forest (Suffolk) Thetford Chase (Suffolk and Norfolk) Swaffham Forest (Norfolk) New Forest (Hampshire) Cannock Chase (Staffordshire) Edensmuir Forest (Fife)* Speymouth Forest (Moray and Banff)
Corsican pine:	Aldewood Forest (Suffolk and Norfolk) Thetford Chase (Suffolk and Norfolk) Sherwood Forest (Notts.)* Swaffham Forest (Norfolk) New Forest (Hampshire) Culbin Forest (Moray) Pembrey Forest (Carmarthen)
European larch:	Forest of Dean (Gloucestershire) Murthly Estate (Perthshire)
Japanese larch:	Bodmin Forest (Cornwall) Stourhead Estate (Wiltshire) Glentress Forest (Peebles) Drumtochty Forest (Kincardine) Brechfa Forest (Carmarthen) Rheola Forest (Glamorgan)
Norway spruce:	Kershope Forest (Cumberland) Bowmont Forest (Duke of Roxburgh's Estate, Roxburghshire)* Bennan, Cairn Edward Forest (Kirkcudbright) Monaughty Forest, near Elgin (Moray) Tintern Forest (Monmouth)
Sitka spruce:	Brendon Forest (Somerset) Dovey Forest (Merioneth)* Forest of Ae (Dumfries) Ardgartan Forest (Argyll) Loch Eck Forest (Argyll)*
Picea omorica:	Bedgebury Forest (Kent)
Douglas fir:	Wensum Forest (Norfolk) Alice Holt (Hampshire)* Glentress Forest (Peebles) Mynydd Ddu (Brecon, Monmouth) Gwydyr Forest (Caernarvon)
Noble fir:	Dovey Forest (Merioneth, Montgomery)
Beech:	Nettlebed Estate (Buckinghamshire) Hampden Estate (Buckinghamshire)

Oak:	Micheldever Forest (Hampshire) Forest of Dean (Gloucestershire) Wensum Forest (Norfolk) Hazelborough Forest (Northamptonshire)

UNDERPLANTING

European larch underplanted with various species:	Dymock Forest (Gloucestershire) Haldon Forest (Devon) Micheldever Forest (Hampshire)

MIXTURES

Oak/larch:	Tintern Forest (Monmouth)
Sitka spruce/Japanese larch *Sitka spruce/Lodgepole pine*	Beddgelert Forest (Caernarvon)

GENETICS

PROPAGATION CENTRES

Alice Holt (Hampshire)
Bush Nursery (near Edinburgh)
Grizedale Nursery (Lancashire)

TREE BANKS

Alice Holt (Hampshire)
Bush Nursery (near Edinburgh)
Newton Nursery (Moray)

SEED ORCHARDS

Alice Holt (Hampshire)
Bradon Forest (Wiltshire)
Drumtochty Forest (Kincardine)
Forest of Dean (Gloucestershire)
Keillour Forest (Perthshire)
Ledmore Forest (Perthshire)
Lynn Forest (Norfolk)
Newton Nursery (Moray)
Stenton Forest (East Lothian)

PROGENY TRIALS

Alice Holt Forest (Hampshire)
Allerston Forest (Yorkshire)
Clocaenog Forest (Denbigh)
Chillingham Forest (Northumberland)
Coed-y-Brenin Forest (Merioneth)
Devilla Forest (Fife and Clackmannan)
Elchies Forest (Banffshire)
Farigaig Forest (Inverness)
Forest of Dean (Gloucester)
Glenlivet Forest (Banffshire)
Gwydyr Forest (Caernarvon)
Kilmichael Forest (Argyll)
Kilmory Forest (Argyll)
Saltoun Forest (East Lothian)
Stenton Forest (East Lothian)
Teindland Forest (Moray)

TREATMENT OF SEED STANDS

Culbin Forest (Moray and Nairn)
Thetford Chase (Norfolk and Suffolk)

PATHOLOGICAL RESEARCH AREAS

ELM DISEASE TRIALS

Alice Holt Forest (Hampshire and Surrey)

TOP DYING OF NORWAY SPRUCE

Knapdale Forest (Argyll)

FOMES ANNOSUS

Bramshill Forest (Berkshire and Hampshire)
Clocaenog Forest (Denbigh)
Kerry Forest (Montgomery)
Lael Forest (Ross)
The Bin Forest (Aberdeen)
Thetford Forest (Norfolk and Suffolk)

ARMILLARIA MELLEA

Alice Holt Forest (Hampshire and Surrey)
Bramshill Forest (Berkshire and Hampshire)

BACTERIAL CANKER OF POPLAR

Aldewood Forest, Fen Row Nursery (Suffolk)
Alice Holt Forest (Hampshire and Surrey)
Blandford Forest (Dorset)
Cannock Chase (Staffs)
Creran Forest (Argyll)
Dean Forest (Gloucester, Hereford and Monmouth)
Dyfnant Forest (Montgomery)
Lynn Forest, Gaywood Nursery (Norfolk)
South Yorkshire (Yorks)
Stenton (East Lothian)
Thetford Forest, Mundford Nursery (Norfolk)
Wynyard Forest (Durham)

DIDYMASCELLA (KEITHIA) THUJINA ON WESTERN RED CEDAR

Alice Holt Forest (Hampshire and Surrey)
Bramshill Forest (Berkshire and Hampshire)
Slebech Forest (Pembrokeshire)

CRUMENULA SORORIA ON PINE

Ringwood Forest (Hampshire and Dorset)

BLUE STAIN IN PINE

Thetford Forest (Norfolk and Suffolk)

ENTOMOLOGY

PINE LOOPER MOTH: BUPALUS PINIARIUS

Cannock Chase (Staffordshire)

LARCH SAWFLY: ANOPLONYX DESTRUCTOR

Drumtochty Forest (Kincardine)
Mortimer Forest (Hereford and Shropshire)

SPRUCE APHID: NEOMYZAPHIS ABIETINA

Alice Holt Forest (Hampshire)
Bramshill Forest (Hampshire)
Dovey Forest (Merioneth and Montgomery)
Forest of Ae (Dumfries)
Inverliever Forest (Argyll)
New Forest (Hampshire)

DOUGLAS FIR SEED WASP: MEGASTIGMUS SPERMOTROPHUS

Brendon Forest (Somerset)
Culloden Forest (Inverness)
Mortimer Forest (Herefordshire)
New Forest (Hampshire)
Thetford Chase (Norfolk)
Thornthwaite Forest (Cumberland)

PINE SHOOT BEETLE: MYELOPHILUS PINIPERDA

Bramshill Forest (Hampshire)

APPENDIX II

Staff Engaged in Research and Development

As at 31st March 1965

The staff listed here are engaged wholly or in part in research and development. Where not indicated otherwise staff belong to the Research Directorate. For convenience certain staff, attached to certain sections, belonging to the Headquarters organisation of the Commission are included, since part of their activities are considered research or development, and these are recorded in the Report on Forest Research.

Staff are stationed at Alice Holt unless otherwise indicated.

FOREST RESEARCH STATION: Alice Holt Lodge, Wrecclesham, Farnham, Surrey.
Tel.: Bentley 2255

Director	A. Watt, C.B.E., B.A.
Conservator	R. F. Wood, B.A., B.Sc.
Chief Clerk	T. D. H. Morris
Director's Secretary	Miss O. A. Harman

SILVICULTURE (SOUTH)

R. M. G. Semple, B.Sc., Head of Section
J. R. Aldhous, B.A.
J. M. B. Brown, B.Sc., Dip.For. (Ecologist)
A. I. Fraser, B.Sc.
J. Jobling, B.Sc.
A. F. Mitchell, B.A., B.Agric.(For.)
M. Nimmo

Office:

R. G. Harris: Miss E. Burnaby, Miss A. Davidge, A. R. Taggart

Research Foresters

Region and Area		*Centre*
England, South-east	R. Hendrie (Head Forester)	Alice Holt
South-east	P. W. W. Daborn: A. J. A. Graver, P. J. Mobbs, A. C. Swinburn	Alice Holt
Wareham	E. E. Fancy, B.E.M.: L. A. Howe, A. M. Jenkin, F. S. Smith	Sugarhill Nursery, Wareham Forest
Bedgebury	A. W. Westall: R. E. A. Lewis	Bedgebury Pinetum
England, South-west	D. A. Cousins (Head Forester)	Bristol
South-west	K. F. Baker: J. E. J. White	Exeter
Dean and South Wales	F. Thompson: M. L. Pearce, R. M. Keir	Dean
Westonbirt	E. Leyshon: D. J. Rice	Westonbirt Arboretum
North Wales	G. Pringle (Head Forester)	Betws-y-Coed
North Wales	G. A. Bacon: C. W. Webber	Betws-y-Coed
Mid-Wales	D. G. Tugwell: P. A. Gregory, D. J. Williams	Knighton, Radnorshire

Research Foresters Region and Area		*Centre*
England, East	W. G. Gray, B.E.M. (Head Forester)	Kennington, Nr. Oxford
Kennington	F. R. H. Stevens: H. C. Caistor	
England, East	R. M. Ure: G. F. Farrimond	Santon Downham, Nr. Thetford

---

EDINBURGH: Government Buildings, Bankhead Avenue, Sighthill, Edinburgh, 11
Tel.: Craiglockhart 4010

SILVICULTURE (NORTH)

M. V. Edwards. M.A., Head of Section
R. Lines, B.Sc., Acting Head of Section
J. Atterson, B.Sc.
D. W. Henman, B.Sc.
S. A. Neustein, B.Sc.

Office:

P. Hunter: T. T. Johnston, D. J. Goddard, Miss M. E. Grant, Miss E. P. Beattie, Mrs. M. J. Pedder

Research Foresters Region and Area		*Centre*
North Scotland	A. Macdonald (Head Forester)	Fort Augustus
North Scotland	W. J. Blair: D. C. Coutts	Fort Augustus
	G. Bartlett: N. P. Danby	Ardross, Ross-shire
North-west Scotland	J. B. MacNeill: A. B. Lewis	Fort Augustus
Central Scotland	J. Farquhar, M.B.E. (Head Forester)	Kincardine-on-Forth
Central Scotland	E. R. Robson: J. D. MacNeill, M. Rodgers	Kincardine-on-Forth
East Scotland	J. H. Thomson: A. W. F. Watson, A. L. Sharpe	Newton, Elgin
South-east Scotland	D. K. Fraser: R. B. Angus	The Bush, by Roslin, Midlothian
Mearns	J. C. Keenleyside: A. H. Reid	Drumtochty
West Scotland	A. R. Mair: J. E. Kirby	Rashfield by Dunoon, Argyll
South-west Scotland	E. Baldwin: K. A. S. Gabriel	Mabie, Dumfries
North England	J. Weatherell (Head Forester)	Wykeham, Scarborough
North-east England	T. C. Booth: M. K. Hollingsworth	Wykeham, Scarborough
Borders	G. S. Forbes: I. H. Blackmore, D. L. Willmott	Kielder, by Hexham, Northumberland
North-west England	A. A. Lightly: D. S. Coutts (see also Genetics)	Grizedale, Nr. Hawkshead, Westmorland

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FOREST RESEARCH STATION: Alice Holt Lodge, Wrecclesham, Farnham, Surrey

SOILS

W. O. Binns, M.A., B.Sc., Ph.D., Head of Section
W. H. Hinson, B.Sc., Ph.D.
R. Kitching, B.Sc., A.R.C.S., Ph.D.

Research Foresters: D. F. Fourt, A. E. Coates, T. E. Radford

Laboratory: Miss M. J. Pedley: Mrs. A. Barlow, R. Carnell, Miss S. Dabek, H. M. Gunston

Instrumentation: R. E. Stickland

STATISTICS

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E. J. F. Tinson, B.Sc. (Econ.)

APPENDIX III

List of Publications

Aaron, J. R.	A Survey of the Literature on the Management Aspect of Large-scale utilisation in Selected European Countries. *For. Comm. Res. Br. Paper* No. 28. April 1965.
Aaron, J. R.	Studies on the Mineral Nutrient Status of Heather. *Forest Record* 53. April 1965.
Aaron, J. R.	Wood Chips as Litter. *Agriculture* December 1964 (570–574).
Aaron, J. R.	Fence Post Trials. *Timb. Tr. J. Supplement* June 1964 (21–23).
Aaron, J. R.	Problems of Home-grown Bark. *Timb. Tr. J. Supplement* November 1964 (21–23).
Batko, S.	New or Uncommon plant diseases and pests, 79. *Sclerotinia lagerbergii* Gremmen (syn. *S. abietina* Lagerb., *Crumenula pinea* (Karst.) Ferd. and Jørg., stat. conid. *Brunchorstia pinea* (Kart.) Hohn. = *B. destruens*. Erikss.) *Trans. Brit. Mycol. Soc.* 48(1) 1965 (145–50).
Batko, S.	New or uncommon plant diseases and pests. 80. *Phomopsis sordidula* (Sacc. and Syd.) Trav. (Syn. *Phoma sordidula*. Sacc.). *Trans. Brit. Mycol. Soc.* 48(1) 1965 (145–50).
Batko, S., and Pawsey, R. G.	Stem canker of Pine caused by *Crumenula sororia*. *Trans. Brit. Mycol* 47(2) (257–61) 1964.
Bevan, D.	Insect Pests of Forest Nurseries and Young Plantations. *Proc. XII Int. Congr. Ent.* Lond. 1964 (1965) (666–668).
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Dannatt, N., and Zehetmayr, J. W. L.	Hydraulic Timber Cranes and Grapples. *Timb. Tr. J.* Supplement. April 1965 (19–20).
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Edlin, H. L.	A Modern Sylva: 10 Cypresses. *Cupressus* and *Chamaecyparis* spp. *Quart. J. For.* 58(3) 1964 (208–217).
Edlin, H. L.	A Modern Sylva: 11. Alder, *Alnus*. spp. *Quart. J. For.* 58(4) 1964 (302–310).
Edlin, H. L.	A Modern Sylva: 12. Elms, *Ulmus* spp. *Quart. J. For.* 59(1) 1965 (41–51)
Edlin, H. L.	Welsh Timber from a Changing Wales. *Y. Coedwigwr* 4(5) 1964–65 (8–12).
Edlin, H. L.	Forestry in Great Britain. (Booklet published by Forestry Commission) 1964.
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Mitchell, A. F.	The Wellingtonia in Scotland. *Scot. For.* 18(4) 1964 (307–314).
Neustein, S. A.	A Review of Pilot and Trial Plantations Established by the Forestry Commission in Shetland. *Scot. For.* 18(3) 1964 (199–211).
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Savory, J. G., Pawsey, R. G., and Lawrence, J. S.	Prevention of Blue-stain in Unpeeled Scots Pine Logs. *Forestry* 38(1) 1965 (59–81).
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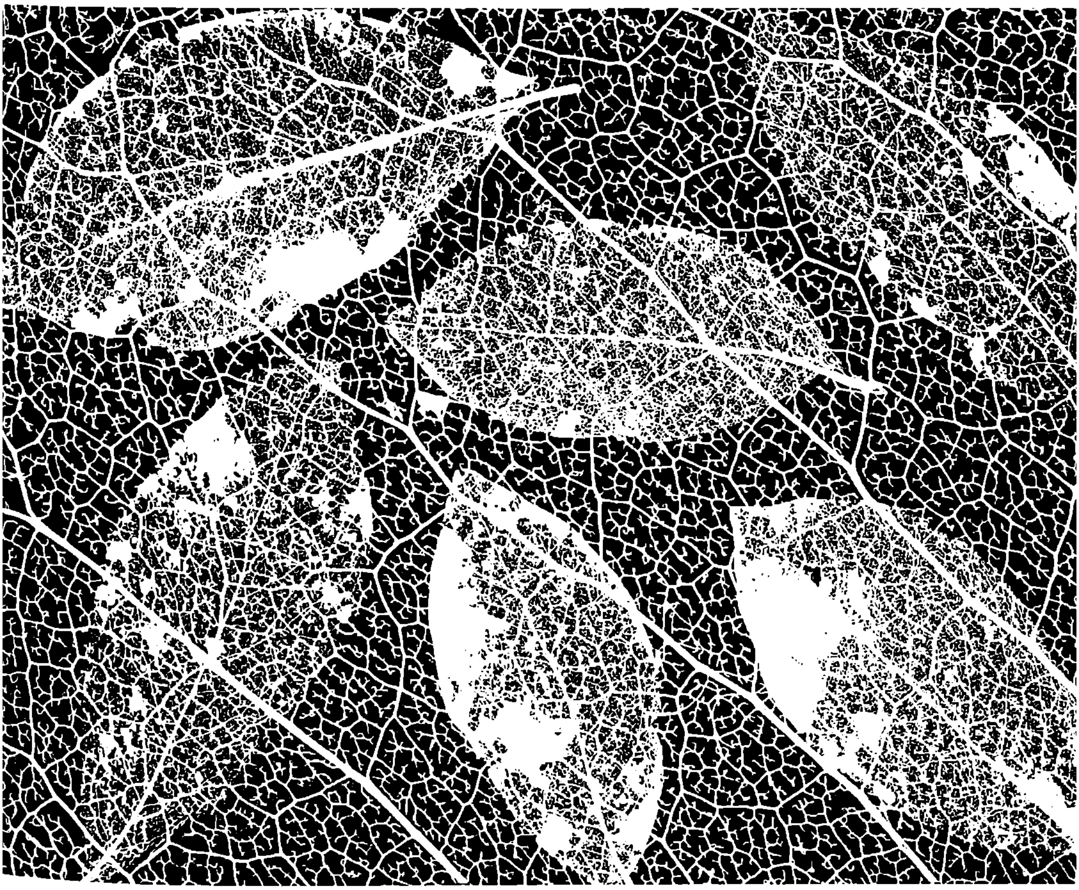
REPORT ON

FOREST RESEARCH

1966

FORESTRY COMMISSION



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REPORT ON FOREST RESEARCH

for the year ended March 1966

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1967

A

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CONTENTS

PART II

RESEARCH UNDERTAKEN FOR THE FORESTRY COMMISSION AT UNIVERSITIES AND OTHER INSTITUTIONS

APPENDICES

All the photographs are taken from the Forestry Commission's own collection. The line drawings, etc., have been supplied by the respective authors.

INTRODUCTION

By J. R. THOM

Director of Research

Organisation and Staffing

A new introduction to the Research Division was the adoption of the procedure of a "Visiting Group" similar to the system used by the Agricultural Research Council. This was recommended by the Advisory Committee on Forest Research at a meeting in December. As a result a Visiting Group of distinguished scientists undertook to examine the work of the Genetics, Seed and Provenance Sections during the summer of 1966. This Report is now being considered.

The Forestry and Woodland Research Committee of the Natural Environment Research Council came into being during the year, and the Research Division is represented by the Director and Conservator. This Committee should greatly improve the machinery for correlating applied and basic research as between the different Universities, the Nature Conservancy and the Forestry Commission. While the problems of applied research will continue to be largely the responsibility of the Commission, the new Committee will allow more fundamental research to be carried out at the various Universities through grants available from the Natural Environment Research Council.

Mr. M. V. Edwards (Silviculturist North) retired after continuing ill-health, due to sclerosis, during the year. Edwards came to the Research Division in 1948 after a distinguished career in the Burma Forest Service, brought prematurely to a close during the Second World War. He made his name quickly in research in Scotland and the North of England, one of his special interests being in provenance studies of the most important conifer species. He also made a special study of many of the problems connected with the afforestation of peatlands. He developed a happy understanding with his fellow foresters in the field, which has contributed so greatly to the application of his research findings throughout Scotland and the North of England. We wish him well in the years ahead.

On 30th March the Lord Lieutenant of Surrey, Lord Munster, presented the British Empire Medal to Mr. E. J. D. Wilkinson, who for many years has been the Forester in charge of the Forestry Commission's travelling exhibit attending the major agricultural shows.

Staff changes are:

Transfers In:

J. V. St. L. Crosland, District Officer, to Work Study
A. A. Cuthbert, District Officer, to Work Study
J. Laurie-Muir, District Officer, to Work Study
A. J. Low, District Officer, to Silvilculture (North)
W. S. Mackenzie, District Officer, to Work Study
G. G. M. Taylor, District Officer, to Silviculture (North)

Transfers Out:

D. W. Henman, District Officer, from Silviculture (North) to North Wales Conservancy.
J. N. Kennedy, District Officer, from Planning and Economics to H.Q. Forest Management on promotion to Assistant Conservator.

H. G. M. Dowden, District Officer (Statistics), resigned to take up an appointment with the Forestry Commission of New South Wales, Sydney, Australia.

J. P. Verel, District Officer (Work Study), was seconded to F.A.O., Mexico.

Visits Abroad

The most notable visit was to North West America, where J. R. Aldhous (Silviculture) spent seven months in the spring and summer of 1965 investigating the possibilities of improving the supply of Lodgepole pine seed of those provenances which have proved most successful in difficult conditions in this country. Mr. H. A. Maxwell, Conservator of Forests for North Scotland, joined Mr. Aldhous for the last month of the tour, and their findings are likely to be published in the near future.

The improved understanding of zones of provenance, mechanics of seed collection and the capabilities of the seed companies concerned with Lodgepole pine, will be invaluable. This tree is rapidly assuming greater prominence and undoubtedly has a major part to play on some of the less fertile sites acquired by the Commission.

Conferences Abroad

No major conferences were attended at home but Research staff travelled to a number of such events in Europe, including:—

XIVth International Seed Testing Congress at Munich in May 1965. Attended by G. M. Buszewicz (Seed Officer).

VIth European Forestry Commission F.A.O. Study Tour on Silviculture in Rumania in June 1965. Attended by R. Faulkner (Geneticist).

Heads of Seed Extractories Working Party at Bad-Bergzaben, Germany, in July 1965. Attended by G. M. Buszewicz.

Meeting of Experts on the Control of Forest Reproductive Material Moving in International Trade, held at the Headquarters of the Organisation for Economic Co-operation and Development, in Paris in July 1965. Attended by R. Faulkner who, with Professor J. D. Matthews, represented the United Kingdom.

Meeting of I.U.F.R.O. Working Group on Provenance Research and Testing at Nancy, France, in September 1965. Attended by R. Lines (Silviculture).

Committees

The Advisory Committee on Forest Research met at Savile Row in December 1965. Mr. F. C. Bawden became Chairman following the resignation of Lord Waldegrave from the Forestry Commission in June 1965. Mr. J. Bryan resigned in December 1965. Two additional members, Dr. W. P. K. Findlay and Professor W. J. Thomas, were appointed in June 1966.

The Research Directorate continued to be represented on a number of Committees concerned with research in forestry and allied fields.

Visitors

Mr. Arthur Skeffington, M.P., Parliamentary Secretary, and Mr. R. C. Chilver, Deputy Secretary, Ministry of Lands and Natural Resources, visited Alice Holt during the year. Other distinguished visitors included the South African Minister of Forestry, the Hon. W. A. Maree, M.P., and members of his staff, accompanied by the Ambassador, Dr. Carel de Wet; Dr. Peder

Braathe, Chief Research Officer of the Norwegian Forest Research Institute; Dr. Bancherd Balankura, Director General of the Department of Land Development, Thailand; and Mr. E. Georgoulis, Hon. Director of the Forest Research Institute, Athens. A visit was also made by the Joint FAO/IUFRO Committee on Bibliography and Terminology, led by Mr. C. Swabey, Director of the Commonwealth Forestry Bureau, Oxford. The Royal Dutch Forestry Society visited Bedgebury, and the Swedish Forestry Society visited the Forest of Ae (Dumfries).

Home visiting parties included the staff of East Malling Research Station; the Joinery Managers' Association; the Imperial College of Science and Technology; and the Senior students from the Forestry Departments of Aberdeen, Edinburgh, Oxford and Wales (Bangor) Universities.

At Grizedale (Westmorland), where the local Conservancy staff are encouraging public interest and access, the propagation centre of the Genetics Section has been visited by 22 societies and over 50 schools or universities.

Format of Report

Part III, which in the past has covered longer progress reports on projects, has been excluded from this Report. This will reduce the size of the Report and, it is hoped, speed up publication. Reports previously appearing in Part III will now appear as Forest Records or as Research and Development Papers at intervals throughout the year. These papers will be published on a more selective basis, aimed at the worker primarily interested in a particular field of research. This whole question of quick and accurate information to the field forester is being tackled with energy by the Research Division, and the first effect of these Research and Development Papers will be noted with particular interest.

REVIEW OF THE YEAR'S WORK

By R. F. WOOD
Conservator, Research Division

The reader will no doubt be relieved to find this Report some 100 pages shorter than the previous issue. This is mainly due to the omission of the longer papers previously presented in Part III. Such material will in future be published in Forest Records, Research and Development Papers, or in the appropriate forestry or specialised journals.

PART I

Forest Tree Seed

The Register of Home Seed Sources was revised during the year, a task which has involved both the Seed and Genetics Sections. Though the area of plantations represented in the Register appears impressive enough, home seed collection continues to prove rather disappointing, and less than half the seed obtained in the year has been from registered stands. Of the imported seed, much the most important is the Lodgepole pine. Good crops are unfortunately rare in some of the more desirable collecting areas, but this season our suppliers have been particularly successful.

The encouraging trend towards better seed economy in stock raising in Commission nurseries continues, and as it is associated with reliability of production, it is more than a matter of saving in cost of seed, significant though that is.

Owing to the increasing weight of service work, research unfortunately comes a bad second. However, the Section continues to play an active part in the improvement of seed test methods in co-operation with the International Seed Testing Association. Work has also been done on storage, packaging, extraction and cleaning techniques.

Nursery Investigations

Joint experimentation with Rothamsted Experimental Station continues to bulk large in the southern programme; notes on this work will be found in Part II of the Report.

Experimental autumn sowings do not suggest that there will be much benefit in this practice, especially with the smaller seeded species; Douglas fir, however, seems to respond well.

Some of the Scottish long-term fertility trials have shown consistent benefits from hopwaste as against inorganic fertilizers, a result which, broadly speaking, was not reflected in the joint Rothamsted/Forestry Commission programme of experiments in southern nurseries. The suggestion that the main virtue of hopwaste might lie in nitrogen is not wholly supported by the introduction of nitrogen rates to the Teindland (Moray) experiment, though it may still be argued that it is a particularly good way to give nitrogen under northern conditions.

Much attention is being given in the north to new compound and slow-acting forms of fertilizer, and with the presumably higher leaching rates compared with those of the south, it is to be expected that these new types will prove of special importance. An interesting and probably important relationship between magnesium deficiency and frost susceptibility has been observed at Inchnacardoch; compare also Miss Benzian's notes on nitrogen and potassium seedling content and frost susceptibility (Part II, pages 99–102). Truly, we are getting a long way from the "starve 'em and they'll be tough" school of thought.

Further evidence on season of lining-out and salt damage from fertilizers has been obtained. *Abies procera* seems highly susceptible, even more so than Norway spruce, the main indicator species in Miss Benzian's experiments.

The herbicide paraquat appears to have proved itself as a pre-emergent application for conifer seedbeds. Simazine continues to offer little cause for alarm in forest nurseries, only damaging transplants of certain species at rates four times higher than necessary for weed control, and showing little signs of build-up of residues.

Most successful results have been obtained with cold storage of oak seedlings; highly satisfactory survival and growth rates being recorded after storage for twelve months at 2°C. Further work on conifers seedlings indicates strongly that lifting prior to cold storage should be delayed till December. Storage at 2°C undoubtedly prolongs the period for safe lining-out in the spring, which is probably the most important economic gain from the practice. It is also of importance that the "difficult" Corsican pine behaves very much better on lining-out after cold storage than it does after spring lifting and immediate lining-out.

Afforestation of Difficult Sites

The far north of Scotland contains considerable reserves of potential forest land. Existing trial plantations have been reviewed to ensure that the distribution of experimental work adequately covers the major site types about which there is doubt. Exposure is perhaps the most important factor, and further trials will be laid down to establish the economic limit with elevation. Further attention will be paid to nutrition and the ability to withstand exposure, a relationship which we believe to be important from a variety of evidence, some of it fortuitous.

It is unfortunate that, at high elevations in Wales, the convenient flag-tatter method of estimating exposure is not so useful as in Scotland, because of the more frequent icing of flags during the winter. In Scotland the technique has reached the 'user' level, and a joint scheme for the siting and interpretation of flags and their behaviour has been arranged between Research and the Conservancies. There is little doubt that the method can give useful guidance on exposure conditions in the absence of direct evidence from tree growth, and do it very cheaply.

Cultivation and Drainage

Further gains in productivity on the locally important indurated heathland soils now await experimental evidence on more drastic cultivation than has as yet been possible; however, much heavier equipment is becoming available.

We have in the last few years established a considerable number of drainage experiments of good design embracing the depths and intensities of drainage which we now think are likely to have significant effects on crop stability and production. Such work, of course, owes much to modern machinery. It is still difficult to get deep drains into wet peats at one pass, and the important experiment at Flanders Moss (Stirling) will not be completed without further enquiries into method. Most modern forest drainage experiments attempt to get some information in advance of crop response by means of soil observations, e.g. bore-hole records. Some are highly instrumented, such as that at Halwill (Devon) (see page 62). Efforts are made to extract all available information from certain of the older experiments. A drainage experiment laid out in a twenty-year-old crop of Sitka spruce at Newcastleton, which has since been thinned and assessed on two occasions, appears to indicate very considerable gains in basal area increment for the most intensive drainage treatment, but the original design makes for difficulty in interpretation. Studies of rooting in this experiment will shortly be made.

Nutrition of Forest Crops

It seems possible that certain of the new slow-acting fertilizers, to which a good deal of attention has been paid in the nursery (see Benzian, page 100, Atterson, page 21), may have applications in the forest. Potassium metaphosphate is under trial on Scottish peats.

Some interesting differences in the nutritional status of Welsh and Scottish peats are appearing, particularly in respect of their power to supply nitrogen, in which the Welsh peats seem much superior. This may 'explain' the Welsh use of spruce on peats which appear to the Scots suited only for Lodgepole pine.

Whilst the modern herbicides in forestry have so far had their main impact on the most competitive weeds (e.g. *Calluna*) and on the economics of weeding, interest is growing in the nutrition of trees in weed-free environments. Traditional prescriptions of manuring have had to take into account the response of weed vegetation, but very different regimes might be appropriate to the weed-free environment.

We are steadily building up evidence on the nutrient responses of crops at the pole stage and older and, as expected, responses vary very greatly between sites. The response of Corsican pine at Culbin (Moray) to nitrogen is perhaps the most dramatic result so far obtained. Miller's comments on the nitrogen cycle at Culbin should also be referred to in this context (pages 94–98).

Regeneration of Tree Stands

A relatively small effort continues to be applied to studies concerned with natural regeneration. The principal limiting factor of seed-fall is being recorded by trapping for certain species. Seed bed conditions for Sitka spruce are being studied. The amount of fortuitous regeneration of this species, even from crops well below the optimum age for seed bearing, suggests that we should not altogether neglect the possibilities of natural regeneration.

The replacement of the less productive crops of the larches and of Scots pine (locally expedited for supplies to Scottish Pulp and Paper Mills Ltd. at Fort William) has stimulated enquiries into underplanting. Several large experiments comparing larch overwood stocking and the behaviour of underplanted species were established some years ago and are beginning to be informative. Other enquiries are more closely concerned with the economics of replacement, overwood stocking, and weeding cost, etc. The very special conditions in the extensive Scots pine plantations at Thetford direct interest to the best means of establishing certain more productive but frost-susceptible species in the most favourable microclimate. Amongst these, the *Abies* species, and notably *A. grandis,* merit special attention because of their relative insusceptibility to *Fomes.* Some special features of work on the microclimate of Thetford are mentioned by the Ecologist (page 59), and regeneration problems at Thetford have also attracted attention by the Pathologist and the Entomologist.

On the regeneration of the extensive Border spruce forests, the experimental evidence so far available indicates that the erosion by windblow of the margins of felling coupes will be greater on an area basis in small felling coupes rather than large ones. (The first such experiment, at Forest of Ae, was described in the report on Forest Research for 1964.) A similar experiment recently established at Redesdale appears to be confirming this evidence.

Some preliminary studies are being made to estimate the amount of erosion taking place following clear-felling on steep slopes in high rainfall country.

Provenance of Seed

New work on provenance of seed includes a fairly comprehensive collection of *Pinus nigra,* with emphasis on seed sources from successful plantations in Denmark and northern England, well on the cool side of the natural range. *Pinus nigra* is comparatively resistant to smoke pollution, and if a provenance could be discovered capable of extending its useful range to higher and more exposed situations, it might well be of use in northern districts where a degree of atmospheric pollution is one of the factors.

Lodgepole pine is one of our most variable species, and we have a wide range of experiments of somewhat unequal merit. A number of the older ones are now giving us information on productivity. Recent experimentation, and that planned for the future, is aimed mainly at filling the gaps in our knowledge about some of the more important regions. We have for instance not been able to make a sufficient study of the north-Pacific coastal provenances of the species, which on current but scanty evidence appear to be of special importance for the north of Scotland. The recent study tour of H. A. Maxwell and J. R. Aldhous to these regions has greatly helped to clarify the position, and important additions to our provenance collections have resulted from the expedition.

Of other new provenance experiments, perhaps the most important is the establishment of the first of a series of experiments covering a wide range of origins of *Abies alba,* a species which many foresters consider we have neglected.

Weed Control in the Forest

Selection amongst the growing range of modern herbicides for forest use and the development of techniques continues to be a very active field of work. Much of it runs parallel with agricultural developments; the forester, for instance, simply tries to fit herbicides such as paraquat and the bracken specific dicamba into his scheme of planting and tending. The economic targets for grass and bracken weeding are quite considerable.

Techniques of spraying inside planted crops continue to receive attention. The main spade work on the important woody weeds has been done some time ago, but certain special cases remain, notably *Rhododendron ponticum.* The most promising line with this species seems to lie in improvement of technique in applying 2,4,5-T.

Tree Stability

In the study of the factors influencing tree stability, further root investigations have been made with the aid of the tree-pulling technique. These continue to demonstrate the very large differences in depth of rooting on well-draining versus poorly-draining soils, which is, of course, the principal encouragement towards improvement of forest drainage methods both for the sustaining of growth and the stability of the crop. It is of interest that alder (in this case *Alnus rubra*) was found rooting to three feet on the unpleasant gleyed clay soils at Lennox (Stirling), whereas the spruces could only root the top foot. Whether it is possible to exploit this great difference in tolerance of imperfect soil conditions is another question, but it certainly suggests one very distinct manner in which alder may be considered a soil improver.

The instrumentation for the large aero-dynamic experiment on spruce crops at Redesdale has been installed, and recording has started with the automatic data logger. Further masts are yet to be erected, and once the basic conditions have been studied, experimental contrast in the thinning of the crops will be introduced.

Field studies have been made of the annoying early instability of Lodgepole pine, which is most marked in the fast-starting American coastal provenances, giving rise to wasteful basal bowing of the stem. The main line of attack on this is through provenance of seed, but this seems likely to be coupled with loss of yield. Hence the continuing interest in any fresh leads for experimental work, which so far has not been very encouraging.

Poplars and Elms

Poplars are a specialised group in which we have a considerable achievement already, certainly adequate for the limited economic status of the crop in this country. Direct research effort is tailing off, but we are exploiting the past investment in experimental work. On the varietal side, one of the Italian clones, P. 'Casale 78', has now collected sufficient favourable evidence to be added to the list of varieties eligible for grant, but should be confined to the south.

If the useful range of poplars in Britain is ever to be greatly extended, it is clear that this will be due to the balsams and balsam hybrids. A small effort has been put into recreating the hybrid *P. maximowiczii* × *trichocarpa*, one of the named clones of which (P. 'Androscoggin') has a fair claim to be the fastest-growing tree in Britain. It is, however, canker-susceptible, and it is hoped that by using resistant or less susceptible parents, we can produce a highly resistant offspring. A number of seedlings have been raised successfully and test inoculations are being made at an early stage by the Pathologist (see page 71), thus eliminating all susceptible seedlings prior to silvicultural tests.

Many of the experiments on planting and tending have fulfilled their objects and been closed. Certain experiments on pruning and spacing are becoming highly informative.

In the elms, it now seems unlikely that any form of hardwood cutting will be a useful means of propagation, and we shall have to rely on softwood cuttings using the mist technique. Whilst there are still problems here (not all elms behave in the same way), the method gives a reasonably high degree of success, and the establishment of quite young plants has been very successful. Some troubles with instability in rapidly growing young elms have been encountered, however. Susceptibility testing for Dutch elm disease continues, and some English selections (including one of *U. carpinifolia* which appears suited to forest cultivation), have shown up well.

Ecology

The autecology of the Black pine, *Pinus nigra*, has continued to absorb most of the Ecologist's time. The status of the die-back disease (which effectively limits the range of the tree) in relation to regional climate and local factors, is now pretty clear. Attention has been paid to young Corsican pine at Thetford, where regeneration fellings are apt to produce severe local frost conditions.

Soil Moisture, Climate and Tree Growth

The sandy soils under pines at Bramshill (Hants) were not re-wetted completely during the winter of 1964/65. This allowed estimates of the water use of the crops to be made from the rainfall over the unusually long period of nineteen months, between the dates when the soils left and re-attained equivalent moisture status. The value arrived at was somewhat smaller than earlier figures based on a single hydrological season.

Studies of soil moisture patterns throughout the season are now carried out on several species on a variety of sites in south-eastern England. It is of some interest that little consistent relationship between rainfall (or the resulting soil moisture conditions) and tree growth has appeared, whether with pines on sand, or beech on chalk. The indications thus far are not very comforting to those of us who would like to construct simple models of moisture and tree growth. About all that the sites so far studied have in common is that they are relatively free-draining, and support healthy and extensive rooting systems. It will be interesting to see what relationships are established on the various impeded soils which are far more important to us. The recently acquired neutron moisture meter has been under trial and shows great promise for future work in this field.

Garnier type gauges maintained at Alice Holt continue to give values for potential evapotranspiration close to those obtained by calculation from meteorological data using the Penman formula.

Genetics

One of the year's principal tasks has been the revision of the Register of Seed Sources and the procedures concerned with it. A special drive has been made on the selection of home seed sources of Lodgepole pine.

Trials were made of a new sampling procedure for the forecasting of cone yields in seed stands. This will be tested by the actual yields obtained. It is also hoped to obtain much-needed information on the periodicity and distribution of coning by maintaining such records over one or two decades.

The Breeding Register for each major species in the programme is a formidable document to keep up to date, since some thousand changes may be required annually. The transfer of an abbreviated form of the register to punched tape for processing by the computer greatly lightens the load, and brings with it the usual computer advantages of speed and flexibility in sorting of information for the management of the programme.

Sitka spruce has not been the easiest of our species to propagate vegetatively. However, last year promising developments in the rooting of cuttings were reported, and now air layering has been found successful. This may be a useful reserve technique.

Some experience has been gained in glasshouse techniques of accelerated progeny testing. At present it appears that Sitka spruce will behave under these conditions, whereas Lodgepole may exhibit abnormal growth habits.

Pathology

It is alarming to note that in an experimental planting on a site in which the first crop was badly infected by *Fomes*, losses have reached 48 per cent and deaths are still occurring. Stump removal has proved the only effective treatment under such conditions. This, of course, emphasises the importance of protective measures against the entry of *Fomes* into thus far uninfected stands.

Peniophora gigantea, the fungus which has proved most successful in rendering pine stumps unsuitable for the entry and development of *Fomes*, also shows some promise of decreasing the level of infection when *Fomes* is already well established.

Work has also been done on another 'replant' problem, the difficulty of establishing Corsican pine (always notorious for high planting losses) in the second rotation. In East Anglia the complex of adverse factors appears to include frosting, locally intensified by insulating layers of felling slash, or grass sward.

Further work on stemcrack in *Abies grandis*, a species which attracts us by its high yield potential and resistance to *Fomes*, has clarified the economic significance of this defect. Neither the incidence of crack nor the amount of degrade where it does occur appear at all alarming; the suggestion indeed is that it will prove an insignificant item in the balance sheet for this species.

The condition known as top-dying of Norway spruce appears to have become more prevalent recently, and so far the observed occurrences of the 'disease' confirm the hypothesis that its onset is causally associated with mild winters. If the climatologists are correct in their predictions, we may have less of this symptom to worry about in a few decades!

Field experimental work on the control of blue stain in felled pine logs suggests that this is an unpleasantly complex story, and that more basic work will require to be done before fungicidal, insecticidal, or combined treatments of felled logs can be recommended. Meanwhile, at least, this problem can be evaded by well-proven harvesting and log storage techniques.*

Bacterial canker of poplar and *Didymascella* (*Keithia*) of Western red cedar (*Thuja*) have received individual attention. Both are troubles we can do something about. A considerable range of troubles due to climatic agencies (or thought to be so) were encountered during the season, and about these we can do less. They are partly responsible for the rather alarming increase in the number of enquiries received by the Pathologist, though this also results from the excellent communications maintained with the 'field'.

Forest Entomology

Our principal defoliator of pine, *Bupalus piniarius*, remained at a low ebb during the year.

Useful progress has been made on the control of the Douglas fir Seed wasp (*Megastigmus spermotrophus*), which represents a considerable handicap to the

*See F.C. Leaflet 53, *Blue Stain*, by B. W. Holtam. H.M.S.O. 1966. 6d.

improvement of this species through a breeding programme based on home seed sources.

Work on the Green Spruce aphis *Elatobium abietinum* (*Neomyzaphis*), which has recently changed its name but unfortunately not its habits, is mainly aimed at an estimation of the effect of infestation upon increment.

Replanting programmes, particularly in pine areas, have forcibly reminded local foresters of the continued existence of our old friends *Hylobius* and *Hylastes*. Whole-plant dipping treatments promise satisfactory protection against both insects. The Pine Shoot beetle is also a familiar creature, usually kept to reasonable levels by sanitation and prompt extraction of produce, etc. However, it is useful to have other protective methods in reserve, and work has been done on the control of the beetle in felled logs and the protection of stacked material.

Detailed studies are proceeding on the various conifer-feeding adelgids.

Mammals and Birds

The population of grey squirrels appears to be recovering from the decline of recent years, and given a mild winter, damage to hardwoods may be expected on a somewhat greater scale in 1967. However, those with valuable and vulnerable crops should note that efficient cage trapping at or about the damage period is now a well-established protection. Squirrels re-invade rapidly, but all talk of completely eradicating this creature is idle self-deception.

Work on deer continues to concentrate on finding out more about the lives and habits of the various species, for better management of the populations. Radio tracking is a new technique under study.

In protecting seedbeds against damage by birds, which may occasionally be very serious, some limited success has been obtained with thiram. But netting seems the better line, and with the excellent modern plastic fibres it should be easy to evolve convenient and labour-saving systems.

A degree of success has been obtained with a chemical repellent against browsing by fallow deer, but repellents seem more likely to interest the horticulturist than the forester in the long run. An interesting variant in electric fencing with six-inch polythene net, the horizontals only being cored and electrified, shows considerable promise. It is easy nowadays to keep electric fences free from vegetation and consequent short-circuiting, by the use of herbicides.

Planning and Economics

Soil survey work has concentrated on two sorts of problem, firstly the study of environments in which the initial choice of species has proved to be unsatisfactory or otherwise unproductive, with special reference to the site requirements of more productive species; and secondly, on the extremely important question of susceptibility to premature wind-throw. Further experience has been gained of the analysis of the factors rendering crops liable to wind-throw, and this leads to the forecast of the risk and the mapping of zones or site types of equal estimated hazards for the use of the local manager.

Mechanical Development

The Commission's varied interest in this field are kept under review, and the necessary investigation and developmental work co-ordinated, by the Mechanical Development Committee, chaired by Mr. J. A. Dickson, Commissioner for Harvesting and Marketing.

Development of machinery for timber extraction, ploughing, etc., is centred on the Headquarters Mechanical Engineering Branch, in close collaboration with Work Study who undertake most of the field trials.

A short report is given about certain new tractors, cableways and winches at present being studied. The proliferation of winches in recent years is remarkable, and evolution must be proceeding very fast.

Utilisation Development

Utilisation problems fall in the field of the Headquarters Marketing Division, who are chiefly responsible for the Commission's side of the joint programme of research on home-grown timbers with the Forest Products Research Laboratory, Princes Risborough (Ministry of Technology). Certain topics in this programme are briefly mentioned here; fuller accounts will be found in the Laboratory's own Report and special publications.

The progress of our own trials of durability of round fence posts has been noted in previous issues (J. R. Aaron, *Report on Forest Research,* 1962; B. W. Holtam, *ibid* 1965). At the present time, that is after eight years in Scotland and seven in England and Wales, virtually all the untreated posts of not naturally durable species have failed, whereas no posts treated by a standard recommended method have failed at any site. Though there are some differences in life of posts between sites, these are (as expected) swamped by the differences in durability due to treatment.

It is satisfactory to note that as a result of trials at the Post Office depôt at Newport (Monmouth), the Post Office have now added Hybrid and Japanese larch to European larch in their specification for home-grown poles, no important difference in permeability to creosote having been observed. This is very much in accord with the results of the Forest Products Research Laboratory's general study on the timber properties of European and Japanese larch, which indicate that there is little need to distinguish between the species. (Forest Products Research Laboratory, 1965. Special Report No. 20, *A Comparative Study of the Properties of European and Japanese Larch.*)

Work Study

The addition of a mechanical engineer to the complement, and the establishment of an experimental team, have much improved the conduct of field trials of machinery, which now bulk large in the work of the branch. Machinery for extraction has received a great deal of attention, and though variations in terrain, and size and kind of produce, offer many permutations, it is thought that a key pattern for most circumstances is beginning to come into view. The work is much influenced by the comparatively rapid evolution in design of specialised forest tractors, winches, etc. It is noticeable that the trend, for produce of our dimensions, is away from the expensive full crawlers to half-tracked and wheeled tractors; the most recent of the latter have all wheels driven and steering is by ram. Mounted winches are becoming general.

Trials have been made of the large Finnish Lokomo plough, which is specially designed for winch traction to prepare deep drains in peats and mineral soils. So far it seems likely that the plough will perform well in the important upland Boulder Clays which are often overlain with thin peat.

We seem to experience heavier drawbar pulls than do the Finns under their conditions, and this has caused some trouble with winches.

Attention has been given to the noise factor with chainsaws, and it seems clear that operators should have some form of ear protection; suitable types have been identified.

The use of chainsaws for snedding (limbing) has been studied; the axe is the traditional tool, but it has been shown that there is a break-even point according to branch size, above which the chainsaw seems likely to be more profitable.

Further work has been done on weeding, and the studies now include the use of herbicides and techniques of application. A new and comprehensive attack is being made on the economics of brashing.

Statistics

Besides rendering the usual services to Research and the Commission in general, the Section has continued to develop facilities and techniques. It is notable that over half the analyses now carried out are on complex studies which could not be undertaken without the modern computer. This may be interpreted cynically as Parkinson's Law in operation, but in both forest research and management there has in fact been a pretty clear (and sometimes discouraging) realisation of the complex nature of many of the questions before the means of solution were to hand. We have not had to search for computer-fodder.

Good progress has been made in investigating and adapting methods of 'capture' of field data to cut out the time-consuming process of manual punching to tape. The Lector Document Reader, which automatically transcribes markings on specially prepared forms to punched tape, is a system which appears able to suit many of our needs, and is now in use for such diverse applications as the census of woodlands, nursery assessments, and fire reports, amongst others.

Publications and Library

Twelve new and twenty revised publications were issued during the year through H.M. Stationery Office. A new issue of the Sectional List provides the latest information on all available Commission publications, and a useful source of information on forestry literature published in Britain is the free pamphlet entitled "Books and Periodicals on Forestry and Allied Subjects".

The library underwent considerable re-arrangement during the year and its storage facilities have now invaded the entrance hall. Against this trespass on our general amenities, the largest room now serves as an attractive occasional conference room.

Microfilm reading facilities have now been installed, and the catalogue of the Commonwealth Forestry Institute with over 200,000 entries is available for consultation through this medium. This is, of course, by no means the most sophisticated use of microfilm, and we are aware that systems of storage and fast retrieval based on microfilm are already developed. They may eventually work as big a revolution in the handling of the printed word as the computer has done in the realm of numbers.

Due as much as anything to the re-vamping and wider distribution of the Library Bulletin (now styled Library Review), our communications with potential readers have greatly improved and loans have risen encouragingly.

PART II

This part contains progress reports of various lengths on research undertaken at Universities or other institutions and supported by Forestry Commission grants. Brief comment only is made here.

J. B. Craig and H. G. Miller of the *Macaulay Institute, Aberdeen*, provide a further instalment on the long-term investigations undertaken for the Commission. The dune forest of Culbin, Moray, has attracted many workers, and the current investigations into the nitrogen story are particularly interesting; the relatively small amount cycling through (or stored by) the crop, compared with that contained in the ecosystem, being especially striking. Greenhouse experiments with Corsican pine have provided further confirmation of the existing evidence that our conifers prefer their nitrogen as ammonium rather than nitrate. The suggestion of copper deficiency on young pines at Culbin is of interest since it has only previously been described as a forest tree deficiency symptom in Britain at Wareham Nursery, Dorset (Benzian, B., and Warren, R. G., 1956),* though there are recent references to it as near at hand as the Netherlands (van Goor, C. P., and Henkens, Ch. H., 1966). Physical studies on moisture and aeration in peats continue.

A number of short reports are reprinted from the *Annual Report of the Rothamsted Experimental Station*, where the long-term collaborative programme on nursery nutrition has frequently provided experimental material of value to more than those concerned with the experiments as such.

J. K. Coulter's observations on rooting of conifer seedlings in the fine sands of Wareham nursery may well have some bearing on cultivation in the forest.

Coulter's "maximum productivity" trials with perennial rye grass in Wareham nursery provide an interesting complementary demonstration to Miss Benzian's similar experiments with Sitka spruce. It is perhaps a little surprising that the Sitka spruce seedbed can produce nearly half the annual dry matter yield of a grass crop under similar luxurious nutrition (5,000 lb. per acre against 10,500 lb.) (A highly productive spruce stand will be producing something of the order of 10,000 lb. per acre per annum on stem wood alone by the age of 25 years, and averaging 7,000 lb. over a rotation of 45 years.)

Further work has been done on the slow-release fertilizers (see also Atterson, page 21), and there is now little doubt that these will enter into our standard manurial prescriptions.

It has been found possible after several efforts to get increased concentrations of potassium and nitrogen into seedlings by late top dressings *without* increasing growth. High concentration of nitrogen reduced winter frost damage and high potassium eliminated it. This result is both interesting and of practical significance, since the otherwise desirable Washington provenances of Sitka spruce are often severely damaged in the seedbed by winter cold. This may well indicate a practical measure against such damage.

From the *Botany Department, University College of Wales, Aberystwyth*, Professor Wareing and D. R. Causton provide a short report on preliminary studies of dry-matter production in broadleaved trees. By experimental pruning of seedlings of birch and sycamore, initial variations in leaf size and number

*Benzian, B., and Warren, R. G. 1956. Copper deficiency in Sitka spruce seedlings. *Nature* 178, (864–865).

Van Goor, C. P., and Henkens, Ch. H. 1966. Groeimisvormigen bij douglas en fijnspar en sporenelementen. *Ned. Bosb. Tijdschr.* 38, (108–124).

have been produced, and their effects on dry-matter production studied. It is of interest that these broadleaved seedlings appear to have strong compensatory mechanisms for such treatments through responses in leaf size, numbers, or net assimilation rates.

Dr. Salt at *Rothamsted Experimental Station* continues his work on the pathology of the conifer seedbed. Especial attention has been given to seed-borne fungi, of which a number are identified and have been shown to play a significant role in early failures of viable seed. One unidentified fungus appears to be specially efficient under relatively cool conditions, e.g. 10°C, and may well find conditions to its liking in the early spring-sown bed. A most valuable body of evidence is now collecting on the complex question of pre-emergent and early seedling losses. Our present seed economy, though nearly twice as efficient as it was fifteen years ago, still shows a good deal of room for improvement.

Work carried out for the Forestry Commission by the *Joint Fire Research Station, Boreham Wood, Herts.*, has now developed from the laboratory and model stages to the testing of theories on the rate of flame-spread under natural conditions in the forest. Controlled burns arranged for fire protection on plantation edges, etc., have provided useful observational evidence, and staff from Boreham Wood have instrumented a number of test fires on Commission property. Parallel with this activity, the Commission has itself recast its fire report for research purposes, and data collected as routine at each occurrence are now recorded on forms specially prepared for the Lector Reader, and subsequent transfer to tape for computer analysis. The Fire Research Station has been able to estimate minimum wetted firebreaks for head and back fires in certain common fuels. While as yet provisional, it is instructive to note the big differences attributable to winds of quite small velocities, e.g. the breaks necessary for a wind of 8 mp.h. in a given fuel are several times those for still air. It is now well-established that the main effect of wind is to make the radiation from the sloping flame itself an increasingly important factor as against radiation in the fuel bed. Brands blown in front of the fire (unpleasantly typical of *Molinia* fires) have not yet been taken into account.

At the *Department of Forestry and Natural Resources, Edinburgh University*, a new grant supports work by Dr. J. D. Lockie on voles and their predators. Dr. Lockie has been looking at weasels and finds both males and females are very concerned about their territorial rights, even to the extent of the male not accepting a wife when there is insufficient food about. Very practical! A promising new technique has been developed to study the social organisation of voles, about which too little is known. Animals are marked by the removal of a particular toe, and then write their own footprints on sensitised paper in tunnels laid in the run.

Dr. Tinsley at the *Commonwealth Forestry Institute, Oxford*, has continued his work on poplar viruses and has preparations in hand to extend his observations to other forest trees. The Commission also supports the *Unit of Insect Pathology* at the Institute, where Mr. Longworth has opened investigations on virus diseases of insects.

PART I

Work carried out by Forestry Commission Research and Development Staff

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FOREST TREE SEED

As in previous years, routine services represented the greater part of the work of the Section, which is responsible for seed procurement, extraction, processing, storage, testing and distribution. These activities serve the private forestry sector as well as the Forestry Commission. The steady increase of these services has limited the capacity available for research.

Seed Procurement

During the year under review the Register of Seed Sources was revised by sub-dividing the seed stands into four categories. The register is printed by the offset-litho process, on loose-leaf forms of different colour for ease of reference and up-dating. The maintenance of the Register is the responsibility of the Seed Officer. The main characteristics of the different stand categories are as follows:—

'A' category contains the best stands which are being converted or are recommended for conversion into seed stands.

'B' category stands are good stands which are not recommended for conversion due to the age and size of the trees. These stands, however, can be utilized for seed collection when seed reserves are low.

'C' category stands are normally near felling-age and may yield large quantities of seed if fellings are arranged to coincide with good seed production.

'D' category consists of:—

1. Very young plantations of highly desirable provenances of Lodgepole pine.
2. Mixed plantations of European and Japanese larches suitable for the production of first generation Hybrid larch.
3. Seedling seed orchards.
4. Native Scots pine sources.

Besides the above, there are 186 acres of clonal seed orchards of which about 24 acres are ready for seed collection. The area of these different seed sources is presented in Table 1.

TABLE 1.

REGISTERED SEED SOURCES
AREA IN ACRES BY CATEGORIES AND SPECIES

Species	Standard Category				Clonal Orchards	Total
	"A"	"B"	"C"	"D"		
Scots pine	390	789	1,067	1,385	95	3,726
Corsican pine	260	739	48	—	—	1,047
Lodgepole pine	37	109	3	294	14	457
European larch	97	101	315	—	3	516
Japanese larch	84	25	13	—	3	125
Hybrid larch	73	6	105	43	40	267
Douglas fir	85	219	201	—	20	525
Norway spruce	22	94	26	—	—	142
Sitka spruce	67	21	12	—	—	100
Other conifers	91	76	20	—	5	192
Oak	143	100	—	—	—	243
Beech	105	458	—	—	5	568
Other hardwoods	13	62	—	—	1	76
Total	1,467	2,799	1,810	1,722	186	7,984

The 1965–66 season did not yield a good crop from home sources. Only 1,455 lb. of conifer and 447 lb. of hardwood seed were collected. The main effort was concentrated on Scots pine and Hybrid larch seed, for which the reserves were low. The crop for the latter was quite good and 503 lb. were collected. This was the largest crop for some years. Despite great efforts, the registered sources only accounted for about 40 per cent of the seed collected.

As usual, home seed shortages had to be supplemented by imports, and 10,827 lb. of conifer and 2,059 lb. of hardwood seed were imported. Almost 50 per cent of the imported seed was Lodgepole pine; the result of a reasonable crop and a special effort to obtain this seed from the most important sources.

The quantities of home-collected and imported seed are given in Table 2.

Seed Supply and Storage

The Seed Section has continued to handle almost the whole of the seed requirements for the country, including those for the private forestry sector. Table 3 sets out the quantities of the different species used. As compared with the previous year, the Forestry Commission used 900 lb. less, and the private forestry sector 100 lb. more, of conifer seed. Seed stock in hand was increased by over 1,000 lb. as compared with the previous year. Although the stock does not cover the desired three-years requirements, none of the species will be in short supply during the next season.

Seed storage services are provided for members of the Forest Seed Association, which include the owners of trade nurseries. Seed is also stored for the Commonwealth Forestry Institute, Oxford, on whose behalf the stored seed is distributed to many overseas countries.

TABLE 2

SEED PROCURED IN FOREST YEAR 1966*

Species	Home-collected (lb.)			Imported (lb.)	Total (lb.)
	General	Registered Sources	Total		
Scots pine	400·8	199·7	600·5	—	600·5
Corsican pine	—	—	—	—	—
Lodgepole pine	27·9	2·3	30·2	5,090·8	5,121·0
Norway spruce	—	—	—	503·9	503·9
Sitka spruce	28·2	2·9	31·1	633·3	664·4
Douglas fir	·7	6·2	6·9	1,000·0	1,006·9
European larch	1·0	13·5	14·5	1,001·0	1,015·5
Japanese larch	39·4	23·5	62·9	1,000·0	1,062·9
Hybrid larch	200·9	302·8	503·7	—	503·7
Western hemlock	—	—	—	—	—
Western red cedar	—	8·7	8·7	19·1	27·8
Noble fir	5·0	60·8	65·8	38·0	103·8
Grand fir	—	—	—	—	—
Lawson cypress	16·1	60·0	76·1	—	76·1
Other conifers	55·1	—	55·1	86·1	141·2
Total conifers	775·1	680·4	1,455·5	9,372·2	10,827·7
Red oak	—	—	—	1,500·0	1,500·0
Beech	330·0	40·0	370·0	—	370·0
Other hardwoods	35·0	42·0	77·0	112·9	189·9
Total hardwoods	365·0	82·0	447·0	1,612·9	2,059·9
Grand Total	1,140·1	762·4	1,902·5	10,985·1	12,887·6

*That is, from 1st October 1965 to 30th September 1966.

Seed Extraction

The volume of cones processed was more than double that of last year. Individual extractory plants processed the following amounts:—

Alice Holt	1,028	bushels	English and Welsh collections
Millbuie	185	„	Scottish collections
Speymouth	1,386	„	
Tulliallan	736	„	
Total	3,335	„	

Seed Testing

Altogether 909 and 272 samples were received for service and research testing respectively. Compared with the testing done in 1965, this was 157 more samples for service and 75 less samples for research. The test numbers for individual tests are presented in Table 4. Here the total increase was 1,113 tests and consisted mainly of service work.

TABLE 3

SEED DESPATCHED AND STOCK IN HAND (LB.)

Species	Amounts Supplied to:				Stock in Hand
	Forestry Commission	Private Forestry	Export, Research or Gifts	Total	
Scots pine	276	408	8	692	1,104
Corsican pine	524	466	12	1,002	1,311
Lodgepole pine	465	327	17	809	5,100
Norway spruce	324	617	20	961	1,553
Sitka spruce	841	369	38	1,248	1,524
Douglas fir	421	455	14	890	2,080
European larch	43	277	4	324	1,250
Japanese larch	168	661	8	837	2,534
Hybrid larch	317	38	1	356	304
Western hemlock	87	146	4	237	584
Western red cedar	35	138	2	175	111
Noble fir	678	138	18	834	683
Grand fir	162	118	11	292	1,246
Lawson cypress	9	2	1	12	78
Other conifers	170	10	5	185	448
Total	4,520	4,170	163	8,854	19,913

TABLE 4

NUMBER OF DIFFERENT KINDS OF TESTS PERFORMED

Test	Service	Research	Total
Purity	619	37	656
Seed size determination	629	80	709
Germination	1,361	328	1,689
Biochemical (Tetrazolium)	27	7	34
X-ray	10	8	18
Cutting	16	82	98
Moisture content	522	79	601
Cone test	3	3	6
Total	3,187	624	3,811

Research

Due to the heavy load of service work, research activities had to be adjusted and reduced. Viability is the outstanding factor in determining seed quality, and here much time has been spent in providing the material for the revision of the International Seed Testing Association Rules. The proposed changes were presented to the Association meeting at Munich in May 1965, and approved there for implementation in August 1966. The results of the work will have important applications in our domestic seed-testing methods.

Work has continued on the storage methods for beechnuts and *Abies procera* seed; also on seed packing in order to discover a suitable container to serve the two purposes of storage and dispatching.

Seed extraction provides several problems. Here attention was concentrated on working out the quickest methods for opening the cones, and also on improving seed dewinging by designing a safe and efficient machine.

The author participated in the 14th Convention of the International Seed Testing Association held in Munich, Germany, in May 1965, followed by attendance at the International Working Party on Seed Extraction at Bergzabern, Germany.

G. M. BUSZEWICZ

NURSERY INVESTIGATIONS

The scale of work in the South in 1965 was similar to that in the two previous years, the bulk of experiments being again at Alice Holt, Hants, Kennington, Oxford, and Wareham, Dorset. Experiments run jointly with the Chemistry and Pathology Departments of Rothamsted Experimental Station continued to form a substantial and important part of the programme. (For notes on work directed by Rothamsted see Part II of this Report.)

Work in the North has concentrated on finding improved nutritional regimes, particular attention being paid to slow-acting compound nitrogenous fertilizers which also provide potash and magnesium.

The long-term benefits of organic fertilizers, such as hopwaste, on the height growth of seedlings of Lodgepole pine and Sitka spruce, have continued in the Teindland Long-term Fertility Trial.

Autumn and Spring Sowing

A series of experiments repeated for the third successive year at Elms Nursery (Thetford Forest), Kennington, Alice Holt and Wareham showed that late autumn was a poor time to sow any of the following three small-seeded species: Lawson cypress, Western red cedar and Western hemlock. But Douglas fir did well when autumn-sown, except at Elms Nursery.

Seed was sown in spring in February, March or April, stratified and untreated. Western hemlock and Lawson cypress responded to stratification; stratified Lawson cypress seed sown in March gave best yields, while stratified Hemlock seed sown in April yielded well. Stratified Western red cedar seed yielded no greater number of seedlings than untreated seed.

J. R. ALDHOUS

Long-term Fertility Trials in Scotland

The trials at Newton and Fleet containing comparisons of rotation cropping and continuous cropping, with or without sterilization, have been closed and the results will be published elsewhere.

The trial in Teindland Heathland Nursery in Morayshire is continuing; it compares inorganic and organic manures singly and in combination. Over the years it has been obvious that the plots receiving organic manure (10 tons hopwaste/acre) were consistently producing larger and healthier seedlings. This difference between the plants receiving inorganic and organic manures was thought possibly to have been due to the higher nitrogen levels supplied in the hopwaste. Consequently, in 1965 the "inorganic-only" plots were split for four rates of nitrogen, applied as one to four top-dressing during the summer and autumn, the rates ranging from 45 to 180 lb. nitrogen per acre, i.e. half to twice the normal rate. The results are given in Table 5 and indicate that even with twice the normal rate of application of nitrogen the mean height attained was still not as great as that of the seedlings on the hopwaste plots.

Slow-acting Inorganic Fertilizers

Further trials of the compound fertilizer, now known as "Enmag", containing magnesium ammonium phosphate plus potassium chloride, were laid out in

TABLE 5

MEAN HEIGHTS OF ONE-YEAR-OLD SEEDLINGS FROM THE TEINDLAND LONG-TERM FERTILITY TRIAL—AT THE END OF 1965

inches

Treatment	Species	
	Lodgepole pine	Sitka spruce
No manures applied	1·32	1·09
45 lb. N/ac. (+ PK)	1·42	1·44
90 lb. N/ac. (+ PK)	1·60	1·58
135 lb. N/ac. (+ PK)	1·84	1·75
180 lb. N/ac. (+ PK)	1·87	1·79
Hopwaste only	2·21	1·93
Hopwaste + 90 lb. N/ac. (+ PK)	2·33	1·95

1965, comparing basal applications of this new material with basal dressings of potassium metaphosphate and potassic superphosphate, both followed by 'Nitro-Chalk' top-dressings and magnesium sulphate sprays. Owing to the wet summer, and to the fact that rather more of the nitrogen content of the "Enmag" was water-soluble than expected, results were very variable. Most seedlings treated with "Enmag" were pale green by the end of the growing season, although the "Enmag"-treated plants on at least one site were greener after their first winter than plants given the other treatments.

The effect of "Enmag" was noticeably different on Lodgepole pine and on Sitka spruce seedlings. Lodgepole pine showed good height responses to "Enmag" whether it was applied before sowing or top-dressed six weeks after germination. Sitka spruce, however, was poorer on all sites (except Fleet) when the "Enmag" was applied before sowing, but better when it was top-dressed six weeks after sowing. This difference in response between the two species is likely to be due to their maximum height increment occurring at different times, that of the spruce being later.

The "Enmag"-treated plots produced significantly fewer Lodgepole pine than the other treatments at three nurseries out of six, but had no significant effect on Sitka spruce numbers.

Colour differences between plots given magnesium, and those that did not get it, were most marked at Fleet, Benmore and Inchnacardoch; lesser differences could be seen at the other nurseries within this trial, viz. Newton, Tulliallan and Bush.

Seedlings from the Fleet trial were chemically analysed. The Sitka spruce seedlings given no magnesium had levels of less than 0·06 per cent Mg. oven-dry weight; those given two sprays of Epsom salt (magnesium sulphate) supplying a total of only 6 lb. Mg. per acre, had slightly less than 0·08 per cent Mg.; and those given 145 lb. Mg. per acre as "Enmag" had 0·15 per cent Mg. Corresponding figures for the Lodgepole pine seedlings were:—slightly more than 0·06 per cent, 0·085 per cent and 0·09 per cent.

The plants given Epsom salt showed slight symptoms of magnesium deficiency, those given "Enmag" showed none, and those given no magnesium generally showed distinct discoloration. The foliage level of magnesium at which deficiency symptoms begin to appear in first-year seedlings of these two species is around 0·08 per cent Mg.

At Inchnacardoch, plants which received no magnesium, either as Epsom salt or as "Enmag", have been frosted during their first winter. The frosting was definitely correlated with the degree of yellowing caused by magnesium deficiency.

J. ATTERSON

Damage to Transplants by Fertilisers

Experiments, similar to those in 1964, tested the effect of potassic superphosphate, at normal and twice-normal rate, on the health and survival of conifer species lined-out in March, April and May at Kennington, Wareham and Alice Holt.

Six conifer species were included at each nursery. At Kennington and Wareham, *Abies procera* exhibited symptoms of severe scorch. Some plants died on plots given the double rate of PK where plants were lined-out late in the season. No symptoms attributable to fertilizer scorch were seen on either Norway or Sitka spruce, Douglas fir, Western hemlock or Corsican pine.

Paraquat for Pre-emergence Control of Weeds in Seedbeds

All the coniferous species commonly used in forestry were included in eighteen experiments, six each at Kennington, Wareham and Alice Holt, to gain a further season's evidence on the value of paraquat as a pre-emergence spray. Three to four days before the emergence of the tree crop, paraquat was applied at ¼, ½ or 1 lb. per acre, in 40 gallons of water per acre.

Two counts of the numbers of crop seedlings were made during the month following first germination. Weeds were removed by hand and the length of time taken to do so was recorded.

In no instance was the crop adversely affected by the paraquat spray. At Wareham and Alice Holt the weed control achieved by paraquat at ½ lb. per acre (the rate currently recommended) was marginally better than that obtained using vaporising oil. At Kennington, however, vaporising oil gave significantly better weed control than the middle rate of paraquat. This difference in weed control achieved between paraquat and vaporising oil has been noted previously (Aldhous, 1964).

Control of Weeds in Transplant Lines using Simazine

The two experiments in which the cumulative effects of annual applications of simazine are observed were repeated at Kennington and Wareham. The results in 1965 were very similar to those in previous years. Very good control of weeds was achieved at both nurseries on plots treated with simazine at 2–8 lb. active ingredient per acre. While damage was observed at Kennington to certain conifer species (Douglas fir, Sitka spruce, Scots pine) growing on plots treated at 8 lbs, trees at Wareham were free from damage. There was no evidence suggesting accumulation of residues.

Cold Storage of Seedlings

(1) *Oak*

At Alice Holt, oak seedlings had been lifted in February 1964. Some were lined-out immediately and others stored in polythene bags in cold store, either at +2°C or -5°C until April, July, October or February 1965, i.e. 2, 5, 8 and 12 months after lifting. Table 6 gives the survival and height growth of these plants, based on two replications each of 100 plants.

TABLE 6

COLD STORAGE OF OAK SEEDLINGS – ALICE HOLT (NURSERY EXPT. 130)

	Mean Height (at end of 1965 growing season)		Growth in 1965		% Survival	
	Stored at		Stored at		Stored at	
Date lined-out	+2°	—5°	+2°	—5°	+2°	—5°
Not stored						
February 1964	10·4	13·7	4·7	7·1	92	92
Stored until:						
April	20·2	13·6	9·6	7·8	95	92
July	7·7	7·1	2·4	2·8	70	57
October	5·8	5·6	0·8	0·3	72	12
February 1965	6·5	4·8	3·4	1·5	93	22

The remarkable feature of these results is the high percentage survival of plants stored for 12 months at +2°C. The poor performance of trees stored at -5°C, and the diminution in height the longer the storage period, have been observed in many conifer species. The high level of survival obtained following 12 months' storage confirms the results of earlier experiments. The height of the plants two years after lifting (i.e. 12 months cold storage + one growing season) was very similar to the height of plants from the same batch of seedlings after one growing season without storage. From these results, oak seedlings appear to be suitable for storage for a full season if surplus to requirements. This might be particularly valuable in a year when acorns are in short supply, following a year when acorns were plentiful.

(2) *Norway spruce, Corsican pine, Western hemlock, Douglas fir and Western red cedar*

At Kennington, these five conifer species were used in a trial testing the effect of date of lifting and the period and temperature of storage. Seedlings had been lifted for storage between October 1963 and May 1964. The experiment terminated at the end of the 1965 growing season.

None of the species did well after storage, either at +2° or -5°C, when lifted in October 1963, and only Norway spruce survived storage after lifting in November. However, all species lifted late in December that year, or in spring 1964, and stored at +2°C, survived and grew well following lining-out in February, March or May. All species except Western hemlock did well following storage at +2°C and lining-out in July.

All species survived and grew better after storage at +2°C than -5°C; Corsican pine was particularly intolerant of storage at -5°C. However, plants of this species lifted in November, December or February, stored at +2°C and lined-out in March or mid-May, survived and grew very much better than plants left in the ground until March or May and lined-out immediately (i.e. without storage).

Spacing in Transplant Lines

Plants lined-out in 1964 at Kennington and Alice Holt remained in the lines for a second year. The Scots pine from Alice Holt at the end of the year were planted out at Thetford Forest; the Sitka spruce at Kennington went to Clocaenog Forest, North Wales.

Assessments at the end of the nursery stage showed that the root-collar diameter of plants grown with "25 square inches per plant" growing area was significantly greater than that of plants grown with 12 or 16/18 square inches per plant. Plants grown "on the square", i.e. at 3½ x 3½, 4 x 4, or 5 x 5 inches were slightly sturdier than plants grown with an equal area arranged as a narrow rectangle, i.e. 1 x 12, 2 x 8, 2 x 12 inches.

J. R. ALDHOUS

Miscellaneous

Stocktaking

The new stocktaking procedure mentioned in previous *Reports on Forest Research* was introduced in all Forestry Commission nurseries in 1965. A full report on the methods adopted and the reasons for these will be published elsewhere.

Nursery Demonstrations

Demonstrations of soil pH, nutrient deficiencies, seed-bed sterilization, etc., were continued at Bush and Newton Nurseries (near Edinburgh and Elgin respectively) for the benefit of visitors.

J. ATTERSON

REFERENCE

ALDHOUS, J. R. 1964. Paraquat as a pre-emergence spray for Conifer Seed-beds. *Proc. 7th British Weed Control Conf.* (256–262).

AFFORESTATION OF DIFFICULT SITES

Plantations on Exposed Sites in the North of Scotland

The contribution of the Research Division to the increased afforestation programme in the Crofting Counties of Scotland was reviewed during the year, and a need for considerable expansion of the coverage of trial plantations was recognised. The following main proposals for further work were agreed and arrangements are being made (including special acquisitions of land in some cases) to begin planting in 1967.

The main factors limiting the extension of planting in North Scotland, are firstly exposure and secondly ground conditions adverse to mechanical drainage or cultivation. In places where the (subjectively judged) planting limit falls below the boundary of the acquired land there is a *prima facie* case for a trial plantation. Hence the Conservancy staff are encouraged, wherever appropriate, to extend a proportion of their planting on to ground classified as "unplantable due to exposure", in order to confirm the accuracy of its classification. In addition to such extensions on ground already owned by the Forestry Commission, special acquisitions are proposed in localities where no tree growth exists. From these it should be possible to estimate site values which are representative of large areas of potential forest land. Several of these have been identified in consultation with Conservancy staff and acquisition is in train. On all estates so far approached, owners have been most co-operative.

As well as trial plantations using standard means of establishment, a new series of plots moving even further on to untried elevations are proposed to test the two main species (Lodgepole pine and Sitka spruce) with above-standard fertilizer applications, on the assumption that a well-nourished plant will better withstand the debilitating effects of exposure. There is evidence for this hypothesis from a number of experimental sites. Exposure will be assessed by means of tatter-flags in all the above work, and a centralised flag manufacturing and assessment service is being arranged.

The encouraging evidence that exposure resistance can be enhanced by adequate nutrition has been followed up by the top-dressing of two older trial plantations at Glentrool and Garraries (Kirkcudbrightshire), where additions of NPK and PK fertilizers are being compared.

Advice has been given in relation to a local site classification exercise at Tornashean Forest (Aberdeenshire) proposed by a consortium of Departments of Aberdeen University, which intends to quantify the factors on which the choice of agricultural or forest use of hill ground must be based.

S. A. NEUSTEIN

Plantations at High Elevation in Wales

The tatter-flags which have been exposed on the five Welsh sites for the past eighteen months are yielding some interesting results. The period November to February is clearly very windy, but since severe icing is known to occur tatter rates are high but unreliable. During the period February to October the results will be more meaningful, and they indicate that only the months of May and June in 1965 had really light winds. The five sites appear to represent two main climatic types, since the pattern of flag-tatter at Myherin (1,750 ft. a.s.l.) and at Hafren (2,300 ft. a.s.l.), both less than 15 miles from the sea, is similar to, but distinct from, the pattern at Radnor (2,100 ft. a.s.l.) and at Mynydd Ddu (2,400 ft. a.s.l.) (2 sites) which are 60 and 40 miles from the sea respectively. The sites nearer the coast show higher tatter rates throughout the year, even though the Myherin site is at a lower elevation than all the others.

In view of the obvious major inhibition of growth and survival caused by the severity of the wind, trials with a shelter fence have so far proved rather disappointing, but this may be due to the adverse soil conditions, and steps are being taken to improve the rooting media for some trees. Survival and growth of various willows has been encouraging, and some of the species may prove valuable as pioneers to provide natural shelter.

A. I. FRASER

The Northern and Western Isles of Scotland

Advisory work to crofters and others continues. The results of experimental plantings were demonstrated to officers of the Zetland County Council with the suggestion that although an agricultural requirement (as yet unquantified) might be met by shelter plantings, there is little hope for afforestation on a scale which would provide a significant amount of local employment.

The possibility of new trial plantations on the Isle of Lewis (briefly referred to in last year's Report) has been deferred pending the possible acquisition of a sizeable area of (safe) ground which would thereafter serve as a base from which trial plantations could be extended. This delay will facilitate resource planning and execution of the work.

S. A. NEUSTEIN

Estimation of Exposure by Flag-tatter

During the year a scheme for using the rate of tatter of flags to estimate exposure was brought into operation on a much wider scale.

The general shortage of plantable land means that greater attention is now being given to the possibility of extending plantations up the hill and on to even more exposed sites. In some cases, the good growth of trees at the existing forest limit gives adequate assurance of the practicability of this extension, but in others there are no existing plantations as a guide, or there may be such an extent of ground above the present limit as to make the estimation of a new limit liable to error.

In these circumstances the use of flags provides a cheap, although admittedly imprecise, method for guiding the local staff as to the practical limit of planting. Joint visits are made by the District Officer and a Research Officer to inspect each area and agree flag positions. It is then the responsibility of Research Division to supply and assess the flags while the local staff are responsible for bi-monthly flag changes.

Because of the difficulties over icing of the flags at high elevation sites in Wales (see *Report on Forest Research* for 1965, page 20) the scheme is for the moment confined to Scotland, where it is envisaged that almost 350 flag sites will shortly be in operation. A temporary delay has occurred because a new (cheaper) pattern of flag and mount has been designed and is currently being tested in comparison with the older pattern. The new flag has the same dimensions as the older one.

Close contact is being maintained with the other research workers who are using the Forestry Commission pattern of flag, e.g. the Forestry Division in Northern Ireland and the University College of North Wales. The flag method has also been adopted for studies of topographic shelter at University College of Wales, Aberystwyth, where much interesting work correlating flag-tatter with meteorological conditions is in progress. Unfortunately, the Aberystwyth flags are of different dimensions to those used by the Forestry Commission.

R. LINES

CULTIVATION AND DRAINAGE

Cultivation of Hard Heathland

North-east Scotland

Continued investigation into the problems associated with these compacted drift soils indicates that considerable areas of post-war plantation, ploughed with early models of the tine plough, may require ameliorative treatment if successful crops are to be grown. Experimental work to date indicates that worthwhile benefits are likely to be obtained with intensive cultivation. Heavy mechanical equipment is now available for really deep cultivation and further experimentation is proposed.

Teindland

An interim assessment of dominant heights at 13 years of age, in Teindland Experiment 81, indicates that the beneficial effects of complete cultivation over single-furrow tine ploughing are being maintained. (See *Report on Forest Research* for 1964, Part III, for details of growth at ten years.) The height differences between "single-furrow tine" and "complete" ploughing treatments are still increasing slightly; but these differences relative to the heights of the trees are the same or less than the differences at 10 years.

G. TAYLOR

Drainage Experiments in Southern England and Wales

The selection of the seven sites required for the four-year drainage research programme was completed, and the drainage of one site at Towy Forest (Breconshire) was carried out during the summer. Boreholes and rain gauges were installed at most of the other sites, in order to measure the conditions for at least one season prior to the installation of the drains.

The boreholes in the two-year-old experiment at Orlestone Forest (Kent) are now showing substantial differences between treatments. The plots drained to 3 ft. now show lower water levels than the plots only drained to 2 ft., although in the first year after drainage there was no apparent difference.

Instrumentation for the drainage experiment at Halwill (Devon) is maintained by the Soils Section, and notes on progress will be found at page 62.

A. I. FRASER

Drainage of Deep Peat

Flanders Moss, Stirlingshire

The large experiment on Flanders Moss (Loch Ard Forest) was cross-drained by the "deep-drainer" single mouldboard plough during the summer of 1965, but depths greater than 28 inches were not achieved, and there is now the problem of how best to deepen the drains over a length of 600 chains. Trials of a number of alternative methods of achieving drain depths of 48 inches are proposed for this summer. Observation of shrinkage of the peat continues. Survival of both the Lodgepole pine and the Sitka spruce planted in 1965 has been excellent.

Inchnacardoch (Inverness-shire)

A joint experiment with the Macaulay Institute, in which water levels are being maintained at fixed depths ranging from the ground surface to 50 cm. below, has, in its third year, given interesting indications of a linear response in rate of height growth of Lodgepole pine with increased depth to the water table. The response to treatment at this early stage in crop development suggests the need for further investigation of the speed of crop response to intensive deep-drainage of peat soils.

Drainage of Heavy Clay Soils

Kershope, Cumberland

Establishment of this experiment is still in progress. Borehole data prior to drainage have been recorded and water-level contour maps of the area have been prepared.

Newcastleton, Roxburghshire

In Experiment 13 at Newcastleton, treatments were designed to test the combined effects of varying drainage intensity with variation in the thinning regime. The treatments were established in a pole-stage crop of Sitka spruce aged 20 years in 1951, but results after 10 years were inconclusive. Assessments have been made after thinning in 1959 and 1963, and again as a check at the end of 1965. Basal area increment for the period 1959–1963 showed an apparent increase of 20 per cent in favour of the most intensive drainage treatment over the least intensive treatment. This result was not found to be statistically significant, partly due to faults in the design of the experiment. The basal area increment for the period 1963 to 1965 showed an apparent increase of 54 per cent in favour of the most intensive drainage treatment. The result is somewhat affected by the high incidence of windthrow in the less intensive drainage treatments, and statistical analysis has not yet been completed.

A subsidiary analysis of the number of windthrown trees in each plot shows that the rate of windthrow is three times greater in the least intensive drainage than in the most intensive drainage treatments. A further result suggested by the data is that windthrow incidence is twice as great in treatments subjected to moderately heavy thinning as in treatments given light, low thinning only.

A closer examination of the results of this experiment suggests that treatment differences may have been confounded to some extent by interactions between treatments, the result in every case being to reduce the size of the difference between treatments. The possibility of the whole experiment area being subject to a benefit from the most intensive drainage treatments is strongly suggested by the high incidence of windthrow in surrounding crops of similar age, but not given any benefit from drain-deepening.

Further information from this experiment is expected to come from tree-pulling studies proposed for 1966.

Rosedale, North Yorkshire

Survival after two growing seasons in the experiment mentioned in last year's *Research Report* has been high in all treatments, but colour and growth differences are quite marked between treatments. Yellow colouring of the plants appears to be most pronounced where they have been established on upturned subsoil. Observations made during the winter suggest that soil temperatures may be markedly lower on riggs, and on complete ploughing, than they are on spaced furrow ploughing; this may be due to the absence of vegetational cover from the two former types.

G. TAYLOR

NUTRITION OF FOREST CROPS

Manuring of Young Crops on Peat Soils

Two more long-term experiments (¼-acre plots) have been established testing PK applications on Lodgepole pine at Shin Forest in Sutherland, and on a Lodgepole pine/Sitka spruce mixture at Selm Muir Forest in Midlothian; both of these are deep, acid peat sites.

A "deficiency garden", i.e. a demonstration of nutrient deficiency symptoms induced by heavy applications of other nutrients, has been established at Selm Muir Forest on a Lodgepole pine/Sitka spruce mixture on deep, acid peat.

In the experiment established in 1964 at Arecleoch Forest, Ayr, comparing potassium metaphosphate with potassic superphosphate (*Report on Forest Research* for 1965), the metaphosphate treatment had by the end of 1965 produced higher potassium concentrations in the foliage of the Lodgepole pine and Sitka spruce than had the superphosphate. This is the reverse of the 1964 results, and indicates that the insoluble metaphosphate is releasing its potassium content more slowly than the soluble potassic superphosphate. However, potassic superphosphate has been the more effective in increasing needle size of the Lodgepole pine.

In an experiment laid down at Naver Forest, Sutherland, in 1958, the application of 80 lb. potassium per acre to Lodgepole pine in early June 1963 (i.e. five years after planting) has now produced a noticeable height increase. The differences in needle weight, foliage colour and potassium concentration in the needles, between the treated and untreated plots, are still marked. In September 1965 the foliar potassium concentration was 0·37 per cent in untreated plots and 0·60 per cent in plots given potassium. The application of potassium has not altered the nitrogen and phosphorus concentrations in the needles.

In an experiment laid down at Inchnacardoch in 1954 and top-dressed with PK as potassic superphosphate in 1961, eight years after planting, foliar potassium concentration of Lodgepole pine increased from less than 0·3 per cent to 0·5 per cent; the rate of potassium was 84 lb. per acre. Now, five years after application, the potassium concentration has fallen to just under 0·4 per cent. There was a marked improvement in height, foliage density, needle weight, and colour during the first few years after top-dressing, but these improvements, including height growth, began to fall off during 1965. It appears that more than 84 lb. potassium per acre is needed on this site.

J. ATTERSON

In Wales, where the area of deep peat is very much smaller than in Scotland, the tendency has been to plant Sitka spruce rather than Lodgepole pine, and from Scottish experience one might have expected widespread *nitrogen* deficiency. In the event, widespread *potassium* deficiency has been diagnosed and large areas treated (*Reports on Forest Research* for 1964 and 1965). Foliage analysis of Sitka spruce in 1964 and 1965 showed remarkably high nitrogen concentrations, generally over 2 per cent. The reasons for this contrast with Scottish experience must presumably lie in the peat itself, though differences in vegetation and climate could also be important. Towy Forest, South Wales, has been chosen as a suitable area for long-term trials of nutrition on peat, since there is a larger extent of peat here than is general in Wales; it is hoped to begin experiments in 1967.

W. O. BINNS

Fertilizer/Herbicide Trials

The five experiments started in 1965 to examine the possibility of speeding up the rate of establishment, by the intensive use of compound fertilizers and the elimination of weed competition with herbicides, have been satisfactorily established. The fifth experiment, additional to those mentioned last year, was laid down after the last report was written, and is at Brendon Forest in Somerset, on an iron-pan soil on shale.

All experiments compare local fertilizer practice with annual NPK treatment, and an additional treatment will attempt to base repeated fertilizer dressings on foliage analysis and observations of growth and colour.

In most experiments more than one species has been used, to compare the standard choice with a higher-yielding one. Corsican pine and Western hemlock have been used in three trials, Scots pine and Sitka spruce in two, and Lodgepole pine, Douglas fir and *Pinus radiata* have each been used in one trial.

No effects of the herbicide treatments (where applied) were seen by the end of the first year, but there were distinct suggestions that some species had benefited from NPK treatments compared with phosphorus alone, or with no fertilizer where this is standard practice. Since response is likely to have been limited in the first year by a planting check, this augurs well for the future.

W. O. BINNS
J. R. ALDHOUS

Nitrogen Top-dressing on Checked Crops

Most of Soussons block of Dartmoor Forest, Devon, was top-dressed with triple superphosphate in 1961, since experiments had shown that the crop of Sitka spruce, in common with a number of other areas in South-west England, was suffering from severe phosphorus deficiency. Some areas did not respond very well to phosphorus, and these were characterised by the virtual absence of dwarf gorse (*Ulex gallii*), a common leguminous component of the vegetation in the area.

Analysis showed the trees to be deficient in nitrogen, so in 1964 two rates of nitrogen and two herbicides, paraquat and 2,4-D, were tried in a 3^2 factorial design. Both nitrogen treatments raised the N concentration in the needles the first year, but these differences had disappeared by the end of the second year. In contrast, both herbicide treatments had increased N concentrations by the end of the second year, regardless of N treatment, and paraquat (which kills grasses as well as heather) appeared to increase it more than 2,4-D (which kills heather only).

Nitrogen gave a very small increase in increment the first year, and a marked increase in the second year which was greater with the higher rate; the increments over the two years were about 7, 16 and 21 inches for the control, N_1, and N_2 treatments. The herbicides have only had a small effect on growth so far, but the long-term effects of these may be considerable.

W. O. BINNS
J. R. ALDHOUS

Manuring of Pole-stage Crops

Further pole-stage manuring experiments have been established in Glenbranter Forest, Argyll, in Sitka spruce planted in 1929, of Yield Class 160, and in Devilla Forest Fife, in Scots pine planted in 1938, of Yield Class 80. Foliage analyses of samples collected in September 1965 from the two similar experiments in Scots pine established in 1964 (*Report on Forest Research* for 1965), show very large increases in needle weight and in needle nitrogen concentration, with both rates of the NPK fertilizer applied. These experiments will be assessed at the end of 1966, and will probably show a marked growth response.

In the four Sample Plots in Corsican pine at Culbin Forest in Morayshire, given 150 lb. nitrogen per acre in May 1963, the basal area increment during 1965 averaged 9 sq. ft. (hoppus) per acre, which compares with 3 sq. ft. in 1963 and $6\frac{1}{2}$ sq. ft. in 1964. This is extremely encouraging, as an increment of 9 sq. ft./annum is very high (even for Sitka spruce) in this country. It will be most interesting to see when this growth response falls off, but already the timber produced by the treatment has more than covered the fertilizer cost.

J. ATTERSON

Four experiments of a simple 2^3 design were established in 1962 on Scots and Corsican pines in Thetford and Swaffham Forests in East Anglia (*Report on Forest Research* for 1962.) The results for the first three years show only small effects, but there is a suggestion that if any major nutrient is generally important in this area it is phosphorus. There was a significant effect of potassium and magnesium (applied together as one treatment) on Scots pine on shallow till over chalk, which is interesting as agricultural crops on these soils respond markedly to potassium.

Foliage analysis shows significant uptake of phosphorus in two experiments. The experiments will be measured again at the end of 1966.

W. O. BINNS
A. E. COATES

Foliage Analysis: Analytical Reorganisation

Until 1965 all the foliage analysis in connection with nutritional research in Scotland and Northern England had been done for the Forestry Commission by the Forest Soils Section at the Macaulay Institute in Aberdeen. In recent years this load had begun to affect the amount of research that could be done by this small Section, so it was agreed to transfer most of the work to Alice Holt from September 1965. During the first half of the year under review a considerable amount of time was spent improving the speed of the routine laboratory processes to cope with the extra load.

In the past, analyses at Alice Holt have almost always been made on needles from individual trees, since investigations had shown that the between-tree variation was often greater than the variation between treatment means. However, an examination of the uses to which the detailed results were being put suggested that in nearly all cases nothing was being gained by individual analysis. From this year, therefore, almost all analysis will be on bulked samples, which reduces the number of determinations by about two-thirds. The change is convenient at this time because the Macaulay Institute has always used bulked samples for analysis.

During the winter approximately 1,500 samples were analysed, about 650 of these coming from Scotland and North England. Most samples were analysed for N, P, and K, and a small proportion for Ca and Mg as well.

W. O. BINNS
J. ATTERSON

Diagnosis of Deficiencies by Foliage Analysis

Most of the analyses have been for fertilizer trials and other experiments, but an appreciable number were from Conservancies, where a confirmation of nutrient deficiency diagnosed in the forest was sought. Most of these come from North Wales, and in many of these samples there was a clear deficiency of phosphorus, while in a smaller number deficiencies of nitrogen and potassium were indicated. In many cases there was no clear deficiency, suggesting that other causes were responsible for the poor growth: furthermore it is always necessary to bear in mind that low concentrations of nutrients in foliage may be the result and not the cause of poor growth. A small number of samples from forest nurseries have also been analysed to check suspected deficiencies.

W. O. BINNS
J. ATTERSON

Permanent Sampling Plots

The 1965 samples from the permanent foliage sampling sites, referred to in the last Report, have given the results shown in Table 7.

The results given in Table 7, when compared with those obtained at the end of 1964, indicate, on average:—

(a) An increase in needle weight in both Sitka spruce and Lodgepole pine;
(b) A slight decrease in N per cent in the spruce needles;
(c) A slight increase in N per cent in the pine needles;
(d) An increase in P per cent in both species;
(e) No change in the K per cent of the spruce in partial check and in the pine;
(f) No change in the Mg per cent;
(g) A decrease in the Ca per cent, marked in the spruce.

The N:P ratio averaged 8 at the end of 1964, but dropped to 6½ at the end of 1965. Similarly the K:P ratio dropped from 5⅓ to 4½. Such changes are probably caused by climatic variation, but it will be some years before we shall be able to relate the changes observed to the variation in climate.

J. ATTERSON

It is hoped to select sites in Wales and the rest of England during the year. There would then be a countrywide coverage of sites which should be invaluable in accounting for the year-to-year variations in nutrient concentrations which make diagnosis through foliage analysis difficult.

W. O. BINNS

Peat Analysis

Samples of peat from three depths, 0–6, 6–12, and 12–18 inches, were collected at the end of 1965 from many sites throughout Scotland for chemical analysis, using a newly developed sampling tool (Jowsey, 1966). One of the aims of such sampling will be to build up, over the years, a picture of the variation in peat nutrient contents and to try to relate any difference found to

TABLE 7

FOLIAGE ANALYSES FROM PERMANENT SAMPLING SITES

Species	Needle Wt. (mg. O.D.)	Nutrient Concentration (% oven dry wt.)					N : P : K (Ratio)
		N	P	K	Ca	Mg	
Sitka spruce (growing well)	*8·1* 4·6—10·4	*1·47* 1·07—1·76	*0·24* 0·18—0·33	*1·15* 0·68—1·58	*0·24* 0·15—0·40	*0·12* 0·09—0·16	6 : 1 : 4¾
Sitka spruce (in partial check)	*5·0* 3·2—6·7	*0·95* 0·72—1·27	*0·16* 0·08—0·19	*0·69* 0·30—0·89	*0·28* 0·21—0·37	*0·10* 0·08—0·12	6 : 1 : 4½
Lodgepole pine (Washington Coastal Provenance)	*18·9* 11·9—26·0	*1·44* 1·11—1·62	*0·19* 0·14—0·26	*0·57* 0·38—0·75	*0·10* 0·06—0·20	*0·09* 0·06—0·18	7¾ : 1 : 3

Notes: Figures in italics are mean values obtained, and the figures below these are the ranges.

tree growth. Until now the analysis of such samples has been done by the Macaulay Institute for Soil Research in Aberdeen, but in future they will be analysed by the Edinburgh School of Agriculture.

J. ATTERSON

So far the amount of peat analysis done in Wales is insufficient to allow useful comparisons with the work done in Scotland, but the apparent difference in nutrient status of spruce grown on peat in the two countries, mentioned above, suggests that this is an important line of work. It is hoped to arrange a programme of peat analysis during the coming year.

W. O. BINNS

Advisory Work

Many field visits to Commission forests and some private estates were undertaken during the year to advise on the use of fertilisers. This activity is likely to increase considerably as the younger forests, often planted on poorer sites than in the past, begin to become deficient in nutrients due to the limited amounts available becoming incorporated in the tree tissues and in the undecomposed humus layers.

J. ATTERSON

Theoretical Comparison of Net Discounted Revenue of Pure Lodgepole Pine and Pure Sitka Spruce on Infertile Peat

Using standard manurial regimes only, Lodgepole pine can produce a merchantable crop on infertile peat, e.g. a stand of Yield Class 100 (Bradley, 1966) has been obtained on the Lon Mor, Fort Augustus, Inverness-shire, with only phosphate at planting and one top-dressing of potassic superphosphate at the pole stage (Inchnacardoch Experiment No. 52 planted 1929).

Sitka spruce, which has never succeeded as a crop on infertile, unflushed peat, has a higher potential yield than pine, and startling but short-lasting growth responses to added nitrogen have been achieved experimentally.

With the assistance of the Economist, a theoretical investigation was completed to determine the yield of Sitka spruce that would have to be attained to justify two levels of manurial input, and to compare this in terms of Net Discounted Revenue with Lodgepole pine, which had received only normal treatment.

The first manurial regime considered for the spruce was a short-term one based on the (unproven) assumption that initial 'pump-priming' additions of nitrogen would thereafter recirculate. For this, four applications of nitrogen—at planting and at 7, 11 and 15 years—plus phosphorus and potassium at 7 and 15 years, were allowed, in addition to the normal application of phosphorus at planting. The second regime assumed that manurial input would be required throughout the rotation, i.e. nitrogen at four-yearly intervals up to the age of 40 years, plus herbicide four years after planting and potassic superphosphate at 7, 15 and 31 years. Current costs were used for all calculations.

The results of this exercise were somewhat surprising in that to equal the Net Discounted Revenue of Lodgepole pine (Yield Class 100), Sitka spruce with the 'pump-priming' regime would have to attain only Yield Class 140, while with the repeated manurial regime a Yield Class of 160 would be adequate.

It should be emphasised that there is no evidence that such yields can be achieved, and experiments are in progress to determine the maximum response of spruce to complete and repeated manuring.

S. A. NEUSTEIN

REFERENCE

JOWSEY, P. C. 1966. An improved peat sampler. *New Phytologist* 65, pp. 245–8.

NOTE

BRADLEY, R.T. 1966. *Forest Management Tables*, Forestry Commission Booklet No. 16. H.M. Stationery Office (30s. net).

The published range of Lodgepole pine Yield Classes runs from 60 to 140. The corresponding range for Sitka spruce is 60 to 280. Both figures refer to annual increment in hoppus feet per acre.

REGENERATION OF TREE STANDS

Estimates of Seedfall

(1) *Douglas Fir*

The seed trapping at six sites, which is being conducted jointly with the Entomologist, has been continued. As forecast last year, the period September 1965 to March 1966 has shown an improvement, with four sites yielding reasonable quantities of seed; Brendon (Devon), Culloden (Inverness-shire), New Forest (Hampshire) and Thornthwaite (Cumberland). The two remaining sites at Mortimer (Herefordshire) and Thetford (Suffolk) have been very poor every year, though the former showed a slight improvement this year.

(2) *Sitka Spruce*

The seed trapping study in a thirty-eight-year-old crop at Glenbranter Forest (Argyll), mentioned in last year's Report, was continued into early summer. The first seedfall was in October when 15 per cent of the total fell (51 per cent viability). Thereafter there was a lull until the period between mid-February and early April 1965, when 74 per cent (66 per cent viability) of the total fell.

Simple graphical correlation of maximum and minimum temperatures, sunshine, rainfall and relative humidity with seedfall were attempted, but nothing obvious emerged. The next step will be to make further seedfall counts in different parts of the country, and these will be sited following the cone crop forecasts to be made in the summer of 1966.

A. I. FRASER
S. A. NEUSTEIN

Underplanting of Japanese Larch

No new experiments have been established in the South, but the existing experiments are now showing interesting treatment differences. The light available, under the various densities of cover which are being investigated, is measured every year, and this is being compared with the growth of the species used for underplanting.

One of the main crop types to be clear-felled for pulp in North Scotland is larch growing on potential spruce sites. During the later stages of larch pole crops, under a normal thinning regime, enough light reaches the forest floor to permit a dense growth of weeds. Conservancy trials were proposed to see whether it was feasible to underplant some of these larch areas without preparatory thinning, prior to clear-felling the larch a few years after planting the undercrop. The advantages of this treatment might be a reduction of the work load during the very busy early years of the Scottish Pulp Project, with a period during which the underplanted Sitka spruce would grow slowly, but without requiring much weeding. The unknown factors are the length of time various species can subsist under various densities of canopy, and the amount of felling and extraction damage to the undercrop.

This sort of problem can be investigated on an *ad hoc* basis, but it seemed worthwhile to study this further. In 1964 an experiment was established under a number of stands at Ratagan Forest (Inverness-shire) varying in mean height from 46 to 67 feet. Several similar trials were undertaken elsewhere by the Conservancy. Preliminary results have not been encouraging as at the end of the second year the Sitka spruce was carrying only the current year's needles, and plants looked exceedingly weak in all plots. The percentage of full light reaching the floor was assessed in mid-summer, and was in the range 12 to 26 per cent. This percentage is roughly half that obtained after normal preparatory thinnings for underplanting.

Light measurements were repeated for the third year in the main northern experiment at Drumtochty (Kincardineshire) and assessment of needle-weight and sturdiness of current shoot (length and diameter) was carried out, but analysis is not yet complete. Weeding was timed by treatment and showed a clear reduction in weeding requirement in the "200 overwood stems per acre" treatment, weeding time being less than 50 per cent of that required in the clear-felled treatment. No significant variation with overwood densities in the range 120 to 140 stems per acre was found.

Preliminary site selection and survey for a new underplanting experiment in Yorkshire has been completed.

The use of paraquat before felling or underplanting is dealt with under the section of this Report entitled "Weed Control in the Forest", pages 47–50.

S. A. NEUSTEIN
A. I. FRASER

Regeneration of Scots Pine

Scotland

This project falls logically into two categories, namely the replacement of Scots pine growing on fertile sites which may be capable of higher yields if planted with Douglas or Grand fir; and the replacement, with suitable site amelioration, of unsatisfactory pine crops. It is considered premature to begin regeneration research in the middle range of pine crops in which felling is not contemplated for perhaps another 25 to 30 years.

An experiment in a Quality Class III Scots pine stand at Culloden (Inverness-shire), comparing a range of overwood intensities from approximately 500 stems per acre down to clear-felling, has been replanted with Douglas and Grand fir. A second similar experiment at Culbin (Moray) has been felled and fenced, and is ready for planting in 1966. A noticeable feature in these good narrow-crowned crops is the ease of planting through untouched slash.

The replacement of poor Scots pine crops is being investigated at three forests in East Scotland (Forest of Deer, Kirkhill and The Bin). The following topics are being studied as appropriate to each site:—

1. The benefit of shelter by means of strip fellings in two orientations.
2. The possibility of herbicidal treatment before felling, coupled with two slash disposal treatments—all operations up to establishment are being timed.
3. The effect of cultivation.
4. The effect of phosphate.
5. A comparison of a variety of species including Lodgepole pine, Hybrid larch, Noble fir and Sitka spruce (pure and in mixture with Lodgepole pine). Crops on these three sites have been felled and will be replanted in 1966.

S. A. NEUSTEIN

Thetford Chase

One new experiment has been laid out, designed to investigate the effect of density of pine cover on the incidence of frost near the ground, and on the light available for the growth of the underplanted crop. The treatments include clear-felling, which will serve as a control.

The first series of plots, planted in 1962 with seven species, under a uniformly thinned overwood of pine, have now had the first thinning of the over-storey. Light intensities had dropped from 60 per cent to 20 per cent of open light over four years, and many of the young trees were showing symptoms of lack of light.

Samples of the overwood were pulled over, and their roots investigated. The results showed that the Scots pine was rooting very deeply (4 ft.) on the deep acid sand, but on the shallow soil over chalk, the rooting depth was only 2 ft. It was interesting to find abundant rooting in the upper 12 in. of the chalky till, and occasional roots penetrating down fissures. Differences in root competition may account for some of the differences between sites.

Frosts were again recorded during the growing season in clear-felled areas, but under the cover freezing point was never reached.

A. I. FRASER

Spruce in the Borders—Size of Felling Area

A second experiment (Redesdale Forest, Northumberland) on this subject was established during the year. (The first was described in the *Report on Forest Research* for 1964.) Unfortunately a severe gale in November 1965 overthrew 254 trees at a stage when felling was not complete in all plots. However, an analysis of the damage supported the results of the former experiment. Eighty-nine per cent of the trees were thrown outwards into the surrounding crop on the lee side, whereas only 9 per cent were thrown from the windward side into the felled area, and 2 per cent were broken. Many more trees, per acre felled, were thrown round the edges of the "one-third-acre" fellings (37 trees) than around the "four-acre" and "five-acre" fellings (13 trees). Although the above data are not capable of statistical analysis, it is reassuring that they do not conflict with previous results.

Direct Sowing of Sitka Spruce

For the third year, intensive trials of direct sowing of Sitka spruce seed under typical regeneration conditions are being established. In the 1964 and 1965 experiments, germination and survival at the end of the first summer, and after the first winter, have been good enough to justify the third year's sowings and probably more extensive subsequent trials.

Manuring Second-rotation Crops

Experiments testing nitrogenous manuring of replanted crops, with the intention of boosting early growth to overcome competition from invading vegetation, show that no worthwhile growth response was achieved.

Erosion following Clear-felling of Spruce

There is a risk of loss of topsoil following clear-felling of spruce on steep open-textured soils in very high rainfall areas, and symptoms of sheet erosion have been noted. Two experiments have been designed to estimate the amount of soil movement on a site at Benmore Forest (Argyll) where an area which may be susceptible to erosion is being clear-felled. In one experiment the water and soil from a defined area will be collected and measured. Within this area, and on adjacent non-isolated plots, changes in micro-topography will be periodically assessed. Rainfall will be recorded continuously, as intensity of precipitation is a key factor. Re-invasion of vegetation will be prevented chemically in order to maintain the plots in a susceptible condition for several years. These preliminary experiments are largely trials of technique.

S. A. NEUSTEIN

PROVENANCE OF SEED

Black Pine, *Pinus nigra*

The large trial planted in England in 1965 suffered very few losses indeed. Growth at Wareham was quite good for the first year, despite the difficult site conditions. A further experiment in the series established on smoke-polluted sites of the Pennines has been planted at South Yorks. Forest. It contains thirty-two origins, including an assortment of seventeen provenances from Central and South-east Europe—thirteen from natural stands and four from plantations. Eight collections from selected Danish plantations, and seven from stands on smoke-polluted sites in the Pennines, complete the total. It is thought that progeny of existing stands in the north of England may well be better adapted to the relatively unfavourable climate there, than are provenances from the natural range of the species. This may be true also of the Danish origins since Denmark, like England, lies well to the north of the natural range.

Small demonstration plots of all the provenances have been planted at Stenton, East Lothian, alongside an existing provenance experiment.

Lodgepole Pine

Two interesting series of experiments have been reviewed, and a separate interim report will be published later. The first of these series, planted in 1957, comprises three experiments comparing fourteen 'home-produced' origins (six from the Republic of Ireland and eight from British stands), and two imported directly from North America. The second series, planted in 1958/59, compares coastal provenances from British Columbia to Oregon. The main findings of this last series are that the southern provenances from Long Beach (Washington) to North Bend (mid-Oregon) are greatly superior in growth to the more northerly ones; this is evident after six years, though it was by no means always clear in the first year of growth. Between these more southerly provenances there is not often a significant difference, but the most southerly (North Bend) tends to be tallest at most sites, whether planted in Cornwall or Sutherland.

The smaller trials, planted in England and Wales in 1964 and 1965, are now well established and growing fast at most sites.

A new experiment planted at Allerston, Yorks., in 1965 compares twenty-two provenances representing a wide range of localities within the natural range of Lodgepole pine. It includes seven collections from British stands and one from a fast-growing plantation of coastal type in New Zealand. Survival at the end of the first year was extremely good, although the New Zealand origin was slightly poorer than the other provenances.

A third thinning was carried out in an experiment at Millbuie, Black Isle Forest, Ross. In the extensive plots planted in 1938, the highest total volume production at twenty-eight years was shown by an inland provenance from Priest River in North Idaho (3,000 cubic feet per acre), followed by a coastal provenance from the Olympic Peninsula, Washington (2,860 cubic feet per acre). A southern inland provenance from Klamath, Oregon, showed the lowest total production, with only 1,650 cubic feet per acre. The Priest River plot is on a slightly better site than the majority of the other plots, and it did not show such good growth in the replicated section of the experiment. But even allowing for this, growth has been very good for an inland provenance coming from just south of the 49th parallel. In the plots planted in 1939, the highest volume production of 2,480 cubic feet per acre at twenty-seven years was shown by two origins—Hazleton (Skeena River), and a home collection from Auchterawe, Inchnacardoch Forest, Inverness-shire, originally coastal U.S.A. In the section planted in 1940, a south coastal Washington lot from Gray's Harbor has produced 2,600 cubic feet per acre at twenty-six years.

Another pole-stage experiment, at Clashindarroch Forest in Aberdeenshire, was thinned for the second time. Most of the provenances in this experiment are of inland origin and have grown well in view of the high, relatively exposed nature of the site. At 34 years of age a provenance from "Inland Canada" had produced a total of 3,030 cubic feet per acre and one from east of Kamloops, British Columbia, 2,600 cubic feet per acre. In the 1938 section, the Skeena River provenances "Smithers" and "Hazelton" produced respectively 1,940 and 1,890 cubic feet per acre at 28 years. Fastest growth in the 25-year-old 1941 section was shown by a collection from Auchterawe (*ex* coastal U.S.A.) with a total production of 2,080 cubic feet per acre. By far the poorest provenance was Lulu Island (British Columbia) with only 1,360 cubic feet per acre.

It should be noted that the data for both the Millbuie and the Clashindarroch experiments are from unreplicated plots. In consequence some caution is required in interpreting them.

Douglas Fir

The seeds of provenances from selected stands in four regions and from five selected areas of the Oregon coastal region have been sown.

Following the 1964 growing season, six-year height assessments were carried out at Elibank (Peebles-shire) and Thornthwaite (Cumberland) in the experiments planted in 1959, which compare eight home and five North American collections. A third experiment at Castle O'er (Dumfries-shire) had been assessed one year previously, after five seasons; while the fourth experiment in the series, at the Forest of Dean, planted one year later than the others, was assessed at the end of 1965. At the two Scottish sites, growth has been slow, with the North American provenances in general showing rather better growth than the Scottish lots. The Culloden provenance is the exception, having grown as rapidly as the best North American lots. Recovery from the severe damage caused during the 1962/63 winter has been reasonably good at the two Scottish sites. At Thornthwaite the experiment is on a north-facing slope and rather exposed to winds from the north and east, which killed many trees in the severe 1962/63 winter. The best height growth is shown by the Culloden lot, closely followed by that from Inveraray, but these results must be treated with caution in view of the low survival, particularly amongst home origins, which is likely to necessitate writing off the experiment. In the Dean experiment, where damage during the 1962/63 winter was slight, growth of all provenances has been considerably better than at the other three sites. The tallest provenances are the home collections from Inveraray and Barcaldine, and the American lots from Joyce and Tenino.

Norway Spruce

A trial was planted out at Brendon (Somerset), Forest of Dean (Gloucestershire), Cannock (Staffordshire) and Gwydyr (N. Wales). This includes the standard Austrian commercial seed for comparison with one from Poland, two from Bulgaria, three from France and four from Switzerland. The sites are representative of districts in which this species is being, or will be, more widely planted.

European Silver Fir, Abies alba

The first of a series of experiments comparing a wide range of origins was planted at Drummond Hill in spring 1965. Plots were laid out in small felled clearings scattered through a forty-three-year-old larch crop, and after the first growing season survival of all provenances was good. The remaining four experiments of the series are to be planted in spring 1966 on sites at Lael, Benmore, Radnor and Thetford. Unfortunately, plants for the latter three sites were badly damaged by late frosts at Fleet nursery on the 19th and 20th May 1965, all provenances being affected more or less equally. A plot of *Abies nordmanniana* within the same area escaped with little injury because of the very late flushing of this species. By the end of the growing season some recovery of the damaged plants had taken place, and it was decided that they would be usable for the experiments, although establishment losses might be high and early growth slow as a result of the damage. Plants for the Lael experiment were re-lined out at Inchnacardoch in spring 1965 and so escaped injury.

During tours in France and Jugoslavia organised by the International Union of Forest Research Organisations Working Group on Provenance, the opportunity was taken to visit several of the parent stands from which seed was sent for this series of experiments. This proved to be of great interest, and a better appreciation of the natural variation of this species and its silvicultural problems has been gained. To pick out one example, the *Abies alba* stands at Mt. Perister, near the southern border of Yugoslavia, are at the extreme end of its range and show certain morphological characteristics intermediate between *Abies alba* and *Abies cephalonica.*

Jack Pine, Pinus banksiana

At the end of the 1965 growing season, all provenances in the Jack pine experiment planted at Broxa in 1961 were assessed for frequency of internodal branching on the current leading shoot, and for percentage of trees with single undamaged stems. Many of the double stems resulted from damage during the severe winter of 1962/63. For internodal branching, overall provenance differences were highly significant; the average number of internodal whorls ranged from 1·0 to 1·7. In contrast, an average of 0·6 was recorded for an Inland Lodgepole pine provenance (Fort Fraser, British Columbia) included in the experiment. Single undamaged stems were recorded for only 52 to 65 per cent of the Jack pine, as compared with 73 per cent for the Inland Lodgepole pine, and provenance differences were significant at the 5 per cent level. There was no obvious relationship between the two characters assessed. The frequency of internodal branching and relatively poor stem form does not augur very well for any future use of the species. A similar assessment will be carried out in the near future at the parallel Inshriach experiment.

During the 1965/66 winter, the foliage of all *P. banksiana* provenances at Broxa took on a pronounced yellow coloration. In comparison, the Inland Fort Fraser Lodgepole pine included in the experiment appeared conspicuously green, although the foliage of Inland Lodgepole pine is prone to yellowing in winter. Foliar analysis revealed that potassium levels in the *P. banksiana* were lower than that in the Lodgepole pine, which was slightly below normal.

Bishop's Pine, Pinus muricata

The promise of this species in resistance to sea-winds and cold has been further tested by two trials comparing four origins (U.S.A., Bedgebury, and two Irish sources) with *Pinus contorta*, on two sites. One is under severe maritime exposure, at Newborough, Anglesey, and one at high altitude, 1,300 feet, at Taliesin, Cardigan.

Californian Redwood, Sequoia sempervirens

Survival in the 1964 experiments has been good at Alice Holt but very poor at Plym (Cornwall). Eight more provenances, two from single selected trees, have been received from America and have been sown.

R. LINES
A. F. MITCHELL
A. J. LOW

WEED CONTROL IN THE FOREST

Weed Control Before Planting

Two vegetation types are being examined at present in Scotland to determine whether the use of herbicides before planting is a satisfactory method of weed control. One is bracken, generally with some grass as an understorey, and granular formulations of dicamba* and 2,6-dichlorothiobenzamide are being tested to determine their effectiveness in controlling the bracken and grass. The latter is most important because if only the bracken is killed, the grass would in most cases become a weed problem which is more difficult to cope with by hand weeding than bracken. Both these herbicides kill bracken and grass, but the rate necessary for a long-term effect either may be too expensive or may kill any trees planted into treated soil.

The second vegetation type, and by far the most important in the North at the present time, is grass under tree crops due to be clear-felled and replanted. An experiment was laid out at Drummond Hill (24/65) in autumn 1965 comparing two methods of applying paraquat to such a grass sward. These methods are:—

(1) Spraying 3 ft.-wide strips at 5–6 ft. intervals (centre to centre) using a knapsack, pressurised sprayer fitted with a suitable boom, and

(2) Treating the whole area using a mistblower.

It took about 1½ minutes to treat a 1/10th acre plot using the mistblower, compared with 10 minutes using the knapsack sprayer. The mistblower is the obvious method if application is uniform enough, and it appeared to be so after browning of the vegetation had occurred one week after spraying. However, it is essential that an effective respirator be worn to avoid danger to the operator. No discomfort was experienced during the spraying of the mistblower plots, as the operator wore a respirator continuously. The kill of the grass appeared to be satisfactory, but it will not be until the end of 1966 that the effect on grass regrowth, and hence weeding required, will be known. It is hoped to repeat this experiment on a range of sites during 1966.

S. A. NEUSTEIN

Control of Bracken

The experiments started in 1964, and reported in the *Report on Forest Research* for 1965, showed little change from the previous year. Bracken growth was almost completely eliminated on plots sprayed with 4, 6 or 8 lbs. of dicamba in 100 gallons of water per acre, whether this was applied in April, May, June, July or August. Bracken on plots sprayed at 2 lb. per acre was weakened.

The experiment had been repeated on four sites; on each, two conifer species were planted—half the number of plants in the autumn and half in the following spring (i.e. spring 1965). At the end of the 1965 growing season, only a little damage was observed on any of the plants. This took the form of mild distortion of the needles of Scots pine planted on plots sprayed at 8 lb. in August. The damage was concentrated at the apex of shoots, especially the leading shoot; however, there was no malformation of the shoots themselves. On sites where

*Full details of the names, formulae and properties of the chemicals mentioned can be found in the 4th Edition *British Weed Control Handbook*, edited by E. K. Woodford, publ. Blackwells, Oxford. Dicamba is also known as 'Banvel' D, Picloram as 'Tordon', and 2,6-dichlorothiobenzamide as 'Prefix'.

there was a sparse cover of grasses present under the bracken at the time of spraying, the grasses had increased and spread following removal of the bracken cover.

Two series of experiments were started in 1965, following up the previous year's series, with dicamba again the principal chemical under investigation. These covered:—

(a) the effects of dicamba at rates 1–8 lb. per acre, applied diluted in 25, 50 or 100 gallons per acre between February and July 1965 to bracken on unplanted ground;

(b) a comparison of dicamba with picloram and 2,6-dichlorothiobenzamide on planted ground.

The first two compounds were sprayed at 2 and 4 lb. active ingredient in 50 gallons of water per acre; the last-named one was applied as granules containing 7½ per cent active ingredient at 4 and 8 lb. per acre (i.e. approx. 50 and 100 lb. of 'Prefix' granules per acre). These compounds were applied at two sites, Rogate, Hants, and Moccas, Hereford, to bracken growing in planted crops of Norway spruce and Corsican pine respectively.

The first series of experiments gave results similar to those of the previous year, i.e. the earlier the application, the better the control of bracken that season; also, the higher the rate, the better the control of bracken, though, as in the 1964 series, good control was usually achieved with applications at 4 lb. per acre. Poorer control of bracken was achieved on plots sprayed at 25 gallons per acre than at the higher dilutions, because of the difficulty of applying an even cover at this rate of dilution, using a knapsack sprayer.

In the second series of experiments, the herbicide was applied to the bracken between, rather than in, the rows of plants. The reasons for this were firstly that the planted crop was expected to be susceptible to direct spray; secondly, the results of the previous year's experiments showed that dicamba was translocated in the bracken rhizomes to reduce the vigour of bracken up to 18 inches outside the treated area, so suggesting that bracken could be treated in strips and all the bracken on the site reduced in vigour sufficiently to obviate the need for weeding, whilst at the same time avoiding damage to the crop.

Both picloram and dicamba had a marked effect on the growth of bracken, to the extent that a year's weeding could probably have been avoided. However, the picloram devastated the planted conifers and could not possibly be considered for use in controlling bracken in planted areas. The dicamba caused slight damage to some Norway spruce and more severe damage to Corsican pine; a further year's growth is required before any sound evaluation can be made of the safety of dicamba as a post-planting treatment.

The 2,6-dichlorothiobenzamide had practically no effect on the bracken at either site.

J. R. ALDHOUS

Control of Rhododendron ponticum in Young Plantations

The use of ammonium sulphamate to control *Rhododendron*, while extremely effective against the weed, has also caused losses wherever young forest trees are rooting in the area treated with this herbicide. Experiments were therefore set up in York Forest and Ringwood Forest (Hants) to examine the effect of picloram, dicamba, 2,4,5-T, paraquat and ammonium sulphamate on *Rhododendron* regrowth and on seedlings in young plantations of Scots and Corsican pine respectively. Because of the irregular distribution of *Rhododendron* stools and seedlings, it was not possible to prescribe a rate of application per planted acre; instead, solutions of differing strengths were used, at 1 gallon of spray solution per 16 square yards of *Rhododendron*.

2,4,5-T was used at 3, 6, 12 and 24 lb. per 100 gallons of oil; dicamba at 2, 4, 8 and 16 lb. per 100 gallons of water; picloram at 1, 2, 4 and 8 lb. per 100 gallons of water; paraquat at ½, 1, 2 and 4 lb. per 100 gallons of water; and ammonium sulphamate at 1, 2, 4 and 8 lb. per 1 gallon of water. Sprays were applied either in September or December 1965, or March or June 1965.

The most successful treatments were the higher rates of 2,4,5-T applied in the dormant season; these gave good kill without affecting the crop, but some crop damage followed treatment in June 1965. Ammonium sulphamate also controlled the *Rhododendron* at the higher concentrations of spray solution, but at York, especially, there was extensive damage to the planted Scots pine. Tordon has been slow in action and has stopped growth in many cases, though the plants have been slow to die. Dicamba has also been slow in action but has achieved a slightly better kill than picloram. Both compounds have damaged the crop, picloram causing more severe crop damage than dicamba, especially to the Corsican pine at Ringwood. Paraquat has defoliated *Rhododendron* shoots but has had no effect on buds or stems, and there is more regrowth on such plants than any others.

At Bramshill Forest (Hants), Bedgebury (Kent) and in the New Forest comparisons were made of the effect on regrowth 2–4 years old from *Rhododendron* stools of sprays of 2,4,5-T in oil with 2,4,5-T in water. 0·35 per cent of sodium alginate was mixed in to thicken the spray solution in certain of the "2,4,5-T in water" treatments to increase the quantity of spray solution retained on the foliage. The concentration of 2,4,5-T used was high, ranging from 20–35 lb. per 100 gallons of spray solution. Some plants were sprayed in November 1965 and others in March 1966.

Two months after treatment, the water borne sprays applied in November had entirely defoliated stools and had given slightly better control than where stools had been sprayed with 2,4,5-T in oil. This difference is probably due not only to the diluent but also to the placement of the spray; the oil spray was applied to the woody stems and stools while the water spray was applied to the foliage. The alginate did not appear to make any lasting difference, though at Bramshill it appeared to bring about a quicker kill of foliage.

J. R. ALDHOUS

Woody Weed Control

Small trials early in 1966 at Alice Holt, and in the Forest of Dean, compared basal bark sprays of 2,4,5-T in oil with 2,4,5-T in water thickened with sodium alginate. Results so far favour the established technique of 2,4,5-T in oil.

J. R. ALDHOUS

Herbaceous Weed Control

Development of Spray Equipment

Paraquat was applied using a modified 'Arbogard' so that all the herbaceous weed round a plant could be sprayed from one position of the spray guard, instead of (as at present) having to spray half the vegetation from one side and the other half from the other side of the tree. It is expected that the prototype under trial will be available commercially late in 1966.

J. R. ALDHOUS
J. ATTERSON

Trials with Chemicals

A trial of 2,6-dichlorothiobenzamide at Brendon Forest confirmed previous results that damage to the crop, here Douglas fir, may occur with rates of 6 lb. active ingredient per acre or more, and that the best balance of absence of crop damage and adequate weed control is achieved when the herbicide (formulated as a 7½ per cent granule) is applied in April, at 4 lb. active ingredient per acre, rather than May or July, or in February. Casuron, also tested in this trial at 10 lb. in 40 gallons of water, was not effective against the mixed grasses and broadleaved herbaceous weeds present.

J. R. ALDHOUS

TREE STABILITY

Records of Windthrow

Reports of windthrow indicate that there were two damaging gales during the year: one on 31st October 1965 and one on 27th March 1966. Between them a total of 90 acres has been reported blown, which is appreciably less than the average figure for the four years since 1961.

Tree-pulling Investigations

During the year studies of rooting by tree pulling were completed on a number of sites which have been in hand for some time.

A series of studies were made at Halwill and Hartland forests in North Devon in which root development was compared on representative areas of each of the main soil types. The already well-established differences in rooting between freely-drained and badly-drained soils were found. The ill-drained soils were only rooted to 12 inches, although better rooting might have been expected in these southerly forests (because of greater drying out during the summer) than in the forests studied in the past.

Studies were made of the effects of ploughing on root development on well-drained and poorly-drained soils, at Carron Valley Forest (Stirlingshire). The results were inconclusive, though on the ill-drained soil the main roots tended to lie parallel with the ploughing, resulting in directional differences in resistance to overthrow. On the well-drained soils the rooting was more symmetrical.

At Lennox Forest (Stirlingshire) the root development of Norway spruce, Sitka spruce and Red alder was compared on a very wet gleyed soil. The roots of the two spruces were confined to the upper 12 in. of the soil, but the alder was rooting to 3 ft. The Norway spruce were slightly less resistant to being pulled over than the Sitka spruce, so that the smaller amount of damage incurred by the Norway spruce appears to be due to the fact that it is less tall than the Sitka, rather than to its being more resistant to windthrow.

Aerodynamic Studies

This year has seen the delivery of our first working automatic data logger, which is now installed in the experiment at Redesdale. Most of the 25 anemometers, 5 wind direction vanes, and 3 thermistors due to be connected to the logger, are actually wired up and recording. The anemometers will eventually be on 5 masts, 80 ft. tall, so that they can be placed well above the forest, but at the moment recordings are being made of the airflow within the forest.

The data logger scans 50 channels in 8 seconds, converts the analogue input to digits and punches the output on paper tape, suitable for direct feed into the computer. The logger is powered by car batteries.

Wind velocity profiles will be computed, thus enabling the 'roughness' of the crop to be estimated, and in due course different thinning regimes will be applied to the forest, so that differences in 'roughness', if any, due to thinning can be assessed.

One of the masts stands in the open well clear of the forest, and comparison with this will enable an estimate of the energy absorbed by the forest to be made.

A. I. FRASER

Wind-loosening of Lodgepole Pine

Wind-loosening in fast-growing Lodgepole pine of South Coastal provenances in exposed situations leading to basal bowing is a serious problem which is to some extent avoidable by the use of more northerly provenances. However, this entails very significant reduction in yield. It was shown in Forest Record No. 50, *Wind-loosening of Young Trees on Upland Heaths* (H.M.S.O., 2s. 0d.) that wind-loosening can be reduced on heaths by planting on the plough ridge rather than in the furrow, but on exposed peatland no experimental treatments (e.g. low rates and delayed application of phosphatic manure) have yet been fully successful.

A review of past experimental experience has been completed, and a new series of experiments at three forests is being planted in 1966 which will screen twelve treatments to determine which show sufficient promise to justify more intensive investigation.

S. A. NEUSTEIN

Miscellaneous

Extraction over Ploughed Ground

An experiment, planted in 1954 at Broxa (Allerton Forest, Yorkshire) and now due for thinning, has given a foretaste of difficulties which may arise on a large scale—namely the extraction across the high ridges produced by the R.L.R. plough. Manual movement of early thinnings will be easier parallel to the ridges, and hence collecting alleys for bulk extraction will have to be across them. As neither a horse nor a wheeled tractor could cope with the high ridges, Work Study advice was sought. Various solutions were considered, namely, winching, crawler tractor extraction, four-wheel-drive tractor extraction, and levelling with a light dozer followed by normal tractor extraction. The last-named was thought most promising and local trials are proposed.

Methods of Planting: High Turves

In normal peat afforestation the ground is prepared by ploughing either with a single mouldboard or a double mouldboard plough; the former producing a 'high turf' which is often cut down at the planting spot, whereas with double mouldboard ploughing the tree is planted directly into turf ribbon. In the course of an appraisal of wind-loosening of Lodgepole pine on peat, the question of the influence of planting method arose, and it was felt that knowledge of Conservancy planting methods was so incomplete as to be incapable of generalisation. In order to obtain information on the diversity of practice and the reason for it, a simple questionnaire was sent to the six northern Conservators, and Assistant Conservators in charge of planting were asked to give their views on current practices in their Conservancies. Two further reasons for the questionnaire were to determine whether new definitive experimentation was called for, and what scope there is for Work Study Branch to recommend changes based on the observed work content of different methods.

The answers received displayed a variety of motives for the use of the preferred methods (i.e. step or notch planting), but further experimentation is not appropriate until a mechanical modification of the plough, for reducing the size of high turfs (and thereby rendering stepping unnecessary), has been tested.

The results of the above questionnaire have been circulated departmentally as a Research and Development Paper (No. 30, entitled *Methods of Planting on Single Mouldboard Cuthbertson Ploughing*).

Mixtures of Lodgepole Pine and Sitka Spruce

There remains some uncertainty about the site type on which Sitka spruce cannot be readily established pure but where it will succeed in admixture with Lodgepole pine. Practically every attempt in experiments to produce Sitka spruce on infertile peat lands by nursing with Lodgepole pine has failed, but nevertheless large areas of mixtures are still being planted in some Conservancies on strongly held local opinion.

A preliminary survey of successful and unsuccessful occurrence of nursing has been carried out in the form of a questionnaire, and this is being followed up by a more detailed examination of sites which will be analysed by means of punched cards. Depending on the results of this analysis, experiments incorporating new mixture patterns using various Lodgepole pine provenances may be established.

S. A. NEUSTEIN

POPLARS AND ELMS

Poplar Varietal Studies

(1) *Varietal Trial Plots*

Selected plots were again assessed at major trials, notably clones in commercial use and a small number of others that are of interest because of their very rapid growth. Several of the most vigorous and oldest plots were pruned for the last time, in some cases to give a pruned height of about 30 feet, to serve as demonstrations to other poplar growers, and they will probably be assessed on only one more occasion before felling. They are plots 12 to 16 years old in which most of the trees are over 60 feet tall and have a lower stem large enough for the production of rotary peeled veneers.

Towards the end of the year, a clone of Italian origin that has been under trial for 15 years was added to the list of poplar varieties eligible for planting grants. Known for several years after its introduction as '78B', it is now called *P.* 'Casale 78' and, in continental literature, *P.* 'I-78'. It is a hybrid black poplar and is classified under the group name *P.* x *euramericana* (Dode) Guinier, along with other common cultivars such as *P.* 'Robusta' and *P.* 'Serotina'. Although it first reached this country in 1939, it was only included in major trials from 1951 onwards and was scarcely ever planted on the best ground. However, it was made available to a number of private growers in southern England, for use on a trial basis, and information from these plantings has supplemented data obtained from the varietal trials. Along with other clones of Italian origin, it was included in several northern trials but, like most selections from southern Europe that prefer a long and mild growing season, it has not been particularly successful in the cooler parts of the country. Though there are certainly fertile and sheltered sites in northern England and Scotland where performance might be acceptable, they are uncommon, and in most northerly conditions growth is likely to be slow and with frequent failure. For this reason *P.* 'Casale 78' will only attract grants in southern England, in East, South-East and South-West Conservancies and in the Surveyorships of the New Forest and Forest of Dean, where milder conditions prevail. Growth data collected during the year from trial plots at Bedgebury Forest, Kent, indicate that its production may be rather greater than most other hybrid black poplars in commercial use. The data in Table 8 are for 14-year-old trees; figures for *P.* 'Gelrica' and *P.* 'Androscoggin', both recognised as high volume producers, are included for comparison.

P. 'Casale 78' is easily propagated from nine-inch hardwood cuttings and vigorous planting stock can often be obtained in the first year. In the field it is straight-stemmed, comparing favourably with *P.* 'Robusta', and, unlike some other *P.* 'Casale' clones, its stem form is not seriously affected by exposure. It has relatively upright branches and in crown width is intermediate between *P.* 'Robusta' and *P.* 'Serotina'.

Pruning in trials has not presented any difficulty and, unless over-pruned, epicormic growth is usually light and may even be absent. Current experience suggests that it has a high resistance to bacterial canker, while none of the fungi attacking poplar in Britain has so far caused permanent damage. It comes into leaf shortly after *P.* 'Robusta', but well before *P.* 'Gelrica' and *P.* 'Serotina'.

TABLE 8

POPLAR TRIAL PLOTS : BEDGEBURY FOREST, KENT
HEIGHT, GIRTH AND VOLUME AT 14 YEARS

Clone	No. of trees per acre	Mean height (feet)	Mean breast height girth (ins.)	Basal area per acre (sq.ft.q.g.)	Volume per acre over bark (hoppus ft.)
P. 'Casale 78'	84	56·6	37·3	50·66	1,045
P. 'Gelrica'	101	53·9	39·2	67·22	1,210
P. 'Androscoggin'	67	63·4	38·0	42·16	1,065

Like other Italian clones, *P.* 'Casale 78' may continue growth into early autumn when unripened shoots may suffer frost injury; but recovery is usually good the following season and poorly formed stems and crowns seldom result.

(2) *Varietal Collection*

There were no additions during the year and, following the successful propagation of some 80 clones introduced in 1965, a start has been made to revise the clonal list. In 1964 a small number of plants was raised at Alice Holt from crosses between *P. maximowiczii* (female) and *P. trichocarpa* and *P.* 'Androscoggin' (male) and, in the year under review, they were made available to the Forest Pathologist for studies on bacterial canker. Both *P. maximowiczii* and *P. trichocarpa* tend to be susceptible to this disease. *P.* 'Androscoggin' certainly is, but the varietal collection includes three resistant forms of *P. trichocarpa* and one of *P. maximowiczii* apparently less susceptible than the rest. It is hoped by crossing these that some resistant progeny will be obtained, possessing the highly desirable attributes of *P.* 'Androscoggin'. Further crosses were made in the early spring of 1965.

(3) *Populetum*

Five clones were planted during the winter, bringing the total now established to 300.

Poplar Establishment Studies

(1) *Mulching*

Several experiments were closed during the year having fulfilled their objective. Of particular interest were the studies on weed suppression by mulching, in which mulches of different materials were maintained for varying periods after planting. These were conducted at Lynn Forest, Norfolk, and Creran Forest, Argyll, on sites on which the ground vegetation was predominantly grass. The mulches were used fertilizer bags, bark peelings and cut vegetation; the last two applied to different depths, and they were maintained for one, three and five years after application. The fertilizer bags were replaced when overgrown, and fresh material was added to the other mulches to maintain their initial thickness of 6 inches or 12 inches. The findings can be summarised as follows:—

(i) All mulch treatments significantly improved height growth, particularly in the early years after planting.

(ii) The 12-inch mulch promoted faster growth than the 6-inch mulch, for both cut vegetation and bark peelings, though differences in vigour became less pronounced after the fifth to sixth years.

(iii) Up to five years of age, the benefits due to mulching for five years were greater than those due to mulching for only one or three years; thereafter the differences became less marked.

(iv) At Lynn Forest, differences in height at nine years due to mulch treatment were not marked; at Creran Forest, differences were still apparent but were clearly becoming less obvious.

Associated work at Lynn Forest also indicates that if young poplar are mulched with bark peelings, growth can be further improved by applying ammonium sulphate, at 8 ounces per tree, either to the soil surface before placing the mulch or to the surface of the mulch soon after it has been applied. Rather faster growth was obtained up to six years of age by applying the fertilizer to the surface of the mulch.

(2) *Liming*

Experiments conducted on the responses of newly planted poplar to liming were also closed. These were located at Harling, Thetford Chase, Norfolk, on an acid fen peat soil of varying depth overlying sand that had a mean pH of 5·0 before treatment. In one experiment the amount of lime applied (3¼ tons per acre) was calculated to raise the pH to 7·0. In the second, varying quantities were applied (2, 3 and 4½ tons per acre) in order to compare the behaviour of poplar in soils having different pH values. In both cases the lime was applied at the time of planting.

In the second season, significant changes in pH value were detected in all limed plots; the range was from 5·9 to 8·1, and these were maintained into the sixth season. Assessments made annually of height growth showed, however, that tree vigour was unaffected by liming, and that even the heaviest application failed to promote additional growth. There were no variations in performance from one year to another, over the ten-year period during which the experiments were assessed. While these results are surprising, other experimentation has disclosed that in soil conditions normally considered marginal for poplar, that is with the pH between 5·0 and 5·5, significant improvements in growth rate can be obtained, without liming, by applying nitrogen, phosphate and potassium fertilizers to the young trees. In such conditions mulching also increases vigour without any adjustment of the pH value.

As poplar planting is not encouraged on very acid soils, the liming study has not been extended to other sites. Where planting is undertaken, however, the admittedly limited experience suggests that liming alone may be of little value in contrast with other well-tried treatments.

Spacing of Poplars

Assessments have again been undertaken in the major experiments. At Alice Holt Forest, where pulpwood production at close spacings is being studied, using *P. trichocarpa*, data collected at the end of the ninth year show that, although the stocking at a spacing of 9 feet is nearly three times that at 15 feet, the volume per acre is only twice that of the wider spacing. The relevant data are given in Table 9 below, from which it will be seen that height growth has not been affected by spacing. There are four plots for each spacing in the experiment, each plot extending to nearly one-fifth of an acre.

TABLE 9

HEIGHT, GIRTH AND VOLUME OF POPULUS TRICHOCARPA AT 9 YEARS

Spacing (feet)	No. of trees per acre	Mean height (feet)	Mean girth (ins.)	Basal area per acre (sq. ft. q.g.)	Volume per acre over bark (hoppus ft.)
9 x 9	538	36·6	18·5	80·162	1,060
12 x 12	302	37·8	21·5	60·702	780
15 x 15	194	37·0	22·8	43·650	540

Pruning of Poplars

Confirmation was obtained at Cannock Chase, Staffordshire, that heavy pruning may significantly reduce the rate of radial growth of young poplar. An early indication that this might happen was obtained at Alice Holt in 1963 and 1964; the findings were summarised in the Annual Research Reports for those years. At Cannock Chase, where pruning is taken to one-quarter, one-half and three-quarters total height at each pruning, carried out annually, bi-annually and tri-annually, it is not yet known if the effects on growth of heavy pruning are permanent, since treatments were started only three years ago. But two years after treatment trees which were pruned to only one-quarter total height were significantly larger in girth than those more heavily pruned. Height growth so far has not been affected by intensity of pruning, but there is a close relationship between the number of branches removed at pruning and the number of epicormic shoots produced in the season following.

Distribution of Poplar Cuttings

More than 19,000 nine-inch cuttings of the recommended clones were made available to trade nurseries and private estates during the winter. As in previous years *P.* 'Robusta' and *P. tacamahaca* x *trichocarpa* were in greatest demand. A further 1,300 cuttings were sent to research workers in the British Isles, Czechoslovakia, Germany, Holland and Turkey.

Bacterial Canker Investigations on Poplars

The testing of clones under trial, and of clones in commercial use, continued at Fenrow Nursery, Aldewood Forest, Suffolk, and at Blandford Forest, Dorset, respectively. Progress is summarised in the chapter 'Forest Pathology' on page 71.

Elm Clonal Collection

Further selections of English elm, together with a number of samples of elm imported from Holland for forest planting, have been introduced for disease testing and propagation studies. Since several clones are no longer being propagated the number under review remains at about 70.

Propagation of Elm

Although work continued to improve the 'take' of both hardwood and softwood cuttings, no useful progress can be reported. In particular, the study on hardwood cuttings has proved to be most disappointing, as although there have been occasional signs that certain techniques might improve rooting ability the results have not been consistent. None of the conventional pre-insertion treatments that have been tried, such as winter chilling and use of growth substances, has increased the amount of rooting, while controlled watering with bottom heat, used in the past season, has failed to improve survival. In the case of softwood cuttings the general techniques are well known, and studies in this field are largely devoted to determining propagation methods that can be used on a commercial scale. The growth of cuttings under mist, and the behaviour of the rooted plants after lining-out, are receiving especial attention. The possibility that different elms might require different treatments is also being considered.

Elm Establishment Studies

Experiments laid down at Alice Holt Forest in 1963 and 1964 have shown that well-grown rooted softwood cuttings survive well after planting and may begin to grow quickly even in the first season. Only small, one-year-old plants, which would not normally be planted out, have been difficult to establish. However, older stock has sometimes proved to be unstable after planting, and trees have had to be staked to keep them upright. The problem appears to be associated mainly with the use of tall planting stock that begins to grow quickly in the first year, but transplants in the nursery have also tended to blow over, and examination of their root systems has disclosed that there was little lateral development of roots at any depth. Other subjects propagated vegetatively, such as fruit trees, are also understood to be unstable after planting. An experiment planted at Alice Holt during the winter is designed to test the effects of deep planting and mounding on survival and growth as well as stability, while during the current season root development in the nursery, particularly of plants raised initially in pots, will be studied.

Elm Disease Testing

Thirty-four clones have been screened at Alice Holt for resistance to Elm disease, *Ceratocystis ulmi.* Five clones selected in Holland, and brought to this country for trial, have shown the greatest resistance; but four clones selected recently in southern England also have a good record over the three-year period in which tests have been conducted and, since one is a clone of *U. carpinifolia* that would be suitable for forest planting, the result is encouraging. Only one clone of English elm has been adequately tested, and this appears to be moderately susceptible to Elm disease; the two clones of Dutch elm so far tested are also susceptible.

J. JOBLING

FOREST ECOLOGY

Studies on Black Pine, Pinus nigra

Continuation work on the Black pines (*Pinus nigra*, sens. lat.) has attracted most attention from the Ecologist during the year. Recent provenance trials, located both in the north and in the south of Britain, and covering nearly all parts of the wide range, are providing much needed opportunities for phenological studies, and for comparative investigations of growth and of all-round ecological fit. In the past, the main problem associated with the cultivation of this tree in Britain has been the die-back disease prevalent on northern and mountain sites and associated with the fungus *Crumenula* (*Scleroderris*) *abietina*, more generally known by the name *Brunchorstia pinea* applied to the conidial form. Field work in all parts of Britain (in line with work in north-western countries of the European mainland), and the more detailed studies of Dr. Read at Hull on the relation between *Brunchorstia* outbreaks and certain environmental factors, have placed this problem in a clear setting, while at the same time drawing attention to some subsidiary features of Corsican pine ecology which are now being looked into.

One of these is the susceptibility of the young pines to frost during the vegetative period, in relation to the topoclimatological environment of replanted sites in Thetford Chase. Early losses have been severe; but bark-beetles and weevils, fungi, handling practice and (at a later stage) roe-deer are important, so that the particular significance of frost needs elucidation. There is ground for believing, too, that the local meteorological conditions of the regeneration clearings may prove unfavourable to *Pinus nigra* beyond the establishment stage (for example by creating a more congenial environment for *Brunchorstia pinea*): some current work aims at throwing light on this. A third issue concerns the production of fertile seed and the lack of natural regeneration (to some extent, no doubt, an independent issue). Some cones are produced each year, but the only abundant yield in the past 15 years was in 1961–62 (presumably connected with the brilliant summer of 1959). Cones are rather plentiful again in 1966, suggesting that the weather of 1964 (a dry summer and early autumn, though not specially sunny or warm) was almost equally favourable to flower production. The factors associated with germination and seedling establishment are certainly less simple and in need of experimental study.

J. M. B. BROWN

SOIL MOISTURE, CLIMATE AND TREE GROWTH

Soil Moisture and Evapotranspiration Studies

This year there are two notable developments in the soil moisture studies. The carry-over of a soil moisture deficit from 1964 into 1965 gave us an unusual opportunity to make an estimate of the water use of Corsican pine at Bramshill, Hants, for the nineteen-month period July 1964 to March 1966. Errors associated with the beginning and end of soil moisture deficit cycles should therefore affect this estimate less than earlier ones, and our present result is about 20 per cent lower than values previously obtained for Scots pine in the same region (Rutter and Fourt, 1965), a difference which could be accounted for by the differences in the seasons, a lower stocking density, and the inclusion of a complete winter. The indication remains that the pine uses more water than grass.

The progress of our work, however, depends very much on accurate and regular measurements of soil moisture, and to this end the adoption of the neutron moisture meter for our studies is a most significant development. Indeed, in a few years we expect to learn as much about water use of forest crops as might have taken a decade or more by older methods. The instrument and its advantages are described below, and it is illustrated in Plates 1 and 2—see central inset. The introduction of the technique has required considerable reorganisation and, as will be seen from the account below, we have been very much occupied with technical matters appertaining to the new instrument. Consequently it has been impracticable to embrace any new sites, though the routine readings of soil moisture, soil temperature, rainfall and tree growth have been maintained as described in previous reports.

Bramshill Forest, Hants
Estimate of Water Use of Corsican pine

After what may be called a false start in April 1964, the soil at a depth of a foot commenced drying rather abruptly in July of that year; prior to this time rainfall slightly exceeded water use. This well-defined date is a regular feature of the drying phenomena of forest soils and has been illustrated in previous Reports (see *Reports on Forest Research* for 1963 and 1964). The soil, which is a sandy podsol, became moist again the following winter, but the wetting fronts which moved down the profile did not penetrate below about four feet and the lowest part of the profile continued to dry very slightly all winter.

Although the following summer was much less dry than 1964, and drying started with a deficit from the previous year, the combined deficits were not completely satisfied by heavy rain during winter 1965/66. In spring 1966, rainfall was fairly low and again exceeded water use by only a small amount. This caused the final stages of rewetting to be approached reasonably slowly. At this stage the soil moisture storage in the profile is conceived to be similar to that of July 1964, and during the intervening period of nineteen months the total water use (by which we mean evaporation from the soil, evaporation of water intercepted by the crop and ground vegetation, and the transpiration) is equal to the total rainfall.

TABLE 10

CORSICAN PINE, PLANTED 1924, YIELD CLASS 240

POTENTIAL EVAPORATION AND RAINFALL IN INCHES OF WATER

Period of Deficit	Profile I E_0	Profile I Rainfall	Profile II E_0	Profile II Rainfall	Profile III E_0	Profile III Rainfall	Profile IV E_0	Profile IV Rainfall
July 1964	2·56	0·29	4·21	0·96	3·61	0·64	3·61	0·64
Aug. 1st–Feb. 28th, 1966	34·23	38·58	34·23	38·58	34·23	38·58	34·23	38·58
March 1st–31st, 1966	1·86	0·55	—	—	—	—	1·86	0·55
Totals	38·65	39·42	38·44	39·54	37·84	39·22	39·70	39·77
Ratio $\frac{\text{Rainfall}}{E_0}$	1·02		1·03		1·04		1·00	

Notes: (1) E_0 = Potential evaporation from open water over the period.
(2) Rainfall = Evapotranspiration for the forest crop.

Table 10 shows the rainfall for four slightly different periods corresponding to the soil drying cycles in four profiles in the stand where gypsum blocks were emplaced. The positions for these four profiles were chosen as representative of the site, rather than at random. The values of E_0 were computed by the Meteorological Office for the same periods. The ratios Rainfall: E_0 for these points are in good agreement, and the mean ratio is 18 per cent lower than the value Rutter and Fourt (*loc. cit.*) obtained for shorter periods for several sites and seasons at Crowthorne, also in Bramshill Forest, Hants.

The main likely sources of error are failure to include moisture rising into the profile from the water table at about 12 feet, and the inclusion of water which leaves the profile by continued drainage in the spring. The former we consider insignificant for reasons similar to those discussed by Rutter and Fourt, and while gains or losses of water in the lower parts of the profile during the period of moisture deficit cannot be ruled out, their net effect on the result is likely to be small. The interest in the present result lies in the fact that errors due to these causes affect our ratio less because of the longer period. Since the value is almost within the range reported by Rutter and Fourt, it would be unwarranted at this stage to read too much into the difference; we would, however, accept the value as a good estimate for pine in north-east Hampshire for the period in question.

Notes from the Routine Records at Bramshill

Drying patterns revealed by transects between trees have again confirmed that drying is more severe at depth "underneath trees" than "between trees". A large soil moisture deficit was achieved in a plot of Corsican pine which was roofed over to prevent entry of rainfall. However, the growth of the trees in this plot was hardly reduced compared with adjoining trees subject to normal moisture conditions. This is all the more striking since it is the second season that the trees in the roofed plot have been subjected to artificial moisture deficits. It would be unwise to assume that pines in other soils or climates would have given a similar result. The blocks in the Douglas fir stand showed very little soil drying this season. The overall growth of both species was better than in 1964.

Buriton, Queen Elizabeth Forest, Hants

The records of rainfall, soil moisture block resistance, and vernier girth band readings were continued on the chalky rendzina sites for the fourth season. The main comparison is between the water regimes of a grassy area, and that in a 30–35 foot-tall beech stand planted in 1932. There are also useful similarities between the wetting and drying patterns here, and those at Thetford, where the rainfall is about half that measured at Buriton.

As at Thetford, there were signs that the deeper levels of the chalk were less than fully saturated at the commencement of the growing season in 1965. However, the wet summer seems to have prevented soil moisture stresses building up in the growing season; the months of June, July, August and September each received between 3·5 and 6 inches of rain, with 18·7 inches during the four months.

Tree growth, as registered on the vernier girth bands, was poor, all the banded trees growing less than in 1964, the average being the lowest in the four seasons. Soil moisture conditions under the grass showed hardly any change throughout the summer from the usual winter levels. The complete absence of any obvious correlation between growth and rainfall for the four years seems worth noting.

Feltwell, Thetford Forest, Norfolk

Observations have been maintained. The moisture tension in the lower part of the profile did not fall to the usual winter value in 1964/5. However, in 1965 the growth of Corsican pine was better than in the previous year.

Rendlesham, Aldewood Forest, Suffolk

Compared with 1964, Corsican pine grew more uniformly over the season, and both it and Douglas fir put on a higher annual increment.

Burley, New Forest, Hants

Growth of the pine (Corsican/Scots mixture) was well maintained throughout the growing season, but the total increment was only very slightly better than in 1964, in contrast to the East Anglian sites. Very little drying was evident in the Sitka spruce stand. There was moderate soil drying in the pine.

Drainage Studies

Observations of the effects of drain spacing and mole ploughing on run-off and water tables, by the use of flow gauges and boreholes, have been continued. The site is a heavy silty clay, formerly derelict pasture, at Halwill Forest, Devon (*Report on Forest Research* for 1963).

Compared with borehole levels before treatment, all drain spacings have been highly effective in reducing winter water levels, and the mole ploughing treatment is still effective after four years. Flow gauge records are maintained for three drain spacings, with and without mole drains, making six instruments in all.

In 1965 neutron moisture meter access tubes were also installed.

Instrumentation and Techniques

Resistance Bridge

The latest design has been thoroughly tested, and has been in routine use for measuring the resistance of gypsum blocks and thermistors for two years (*Report on Forest Research* for 1963). A paper describing it was published during the year (Kitching 1965).

Soil Sampler

The soil sampler, described in last year's *Report*, has been improved by making the cutting head slimmer. This results in easier insertion into and extraction from the soil, so the whole process is less tedious.

Data Logging

Further tests have been made on the commercial automatic field recording device mentioned in last year's Report, but the system is still not reliable enough for field use. Tests, for the Statistics Section, have also been made on a hand-held magnetic-tape data-capture instrument imported from the U.S.A. The instrument worked well, but had the disadvantage that figures, once recorded, were not visible for checking by the field operator.

Neutron Moisture Meter

A neutron soil moisture probe was acquired in the spring of 1965 and has been used during the past year to assess soil moisture at a number of sites. The features of the system are as follows:—

The equipment consists of the probe itself together with a protective shield which fits over the ends of the access tubes, a scaler unit to record the neutron count rate, and a 6-volt lead-acid battery to provide the power; the total weight is 25 kg. (around 50 lbs.). These items have been mounted on a wheelbarrow frame for easy transport by one man through the forest (see Plate 1).

The probe contains a source of fast neutrons, together with a slow neutron detector. This probe is lowered on a cable into an access tube which is permanently installed in the soil (see Plate 2). The fast neutrons are slowed (moderated) by collision with atomic nuclei, and hydrogen nuclei do this much more effectively than the nuclei of other elements. The resulting slow neutrons are then measured by the detector, which passes electrical pulses through the cable to the measuring unit at the soil surface. Most of the hydrogen present in soils occurs in water, so the slow neutron count depends very largely on the amount of soil moisture present. Hydrogen occurring in other forms, and also neutron absorbers (e.g. boron), affect the absolute slow neutron count rate but have little effect on assessments of changes of soil moisture in the same soil.

The method causes less disturbance to the soil than most other methods, nearly all of which involve the insertion of an instrument into the soil and then repacking the soil behind it; it is difficult to recreate the natural degree of packing, and any alterations may cause abnormal movements of soil moisture.

The neutron probe samples a relatively large volume which is a rough sphere of soil about 30 cm. in diameter. This large sample helps to smooth out horizontal variations of soil moisture, but appreciable moisture gradients in the soil result in a small negative error.

Repeated measurements may be made at the same place, thus minimizing errors due to the variability of soil from point to point. The instrument is equally sensitive over the range of moisture contents met with under natural conditions, and may be conveniently calibrated in terms of the gravimetrically assessed moisture contents. A separate calibration is necessary near the surface of the soil due to the escape of fast neutrons; a special reflecting shield may also be used for the surface measurements. The vertical access tube enables accurate depth measurements to be made, and soil moisture measurements may be made at as many points down the profile as desired.

The following technique has been devised to install the access tubes (see Plate 2). A soil auger is used inside an open-ended stainless steel cutting tube pressed vertically a short distance into the soil. Alternate augering and pressing is done until the required depth is reached. It has been found helpful to use a sequence of augers and tubes of one, two and three metres length to avoid working at an inconvenient height above the ground. On removal of the cutting tube the hole is inspected carefully from the surface, using a torch. If any cavities exist in the walls of the hole, due to stones being dislodged, the soil is repacked carefully in sequence into the hole. The auger and tube are then used as before, which yields a smooth-walled hole, and since little of the repacked soil remains in the hole the disturbance is minimal. Finally, an aluminium alloy tube 4·45 cm. in diameter and of appropriate length, with a plugged lower end, is pushed carefully into the hole, and closed with a rubber bung under which hangs a bag of silica gel. The bung is flush with the soil and is covered over with litter.

Experience over the past year has enabled our own staff to service the neutron probe and associated equipment. This is a great advantage since it helps to ensure uninterrupted measurements throughout the year. The radioactive source is a potential hazard to health and strict precautions must be observed in its use. All staff using the equipment are Designated Radiation Workers and wear film badge dosimeters to measure exposure to gamma and neutron radiation. So far no exposures reaching the threshold for detection have been found.

As well as installing access tubes at experimental sites, a calibration programme has been pursued. After measurements with the neutron probe, soil samples have been taken adjacent to several access tubes, using the sampler described above. Comparison of the neutron count rate with the moisture content obtained by oven-drying the samples, has revealed that the calibration of the neutron probe varies little at the present experimental sites. However, it is intended to make further measurements over a range of moisture contents at all sites where the neutron probe is used.

Plate 3 (see central inset) shows the form in which soil moisture profiles may be plotted. Three profiles are shown, for 22nd April, 3rd June and 23rd July, 1965, for one access tube in a Sitka spruce plot at Burley, New Forest. Profiles are assessed more often than this, but for clarity only three are shown. Below 40 cm. drying is progressive with time, but heavy rainfall caused a large increase of soil moisture on 23rd July.

Garnier Gauge Records

During 1965, records were kept of additions and leachate volumes from the pair of similar Garnier gauges at Alice Holt Lodge, as in previous years (*Reports on Forest Research* for 1962–1965). The summer six months were dull and moist, and apart from about a fortnight in August there were no dry periods of more than six days. In particular the July sunshine was much below average.

There were no difficulties at either end of the year due to frost or snow, and the grass mowings were carried out without drastic alteration of conditions. The effects of dry surrounds were probably very small.

Table 11 shows the results for 1965 in the same form as in previous years, except that the quantity previously termed "potential evaporation" is now more correctly termed "potential evapotranspiration".

TABLE 11

GARNIER GAUGE RECORDS – ALICE HOLT, 1965

Month		Potential evapotranspiration (ins.) (E_t)			Rainfall at Alice Holt (ins.)	Sunshine, daily mean hours	
		Lysimeters		Calculated value*		Normal from tables	Actual 1964
		A	B				
January		0·31	0·10	0·25	3·06	—	2·15
February		0·56	0·52	0·40	0·39	—	1·55
March		1·16	1·34	1·00	2·75	—	4·80
April		2·44	2·28	1·96	2·05	5·05	5·15
May		3·20	3·04	3·03	1·65	6·20	6·15
June		2·95	2·61	3·43	2·59	6·90	6·20
July		3·37	3·03	3·12	2·93	6·50	4·45
August		3·05	2·71	3·07	2·29	6·30	6·10
September		2·18	1·79	1·65	4·37	4·60	4·60
October		1·17	1·21	0·65	0·50	—	4·50
November		0·87	0·71	0·20	3·62	—	3·10
December		0·35	0·80	0·15	5·25	—	2·15
Total 1965		21·61	20·14	18·91	31·45	—	—
Summer months		17·19	15·46	16·26	15·88	5·93	5·44
5-Year Average	Total	21·76	20·67	19·29	29·49	—	—
	Summer Months	18·57	17·63	16·64	14·32	5·93	5·60

*See Technical Bulletin No. 4, Ministry of Agriculture 1954, entitled: *The Calculation of Irrigation Need.*

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W. H. HINSON, R. KITCHING,

and D. F. COURT

FOREST GENETICS

Register of Seed Sources

The full revision of the Register of Seed Sources and Seed Stands was completed during the year and either the whole Register, or appropriate parts of it, will be issued to field staff and to members of the Tree Seed Association during 1966. The procedures for surveying, and the registration of, seed sources and the policy for the selection of seed sources have been revised. The more important aspects of seed source selection, classification, categorisation and methods to be used in converting seed sources into seed stands, have all been given attention in the revised procedure.

In the course of the year one hundred and fifty acres of Category 'D' coastal Washington Lodgepole pine seed sources were registered, all of which are under ten years old. They will be intensively managed for seed production by repeated heavy thinnings aiming at isolating the best phenotypes and, where necessary, fertilizer applications will be made to encourage flower and cone production. As a result of this effort, it is hoped that our present heavy dependence upon foreign suppliers of seed of this important provenance will be greatly reduced during the next five to ten-year period.

Seed Crops

1965 was a good seed year for larch, Douglas fir, Sitka spruce and beech on low elevation sites with southern aspects in central, eastern and some southern areas of Scotland, probably as a result of the warm and dry late summer of 1963. Pine seed crops were light to moderate throughout Scotland and England. Full advantage was taken of the heavy Douglas fir crops on many of the plus trees, and some 58 separate cone collections were made, mostly in central Perthshire, Aberdeenshire, Inverness, Moray and Nairn for use in future one-parent progeny trials.

Scots pine clonal seed orchards at Bradon, Wiltshire; Lynn, Norfolk; and Ledmore, Perthshire, which were planted in the period 1956/57, and the Hybrid larch seed orchards at Newton, Morayshire, which were established in 1952 and 1958, all produced commercial quantities of cones.

During June a new procedure for the assessment of cone crops in seed stands was tried out, on quite a wide scale, in collaboration with the Silviculture Sections. The procedure is based on actual cone counts on forty sample trees in each seed stand over five acres in size. Fewer sample trees are used in smaller stands. Ten trees in each of four circular sample plots located at random, one in each quarter of the seed stand, are selected, marked and numbered. Cones on the sun-lit part of the crown are counted, with the aid of x 10 binoculars, and recorded. The number of cones per acre for practical collection is calculated on the basis of the product of the observed cones and the number of seed trees per acre, multiplied by a correction factor. The estimated collectable cone crop will be compared with the actual cone collections over several years, the data obtained being used for calculating an improved correction factor. The recorded information for several species, covering a period of ten to twenty years, will provide much needed reliable data on periodicity both between, and within, populations.

The Breeding Register

A permanent Breeding Register was designed and brought into use during the period 1962/63 for each species on which breeding work had begun. This Register is in loose-leaf form, having a separate page for each plus tree, on which are recorded:—

(a) The location (by estate name or forest);

(b) The clonal seed orchards and tree banks in which ramets are established;

(c) Serial numbers and brief details of the crosses in which the plus tree has been used as a parent;

(d) The nursery and forest experiments in which the progenies resulting from open or cross-pollinations have been established.

Copies of the Breeding Register are held at Alice Holt, and also at Edinburgh for safety purposes. At present some 1,000 changes or additions to this Register are required annually.

In order to reduce the amount of work connected with the updating of the duplicate copy, a new Abbreviated Breeding Register has been produced on punched tape, suitable for processing by the Sirius computer at Alice Holt. The master tape, which can be rapidly updated at several important stages during the year, also indicates the general performance of progenies based on assessments at 6, 10 or 15 years following planting. Several copies of the print-out data, which is presented in list form, can be produced. The master tape may be used by the computer for producing a wide range of summarised statistics. A small part of a print-out of the Abbreviated Register for Scots pine is illustrated in Plate 5 (see central inset).

Vegetative Propagation

Natural layering of both young and old Sitka spruce trees has been observed on moist sites where branches are in permanent contact with the soil—particularly if the soil has a high peat content. An exploratory trial of air-layering was carried out in late June 1964 on two 25-ft. tall, and one 60-ft. tall, ride-side trees growing in Grizedale Forest, Lancashire, to see whether this technique could be successfully used for plus tree propagation. The air-layering treatments were applied to the previous year's terminal shoots in the upper third of the crown. They consisted of either the complete removal of a ½-in. to 1 in.-wide ring of bark, phloem and cambium tissues, or an upward sloping cut 1½ in. to 2 in. long, in which the cut surfaces were wedged apart, using a sl ver of wood. These two treatments were factorially combined with applications of indol-acetic acid (IAA) in talc at concentrations of 0·8%, 1·5% or 3·0% IAA. The air layers were completed by placing damp (squeeze-dry) *Sphagnum* moss around the cut surfaces and sealing them inside a sheath of ·004–·006 inch gauge transparent polythene film, firmly secured to the branch at each end to prevent moisture loss.

The rooting was assessed after fifteen months, when it was found that none of the ring-wounded treatments had rooted. The wedge-cut treatments, however, were highly successful on two of the three trees. The concentration of IAA did not show any consistent trends for all three trees. Table 12 summarises the results of the successful wedge-cut treatments. A more detailed investigation into air layering is to be undertaken in 1966.

TABLE 12

SUCCESSFUL AIR-LAYERS RESULTING FROM WEDGE-CUTS TREATED WITH 3 CONCENTRATIONS OF IAA 18 MONTHS AFTER TREATMENT

Tree	Active IAA per cent	No. of successfully rooted air layers	% Success	Mean %
A – 25 ft. tall	0·8 1·5 3·0	5 3 4	100 60 80	80
B – do.	0·8 1·5 3·0	3 1 0	60 20 0	27
C – 60 ft. tall	0·8 1·5 3·0	5 5 4	100 100 80	94

Following the success of rooting Sitka spruce cuttings, which was reported last year, cuttings from the twelfth internode from the top of sixteen candidate plus trees were collected in late September and inserted into a 3:1 mixture of sand and peat, at a temperature of 70°F, in the growth-room at Grizedale, under a 20-hour photo-period. This experiment should give some indications on the clonal variation in rootability, and at the same time confirm the results obtained in 1964/65.

Glasshouse Investigations

As the first phase in the development of suitable early-test procedures, a small preliminary trial was undertaken at Alice Holt to study the suitability of Lodgepole pine and Sitka spruce as subjects for intensive methods of raising under glasshouse conditions, in which both temperature and photo-period can be partially controlled. Since this was the first experiment in the glasshouse, several modifications had to be made to the control equipment and cultural techniques during the season. The experience gained has been invaluable and showed that Lodgepole pine seedlings are unsuitable for raising under the conditions provided, mainly because they produce several growth flushes. Sitka spruce, on the other hand, seems to be more promising.

The experiment was a simple one using five different types of container for raising the seedlings before potting-up into five-inch clay pots; of these, clear, three-inch deep P.V.C. trays and individual 'Jiffypots' (peat pots) proved most satisfactory. The seed for the experiment was obtained from open pollinated flowers; it was collected from two Sitka spruce candidate plus trees and two Lodgepole pine plus trees. Large variations in vigour, stem straightness and branching habit were found in the Sitka spruce progenies. A proportion of the plants showing average and extremes in variation have been repotted in ten-inch pots to grow-on under glass for a further year. Other similar plant material has been planted in the open nursery. Further measurements will be made in subsequent years, to determine whether the early features of stem straightness, vigour and branching habit are maintained.

During the experiment several detailed assessments of the growth habit of the progenies were made, and a standard assessment method has been devised which will be used in future glasshouse experiments involving progenies.

A second series of experiments was sown in January 1966, based on the initial experiment. The first of these employs seed from twelve open-pollinated candidate plus trees of Sitka spruce, and will test the new techniques with a wider range of material. The second experiment aims to develop techniques for raising European, Japanese and Hybrid larch progenies. Because of limited space, only two progenies of each species are being used in this preliminary trial.

Staff Changes

During the year Mr. R. T. Wheeler, who has contributed much to the development of safety equipment for cone collection purposes, techniques for obtaining 12 mm. cores from standing trees, and the reorganisation of the Register of Seed Sources, was transferred to the Education Branch. Mr. G. C. Webb was transferred from Grizedale to Westonbirt to take charge of all field work connected with the Genetics Section in South Wales and S.W. England. Mr. Webb was replaced at Grizedale by Mr. D. S. Coutts on transfer from Conservancy duties in North Scotland.

R. FAULKNER, R. B. HERBERT

and A. M. FLETCHER

FOREST PATHOLOGY

Death and Decay caused by Fomes annosus

Most of the work on *Fomes annosus* (Fr.) Cooke, in the past season has been on biological control in pine crops in both the first and second rotation, using the competing fungus *Peniophora gigantea*, and on measures to reduce *Fomes* losses in second rotation pine on alkaline sites.

Over a number of years, a series of experiments has been laid down to study the problems of *F. annosus* in second-rotation sites already infested by the fungus. Treatments have included girdling and poisoning of the trees of the previous crop before felling, chemical treatments to stumps after felling, and stump removal by winching and by heavy lifting equipment. Nine years after replanting took place in the first of these experiments, losses caused by *F. annosus* have now reached 48% in the untreated control plots, and deaths are still occurring. Of the treatments tested, only stump removal (in this case by winching) significantly reduced the losses in the plots, 18% of the second-rotation trees being killed so far in the plots from which the stumps were extracted. Stump removal can now be carried out more effectively and more cheaply by means of the heavy earth-moving equipment used in later experiments now in progress. Such equipment may make it economically possible to remove stumps on heavily infested sites, on which severe losses through attack by *F. annosus* are otherwise inevitable after replanting.

In later experiments carried out on the same problem, inoculation of stumps with *Peniophora gigantea* has given promising results. In a preliminary assessment of one of these trials, roots were excavated 5½ years after inoculation, and their cross-sections examined for *F. annosus*. The area covered by the latter fungus in the stumps treated with *P. gigantea* was only 61% of that in the untreated ones. It is still too early to judge the practical value of this inoculation, the full effects of which will be better shown in a few years time by a comparison of losses in the trees planted in the plots in which this and other treatments were used. It is unlikely that inoculation with *P. gigantea* will prove as effective as stump removal, but it may well be a reasonably good and very cheap alternative on sites on which infestation is relatively low, or where stump extraction is difficult, or too costly to be contemplated.

Establishment of Corsican Pine in the Second Rotation

Studies were continued on sites in which it has been found difficult and expensive to establish Corsican pine in the second rotation. These investigations made clearer the importance of low temperatures as a factor additional to attack by *Fomes annosus* and damage by insects, both of which are associated with the stumps remaining from the first rotation. Plants in test plots set up on sites with a range of ground conditions showed variations in growth and extent of frost damage that correlated well with temperature observations. Growth was checked and damage by frost was observed on those sites on which the temperature on cold nights was reduced by a heavy grass mat, or a layer of deep litter or brash, all of which insulate the mineral soil and limit heat exchange. Where cultivation or deep ploughing resulted in the exposure of bare soil, markedly higher temperatures and better growth were recorded, as

PLATE 1. Hinson, Kitching and Fourt: Soil Moisture and Tree Growth (p.60).

Neutron soil moisture measuring equipment. On the right is the shield containing the probe. The end of the shield is fitted over an access tube inserted into the soil.

PLATE 2. Hinson, Kitching and Fourt: Soil Moisture and Tree Growth (p.60).
Installation of access tubes for use with neutron soil moisture measuring equipment. A soil auger, an access tube and a cutting tube are shown.

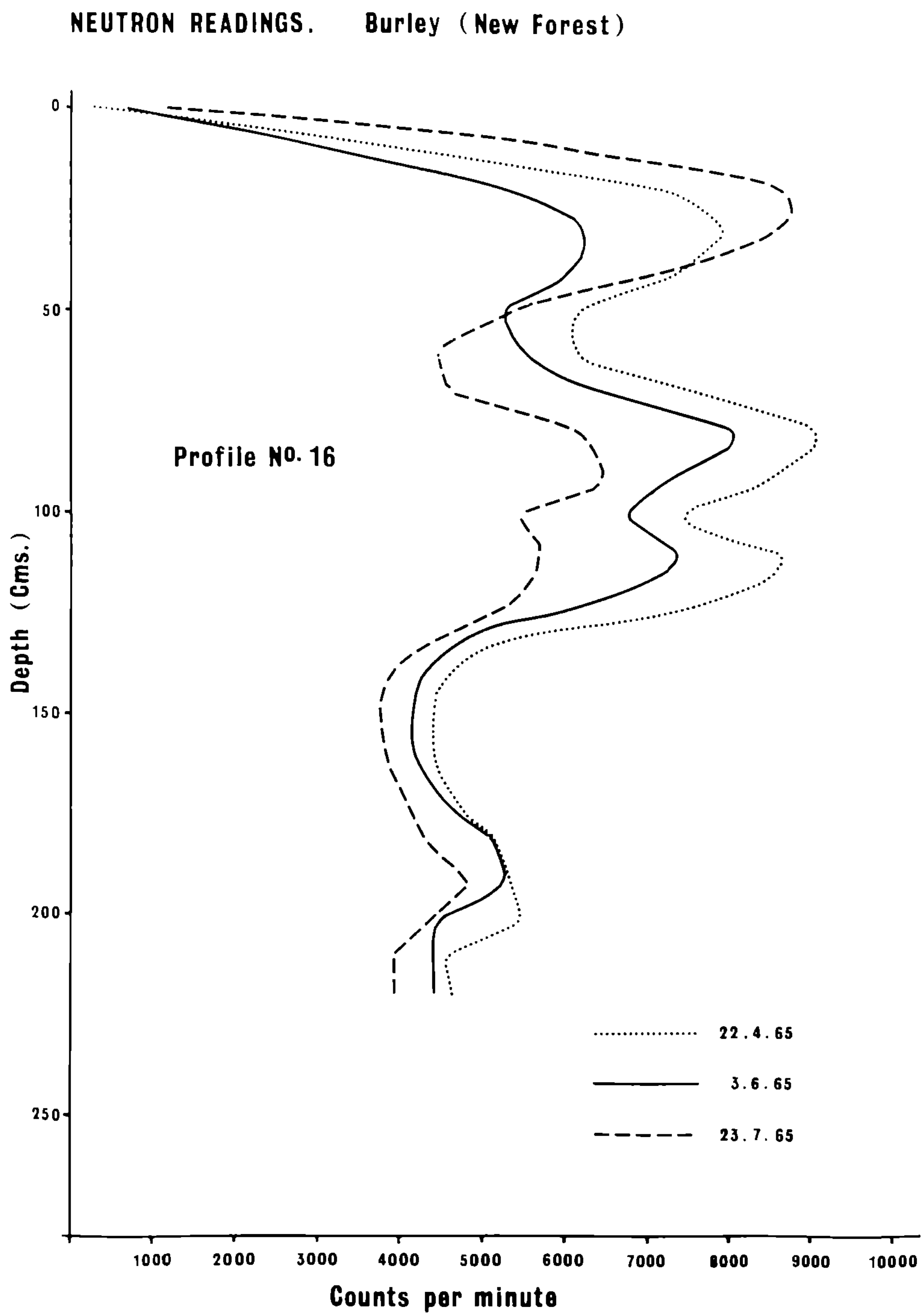
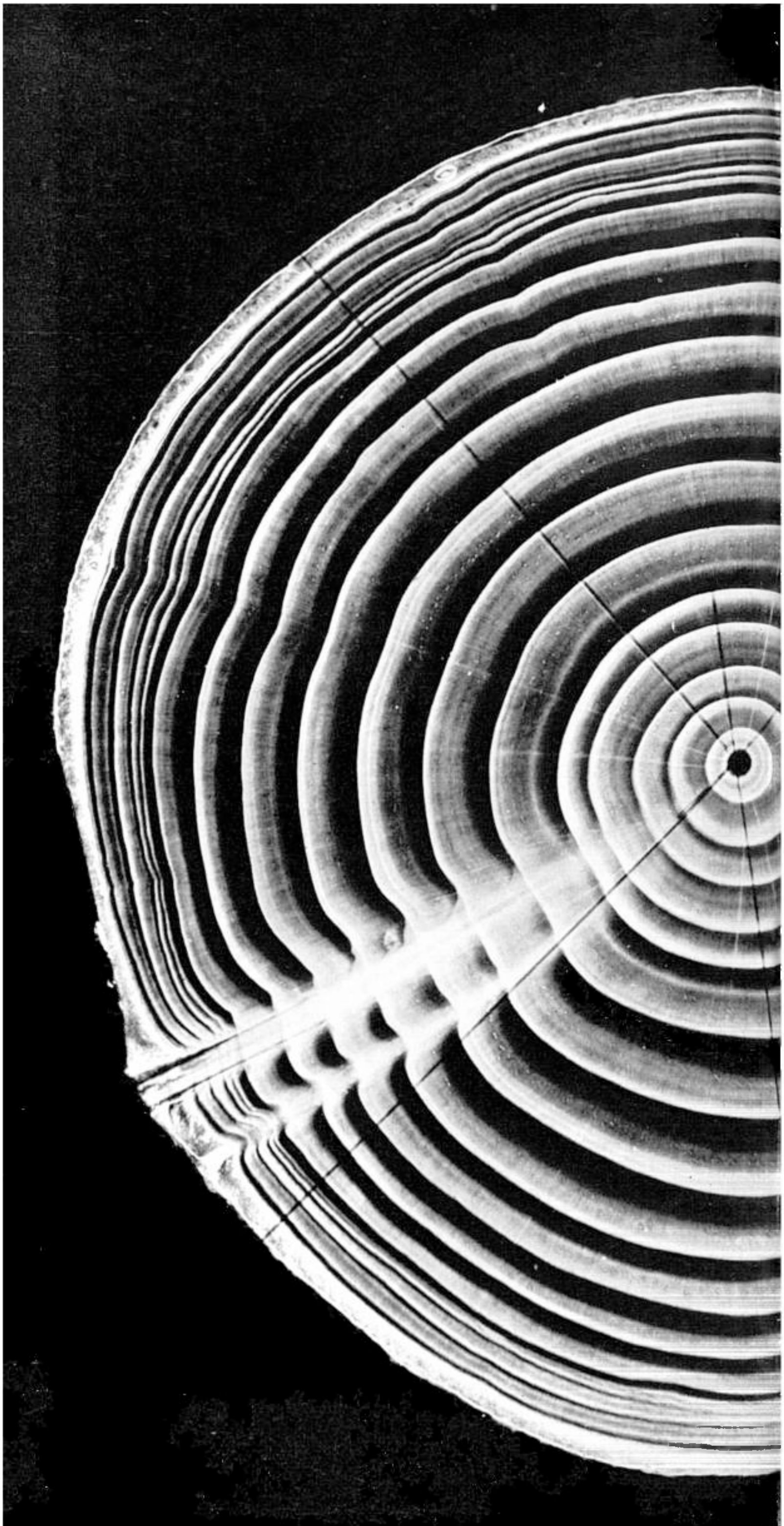


PLATE 3. Hinson, Kitching and Fourt: Soil Moisture and Tree Growth (p. 60).
Neutron readings. Burley, New Forest.



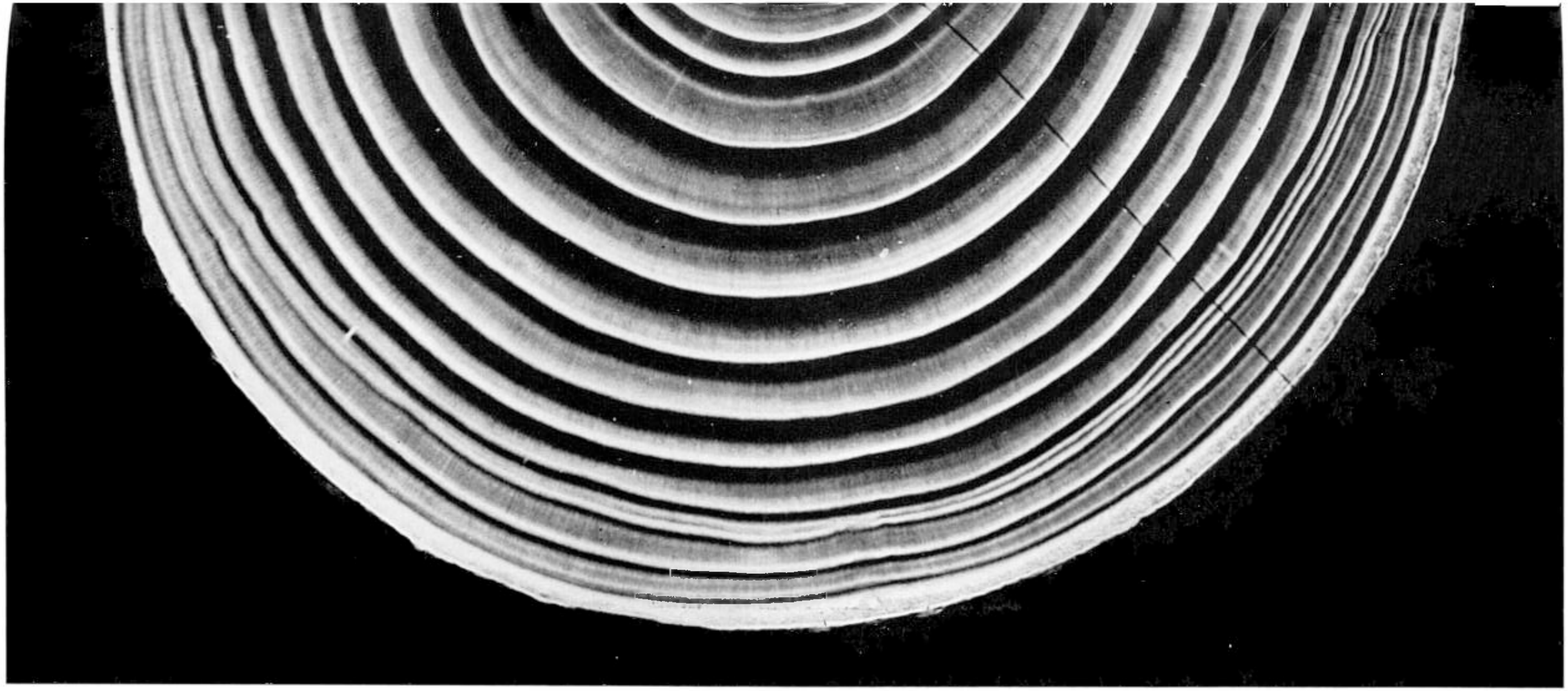


PLATE 4. Bevan: Forest Entomology (p. 75).

Radiograph of Sitka spruce disc (x 1.4) taken early in 1964 at Alice Holt, showing poor growth ring of 1961 (third ring in from bark), due to the combined effects of severe *Elatobium* insect defoliation and late May air frosts. (N.B.—In this picture the outer zone of each annual ring, i.e. the summer wood, registers as a *pale* band.)

SCOTS PINE PLUS TREE STATE AT 1. 3.1966

a	b	c	d	e	f	ghijkl	m n o	m n o	m n o	m n o
1	O		DARNAWAY	MORAY	N(S)	B10PPS	57GL R	57KM W	57CH W	57GH O
							0000 O			
2	O		DARNAWAY	MORAY	N(S)	B10000	0000 O			
3	O		DARNAWAY	MORAY	N(S)	B10P00	58TE W	0000 O		
4	O		DARNAWAY	MORAY	N(S)	B10P00	57GL R	57KM R	57CH W	57GH O
							0000 O			
5	F		DARNAWAY	MORAY	N(S)	B30000	0000 O			
6	O		DARNAWAY	MORAY	N(S)	V00PP0	0000 O			
7	O		DARNAWAY	MORAY	N(S)	B100P0	0000 O			
8	O	*	DARNAWAY	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
9	O		DARNAWAY	MORAY	N(S)	B10PX0	57CH Y	66AD O	66SP O	66EL O
							66BR O	0000 O		
10	O		DARNAWAY	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
11	O		DARNAWAY	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
12	O		DARNAWAY	MORAY	N(S)	B10P00	58TE Y	0000 O		
13	O		DARNAWAY	MORAY	N(S)	B10000	0000 O			
14	O		DARNAWAY	MORAY	N(S)	B10P00	57GL R	57KM R	57CH W	57GH O
							0000 O			
15	O		DARNAWAY	MORAY	N(S)	B10PP0	57GL W	57KM R	57CH Y	57GH O
							0000 O			
16	O		DARNAWAY	MORAY	N(S)	L00P00	57GL W	57KM W	57CH Y	57GH O
							59CL W	0000 O		
17	O		DARNAWAY	MORAY	N(S)	B10P00	57CH R	66AD O	66SP O	66EL O
							66BR O	0000 O		
18	O		DARNAWAY	MORAY	N(S)	B10P00	57GL Y	57KM R	57CH W	57GH O
							0000 O			
19	O		DARNAWAY	MORAY	N(S)	B10PP0	58TE R	66AD O	66SP O	66EL O
							66BR O	0000 O		
20	O		GRANT.	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
21	O		GRANT.	MORAY	N(S)	B10PP0	66AD O	66SP O	66EL O	66BL O
							57CH R	0000 O		
22	O		GRANT.	MORAY	N(S)	B100P0	0000 O			
23	O		GRANT.	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
24	O		GRANT.	MORAY	N(S)	B10PPS	66AD O	66SP O	66EL O	66BL O
							0000 O			
25	O		GRANT.	MORAY	N(S)	B10P00	57GL W	57KM R	57CH Y	57GH O
							0000 O			
26	O		GRANT.	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
27	O		GRANT.	MORAY	N(S)	B10P00	57GL W	57KM R	57CH R	57GH O
							0000 O			
28	O		GRANT.	MORAY	N(S)	B10P00	66AD O	66SP O	66EL O	66BL O
							0000 O			
29	O		GRANT.	MORAY	N(S)	B10PP0	66AD O	66SP O	66EL O	66BL O

PLATE 5

Plate 5

Part of the Computer Print-out of the first page of the Abbreviated Scots Pine Breeding Register as at March 1st, 1966. (see page 67)

Key to column headings:

Description

a. Plus Tree Number.

b. O = Forest or Plantation Selection.
   F = Selection from a Progeny trial.

c. * = Indicator mark signifying that data has been amended or updated since last revision.

d. Forest or estate name on which the Plus Tree is growing.

e. County do. do.

f. Conservancy do. do.

History

g. O = Not vegetatively propagated.
   V = Currently under vegetative propagation.
   B = Established in a Tree Bank.
   L = Parent tree lost before vegetatively propagated.

h. O. = Not yet established in an untested clonal seed orchard.
   1–9 = Numbers of clonal seed orchards in which it is represented.

i. O = Not yet established in a tested seed orchard.
   1–9 = Number of tested clonal seed orchards in which it is established.

History—contd.

j. O = Not represented in an open pollinated progeny test.
   P = Represented in an open pollinated progeny test.

k. O = No artificial crossing work.
   P = Artificial polycross only.
   S = Specific cross only.
   X = Both polycross and artificial crosses made.

l. O = Not selfed.
   S = Selfed.

Performance in Progeny Trials

m. Year of planting (Forest Year).

n. Test site code letters
   e.g. TE = Torrie
   CH = Chillingham
   AD = Ardross
   etc.

o. O = Not yet assessed.
   R = Poor overall progeny performance (based on objective and subjective assessments at 6th, 10th, 15th years).
   W = Average do. do.
   Y = Good do. do.

ooOOO = Computer instructions.

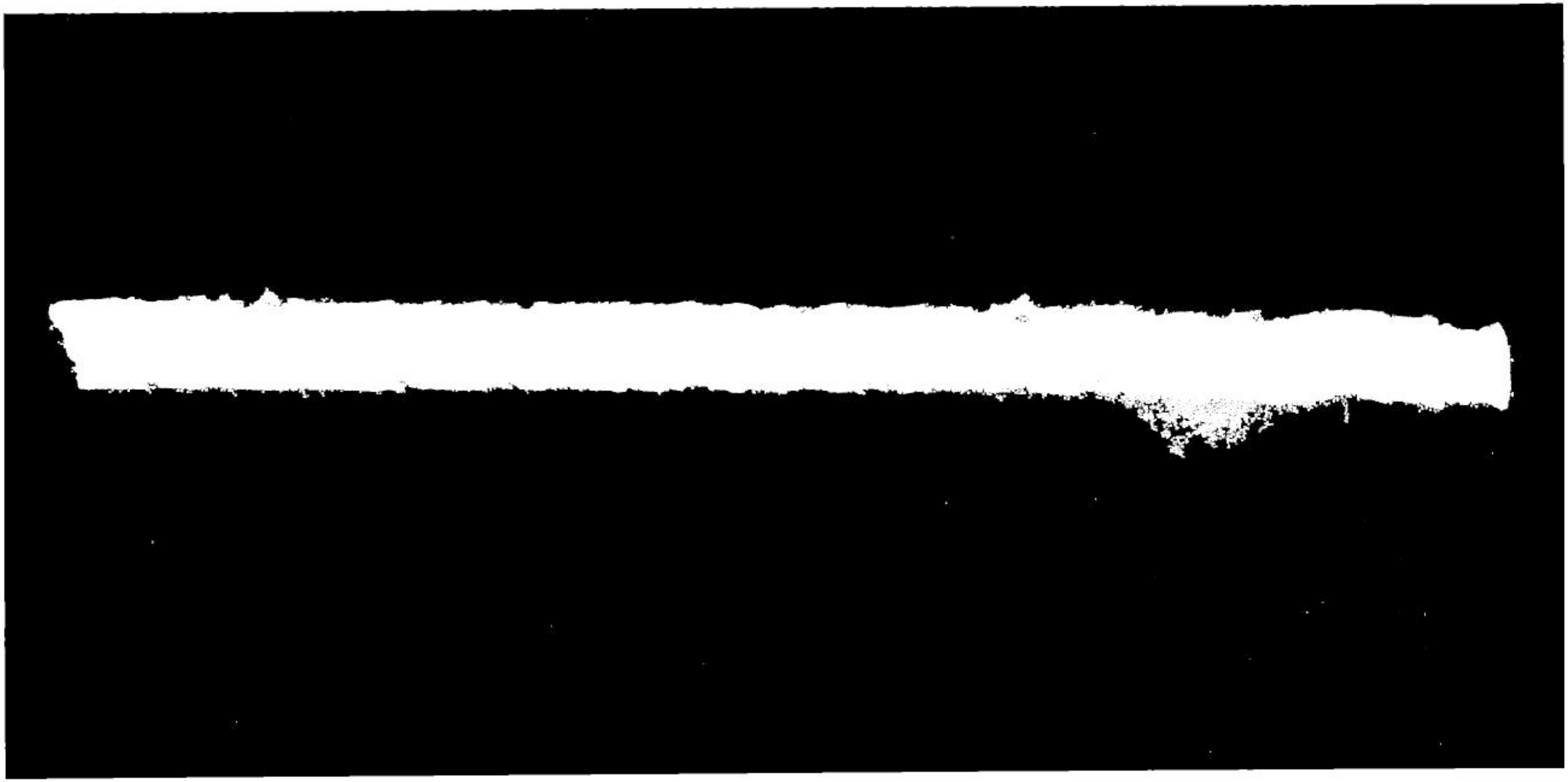


PLATE 6. Bevan: Forest Entomology (p. 75).

Radiograph of Sitka spruce core (x 3) taken in 1965 at Clashindarroch. The prolonged summer drought of 1955 (tenth ring up from bottom) is clearly indicated. (*Note*. The outer zone of each annual ring, i.e. summer wood, appears pale.)

they were also on sites on which partial cover was retained from the first rotation.

Stem Crack in Abies grandis

Following the survey made in 1964–65 to determine the distribution and extent of stem crack in *Abies grandis*, the relationship between external stem scarring and internal cracking was investigated. No cracks were found in trees with no scars, and only 2% of 803 scars less than 3 ft. in length showed associated cracks in the wood. On the other hand, of 47 scars more than 3 ft. long, only two had no associated cracks, and where both scars and cracks were found they were always associated with one another. A high correlation was found between the lengths of the scars and of the cracks. The occurrence of the cracks was closely correlated with the years 1947, 1955 and 1959, when drought conditions prevailed.

A second conversion study was made in a commercial sawmill. The sample studied was of badly scarred trees, and the overall loss in value, including the extra cost of reconversion of the affected material, was found to be 10·7 per cent. The results of the two conversion studies so far made, when combined with those of the stem crack survey, in which 7·7 per cent of the trees showed scars over 3 ft. long, suggest that in Forestry Commission plantings of Grand fir as a whole, the overall loss in value through stem crack is less than one per cent, while even in the worst site studied it is not more than 4 per cent. It would appear that both the extent and the economic effect of stem crack in this species have been over-emphasized in the past.

These studies showed that the main losses from stem cracking arise from the presence of a small number of badly affected trees, some with several cracks. The earlier cracks appear at the base of the tree, but subsequent cracking takes place progressively higher up, further from the most valuable part of the timber. It appears that appropriate thinning effectively reduces the proportion of cracked trees, and further work is being carried out to relate loss as closely as possible to length of crack and of external scar, in order to assist in the identification of those trees that require early removal in thinnings.

Bacterial Canker of Poplar caused by Aplanobacterium populi

Work was continued on methods of screening for resistance to bacterial canker, with supporting studies in the laboratory on the growth of the causal bacterium, and in the field on its general biology.

(1) *Methods of Screening for Resistance*

In the past, routine tests for resistance have been carried out with natural bacterial slime employed in the spring. In recent years, following the discovery of *Aplanobacterium populi* by Ridé (1958), Continental European workers have regularly made their inoculations in autumn, using pure cultures. Comparisons between natural slime and pure cultures as sources of inoculum are being made in this country at Fen Row Nursery (Rendlesham, Suffolk), and Blandford (Dorset), and autumn inoculations with pure cultures have been included in the tests. Preliminary assessments of the first comparative experiments indicate that the spring inoculations have produced similar results, regardless of the type of inoculum. As yet it is too early to assess the results of the autumn inoculations, though if these finally prove satisfactory, it is likely that our routine tests will in future be carried out at this season with bacterial cultures.

(2) *Laboratory Studies*

Laboratory studies to find materials to stimulate the growth of *A. populi* in culture have not been very successful. Limited growth stimulation has been achieved, but the organism grows very slowly when compared with associated saprophytic bacteria.

(3) *Biological Studies in the Field*

(a) Careful observations on the seasonal variations in canker and bacterial slime production have yielded interesting results. Slime production is heavy in the spring, and very limited (though it still occurs) during the rest of the season. These limited amounts of slime produced later in the year may be important in the persistence of the disease through the season, and act as sources of inoculum in the autumn for the infection of natural leaf scars.

The evidence so far available suggests that *A. populi* has a most inefficient means of spread, and this helps to explain the observed wide variations in the intensity of attack between various poplar sites in this country.

(b) Assessments at the sites of poplar trials have indicated that cankers produced in association with Agromyzid cambial mining insects may cause serious damage to the main stems of trees. Further studies are in progress.

(c) Assessments of trials comparing the infections produced by bacteria isolated in different parts of the country, are continuing.

Top Dying of Norway Spruce

As a result of a considerable increase in the number of cases of Top dying of Norway spruce, a more detailed investigation of this condition has begun. The previously established relation between Top dying and mild oceanic winters has been confirmed by field assessments.

It is proposed to prepare a more detailed programme of research, including further surveys and physiological studies. A clonal collection from affected and unaffected trees has been made for future work.

Blue Stain in Pine Timber

Work on blue stain was again carried on jointly with the Forest Products Research Laboratory, Princes Risborough. Two field trials were set up in Thetford Forest to test the effectiveness of a range of chemicals in control of stain in Scots pine. One experiment was set up in May, and a second, almost identical with the first, and on the same site, began in July. Logs in the treated plots were sprayed either with the insecticide lindane (gamma–BHC) to control the bark beetles that sometimes introduce blue stain fungi, or with this insecticide mixed with one or other of the fungicides tribromophenol, orthophenylphenol, pentachlorophenol, sodium pentachlorophenate and borax, or disodium octoborate decahydrate. The logs were assessed after three months.

In the first experiment, both bark beetles and blue stain associated with their galleries were abundant in the unsprayed control logs. Beetles were few and blue stain slight in all the sprayed logs. Control of blue stain was generally as effective in the logs sprayed with lindane alone, as in those sprayed also with a fungicide, though the fungicides did reduce the amount of stain on exposed log ends.

In the second experiment, beetles, which were found only on the control logs, were very few in number, but a moderate amount of blue stain was present in both control and treated logs. None of the treatments significantly reduced the staining. Brown staining, caused mainly by *Stereum sanguinolentum*, was present in both experiments, though it was much more severe in the second one. It was not affected significantly by any of the chemical treatments, but disappeared on drying.

The conflicting results obtained in these two experiments point to a need for more basic information on this problem. Work to this end has now begun in the University of Cambridge.

Needle Blight of Western Red Cedar caused by Didymascella thujina (Dur.) Maire (Keithia thujina Dur.)

Work was continued on the chemical control of this disease. Earlier studies showed that in South-East England good control of needle blight could usually be obtained by applying one spray of cycloheximide at 85 p.p.m. and 250 gal./acre in late March. One spray at this time has proved inadequate in some Scottish and Welsh nurseries, however. This was so in Wiston Nursery, Pembrokeshire, where small, sporadic patches of diseased plants were reported in December 1963, and the nursery was then sprayed in March 1964. By August 1964 it was clear that the spray had been ineffective, and infection was widespread throughout the crop.

In 1965, therefore, the main *Thuja* area of the nursery was sprayed three times with cycloheximide at 85 p.p.m. at 100 gal./acre at the end of March and April and in mid-June. Excellent control was achieved.

On part of the nursery, a randomised block experiment was laid down in which unsprayed plots were compared with plots sprayed once (in March), twice (in March and April), three times (in March, April and June), and four times (in March, April, June and July). The sprays were applied at 50 and 200 gal./acre. It was found that in this trial *one* or *two* sprays were ineffective, while *three* sprays gave adequate control. Applications at 200 gal./acre gave slightly better results than those at 50 gal./acre, but the difference was too small to be statistically significant.

At a nursery in Bramshill Forest, Hants., Venturicidin at concentrations up to 400 p.p.m. was compared with cycloheximide. Applications were made at various rates per acre, and plots were sprayed either in March only, or in March and April. Venturicidin was found to be ineffective at all the concentrations and rates used. Cycloheximide gave adequate control with one spray application, though improved control was obtained when the plants were sprayed in both March and April.

In a preliminary biological study of infection conditions, groups of healthy plants were exposed for fortnightly periods in an infected plot. Only two of these groups later developed infection, and the fortnightly periods during which they were exposed were both notably wet. Similar, more detailed studies are now being carried out, using a spore trap, a recording rain gauge, a surface wetness recorder and other equipment.

Resin Top of Scots Pine caused by Peridermium pini

Assistance was given with a survey to establish the incidence of Resin top in Scots pine crops in Scotland. Work on this desease is being carried out under J. S. Murray in the Department of Forestry, University of Aberdeen.

Peridermium pini (*Pers.*) *Lev.* was also found causing moderate damage on

Scots pine in Llantrisant Forest, Glamorgan. This is the first time this fungus has been found in Wales.

Leaf Spot of Poplars, caused by Marssonina brunnea

Marssonina brunnea (*E. & E.*) *Magn.* which causes small lesions on the leaves of poplars, followed by premature leaf-cast, has become widespread and very damaging in plantations in Italy, Holland and Belgium, and in nurseries in France, and is now becoming important in Austria and Germany. In view of this, a limited survey covering eleven of our poplar trial sites was carried out with the help of our regional research foresters. *M. brunnea* was not found on any of the sites, though the much less virulent *M. populi-nigrae* Kleb. (which causes large blotches on the leaves) was found on them all, and also on leaf samples from three large commercial poplar plantations.

In future, susceptibility to *M. brunnea* will be taken into account when recommending poplar clones suitable for commercial planting.

General

A further increase in advisory work took place, and 404 enquiries were received, 130 being from Commission forests and 274 from elsewhere, while 100 advisory visits were made.

The weather during most of the growing season was dull, cool, and often wet. Widespread frosts in March, April, and particularly towards the end of May, caused damage to a large range of species, and were followed by Grey mould (*Botrytis cinerea* Fr.) in some nurseries.

At the end of the season, in September and October, there was an exceptionally severe and widespread outbreak of non-pathogenic browning of pine needles in nurseries and plantations. The precise cause was not ascertained, though it was thought to be climatic.

In the winter of 1965–66, defoliation and sometimes also dieback of young Sitka spruce took place in exposed areas, and was considered to have been caused mainly by cold winds, though in many instances previous damage by spring frosts and by insects was also involved.

A good many new cases of Top dying of Norway spruce were brought to our notice, and some were very severe. In those given a detailed examination, the condition was found to date back to the mild winter of 1960/61.

Drought damage on *Abies grandis* in Sussex was found to have originated in the hot dry summer of 1959.

A striking variegation was very common on the foliage of Lawson cypress. In a number of cases analysis of foliage showed that the symptoms were the result of magnesium deficiency. In case a virus might also be involved, specimens were sent for examination by Dr. T. W. Tinsley, of the Commonwealth Forestry Institute, Oxford, who is studying virus diseases of trees.

The Anthracnose of Weeping willow, caused by *Marssonina salicicola* (Bres.) Magn. was again very common. As in the previous year most records were from Southern England, though one case was in Lancashire.

D. H. PHILLIPS

REFERENCE

RIDE, M. (1958) Sur l'étiologie du chancre suintant du peuplier. *C. R. Acad. Sci. Paris*, 246, 2795–8.

FOREST ENTOMOLOGY

Pine Looper Moth, Bupalus piniarius

Populations of Pine looper pupae during the winter 1965/66 were generally low throughout the country. The highest compartment-mean pupal count was found at Inglismaldie, 4·8 pupae per sq. yard.

Douglas Fir Seed Wasp, Megastigmus spermotrophus

An investigation into the oviposition period was continued and provided further information on which to base the timing of spray applications. Allowing for seasonal variations, it appears that the cones must be protected from June 1–July 7.

Laboratory tests with D.D.T., B.H.C., Diazinon, Carbaryl, Azinphos-Methyl and Malathion were made to select an insecticide with good contact action against the adult seed wasp. Malathion proved to be the most effective material, although the fact that its field persistence is not more than seven days is a disadvantage. In a field experiment a 0·5% solution of Malathion was applied to cone-bearing trees four times, at intervals of approximately seven days, over the month of June, by means of a semi-permanent sprinkler system attached to each tree. Good control was achieved.

Population studies were continued by means of seed trapping and assessment of cone samples. Several stands produced good seed crops following a number of poor years, and as expected the percentage of infested seed was greatly reduced.

Green Spruce Aphis, Elatobium abietinum

A method has been developed in which thin discs are radiographed for the purposes of annual ring measurement and accurate stem-analysis. Internodal discs, $\frac{1}{8}$–$\frac{1}{4}$ in. in thickness, are saw cut, partly dried and radiographed. Four radii in each disc are then marked and measured, using a Benson-Lehner trace-reader, which produces the results on tape for computer input. It is intended to use the method during the coming season in a sampling survey of Sitka forests with known *Elatobium* history, in which attempts will be made to approximate the effect of infestation upon increment. (See Plates 4 and 6 in central inset.)

Trials of systemic insecticides, applied in various ways, continue. This year trunk injection with Bidrin is being tested for the first time.

Pine Weevil, Hylobius abietis

Two experiments on effectiveness and phytotoxicity of dipping treatments on Corsican pine planting stock, laid down in 1964, were completed. The results showed few statistically significant differences between a number of satisfactory treatments. Nevertheless there were indications that dipping complete plants in 1·5% Gammacol was the most satisfactory. Dipping whole plants, rather than only the shoots, is expected to provide protections against *Hylastes* spp., as well as against *Hylobius abietis,* and to reduce the need for close supervision of dipping.

Field trials to compare complete dipping in 1·5% Gammacol with the present standard treatment (dipping tops only in 5% Didimac) on Douglas fir, Sitka spruce and Scots pine were planted in March 1966. These trials will be assessed before considering a change in the current recommendation.

Control of Pine Shoot Beetle, Tomicus (*Myelophilus*) piniperda

Experiments were carried out into the protection of logs before attack, and into the control of the beetle in already-infested material. Various concentrations of Lindane emulsion diluted in diesel oil were tested, and, in the case of the infested material, also a water-carried formulation of the same chemical known under the proprietary name of Gammacol.

In both experiments, applications of the emulsion in oil, at 0·25, 0·5, 0·75 and 1% at dosages of 1 gallon of diluted material per 100 sq. ft. of bark surface, gave significant control. It is considered that a concentration of 0·5% can be recommended for practical use. Gammacol was effective only at the highest concentration. Investigations into the relationship between susceptibility and date of felling, and into the treatment of logs in the stack by mistblower, are now in progress.

Adelges Species on Conifers

Field and suction trap collections continue to be made of species in the *Adelges* group. Winged migrants have been bred from galls derived from various spruce species collected in the unopened state. These have been used in experimental transfers to their secondary hosts, and also for taxonomic studies. Both the galls of *Pineus pini* and *Adelges nusslini* have been taken during the year on their primary host, the Oriental spruce, *Picea orientalis*. The transference of the first-named was successfully made on to its secondary host, Scots pine.

Collections of the exclusively conifer-feeding aphid genus *Cinara* were made whenever opportunity arose. It appears that *Cinara pinicola* on *Picea* spp. is very common and widely distributed in most years. Our largest species, *Cinara abieticola*, previously recorded only on Eurasian *Abies* spp., has been found this year on the American silver firs, *Abies grandis*, in Kent and *A. lasiocarpa* in Argyll.

Enquiries

There were 135 written enquiries to the Section from Forestry Commission and 103 from private sources during the year.

D. BEVAN

MAMMALS AND BIRDS

Grey Squirrels

Investigations of methods of Grey squirrel control are carried out jointly with the Infestation Control Laboratory (Land Pest Branch) of the Ministry of Agriculture, Fisheries and Food.

A field trial of the technique of poisoning Grey squirrels with warfarin-treated wheat was carried out on part of a private estate in Scotland, by courtesy of the Marquis of Linlithgow and his factor. A commercially available poisoned wheat, 'Biotrol' was laid in ground hoppers with a six-inch tunnel entrance. Dead squirrels showing signs of warfarin poisoning were picked up during the course of the trial. Unpoisoned squirrels, possibly from adjoining woodland, were captured by trapping immediately after the poison period. Numbers in both cases were very low.

Over the period of seven years of trials with warfarin-poisoned baits, it has become apparent that this technique can be successfully used to reduce squirrel populations in these Scottish areas where the populations are not of a high level. Legislation would be necessary before the technique could be applied in the trouble spots of England and Wales where the problem is most serious.

Protection of a vulnerable crop in non-isolated woodland, by cage-trapping in and around it just prior to the damage period, has now apparently been achieved for five successive years. The last trial consisted of three operations; a capture/mark/release trapping in March, eight weeks before the capture/kill operation in May. The latter was followed eight weeks later by a capture/mark/release trapping in July. The results of sporadic control by the keeper between March and May last year suggested that animals killed were rapidly replaced. This year, half the animals captured in March were killed. The May trap round showed that there had been an influx of squirrels to replace those killed. In both years the proportion of unmarked adults was much greater than that of spring-born young just leaving the nest. The July trapping again showed that the population had been replaced by unmarked animals in the eight-week interval between trap rounds.

Red Squirrels

A capture/recapture project was begun in Edensmuir Forest in Fife, East Scotland. It was found that the Legg Single and Young cage-traps were more successful than the Legg Midget, Legg P.B. and Fuller Bullseye traps. Weather conditions appeared to have a marked effect on daily trapping success, and a longer pre-bait period was necessary than for Grey squirrels.

Deer

Radio-tracking equipment has been obtained for a study of daily and seasonal movements of Roe deer. Difficulty has been experienced in getting sufficient power from the collar transmitter. Work has been continued on methods of ageing deer, and a study of a possible technique for assessing the winter health of deer populations is being initiated. Ear-tagging Red-deer calves has been begun in Galloway, to provide basic information on movements for use in management of the population.

Starlings

An attempt to disperse a starling roost at Slebech Forest, South Wales, showed that bird-scaring cartridges fired from a 12-bore shot-gun were more effective than rockets, bangers, etc., in disturbing and eventually moving the roost off the forest. It was not possible to test the broadcast distress call apparatus during the short period for which we were able to borrow it.

Nursery: Protection of Seed from Birds

Seed-dressing trials have been continued with the thiram formulation, Fernasan S, applied with a latex sticker to pine and spruce seed at a rate of 15 per cent w/w. Results suggest that while considerable protection from bird predation can be achieved, complete protection is better achieved by using half-inch mesh netting. Investigations of techniques of reducing material and labour costs of netting are being made.

Chemical Repellants in the Forest

Trials of chemical repellants have been confined to one new material, Aaprotect. This has prevented fallow deer browsing for at least eight weeks. Trials of repellants against blackgame and capercaillie suggest that any protection is of limited duration unless re-treatment is carried out.

Electric Fencing

A new form of electric fencing has been under trial and has given satisfactory results against Fallow deer during the past winter. This consists of six-inch square mesh polythene netting in which the horizontal, but not the vertical strands (of plain polythene), can be electrified. Herbicidal spraying around the fence-line prevented short-circuiting during the summer.

Other Fencing

The Swyftyte fence in Thetford Chase continues to be satisfactory. A hydraulically operated gate, which is bumped open and then closes automatically after a given interval, is being tried out in various Conservancies.

Squirrel Questionnaire

The annual questionnaire on Red and Grey squirrels for the year ending September 1965 showed that Grey squirrels were recovering slightly from decline in numbers observed since 1961. It is possible that, given mild winters and good feeding conditions, more damage and high populations could be expected in 1967. No major changes in distribution were apparent for either species in Forestry Commission plantations.

JUDITH J. ROWE

PLANNING AND ECONOMICS

Soil Surveys for Working Plans

Surveys of chalkland forests in southwest England have been completed. The forests of Salisbury, Blandford, Cranborne and Poorstock in Wiltshire and Dorset were dealt with during the year.

A survey was undertaken in Brendon and Quantocks forests, Somerset. On the Devonian sandstones, humus iron podzols and iron pan soils (Fitzpatrick 1964) predominate. These soils are associated with semi-natural vegetation dominated by heather, *Calluna vulgaris*. Such sites present difficulties of establishment for spruces due to the *Calluna* competition. Pines were often planted and grew satisfactorily for a while, but it is now thought that higher yields could be obtained in the second rotation with Sitka spruce on exposed sites and with Douglas fir on sheltered sites. Corsican pine has suffered severe die-back after reaching the pole-stage on the highest ground, thereby considerably accentuating the need for replacement. On the Devonian silty shales, brown earths predominate and growth of Douglas fir and Sitka spruce is extremely rapid. General yield classes of 240 for Sitka spruce and 210 for Douglas fir are found on sheltered steep slopes up to 1,200 feet elevation, but the yield class for Sitka spruce on the exposed plateau at 1,200–1,300 feet was only 140.

Part of the Forest of Ae, Dumfriesshire, was surveyed with the principal aim of producing a forecast of windthrow. Soil and windthrow maps were produced, and a clear association between soil types and the severity of wind damage was apparent. A relationship between the relative exposure of sites and the top height of crops affected, was also established; this made possible forecasts of the time as well as the location of damage. The computer was used to analyse and correlate the information contained on maps of soil types, exposure zones, crop top heights and windthrow.

Garadhban Forest, Stirling and Dunbartonshire, was surveyed in order to assess the risk of wind damage in the older plantations, and to assist the planning of afforestation of a large area of bare ground.

Work was started on a soil and windthrow survey in Hamsterley Forest, an ex-heathland forest in County Durham.

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D. G. PYATT

WORK STUDY

Machinery Investigations

These took a new impetus with the recruitment of a mechanical engineer at Work Study headquarters and the formation of an experimental team, based upon Kielder Forest. The main emphasis has been the upon study of equipment for extraction, with particular reference to optimum road espacements, terrain limitations and the overall logging systems best suited to particular machines. Although much work remains to be done, the formulation of a reliable extraction "key" seems to be in sight. Notes on the main machines investigated or being investigated follow.

Tractor/Crane/Trailer Combinations

The extraction of material by tractor and trailer is by no means a new conception, but trailer loads have normally been relatively small, and the agricultural tractors generally used have imposed obvious terrain limitations. In the attempt to increase the load, and to extend the range of terrain which may be dealt with by this form of extractor, trials were undertaken with a County Super Four tractor with a rear-mounted Hiab 172 hydraulic crane and grapple. This Hiab outfit was originally designed for lorry loading, but, coupled to a trailer of 8 tons capacity, it provided a fair test of the conception. Studies indicated that outputs from thinning should exceed 1,000 hoppus feet per day over average distances of 200 yards. Costs at this distance were 3½d.–4d. per hoppus foot, including labour, labour on-cost and machine charges. Although the outfit had many design defects, and was not suited to soft conditions, it nevertheless demonstrated that the principle is sound. Current studies are on the Robur—a Swedish machine which consists of a three-quarter track Massey Ferguson tractor with mid-mounted Hiab crane and grapple, and ram-steering to a wheeled trailer of 8–10 tons capacity. First trials indicate that this outfit, unlike the Super Four combination, will cross stumps; stump removal from extraction racks is not likely to be necessary. Later studies are also planned for a half-tracked Massey Ferguson with an Osa hydraulic crane mounted on the safety frame and an 8–10 ton trailer.

Frame Steering Tractors

There has been a general tendency overseas to replace crawler tractors, used in extraction, by wheeled tractors operating on the frame steering principle, i.e. fixed wheels (all driven) and hydraulic rams which move the machine left or right about a central pivot. Significant cost reductions have generally been shown.

Such a machine, the County Timber Tractor, has been studied at Inshriach Forest on hard gravels and at Halwill Forest on heavy, wet, Culm clay. At Inshriach Forest outputs of 900 hoppus feet per day were reached on selective felling of Scots pine (average volume 11 hoppus feet), with extraction in the tree length over an average distance of 100 yards. At Halwill spruce clear felling was extracted, and output for a 150-yard haul exceeded 1,000 hoppus feet per day. Costs including labour, labour on-cost and machine costs were, in this case, less than 3d. per hoppus foot; this represented a 50 per cent saving on the previous method, a crawler tractor with an Oliver logger.

Machines of this class are suitable for clear fellings or later thinnings. Extraction is by means of a rear-mounted winch, the winch rope being furnished with up to eight sliding chokers. Trees are directionally felled towards extraction racks, the winch rope pulled out and the sliding choker fixed to the trees; the trees are then winched in and their ends come to rest against a rear tractor plate, clear of the ground.

Currently being studied is the Holder A 20 tractor, a small 20 horse-power frame steering machine developed originally for work in vineyards. First indications are that this machine will prove valuable for the extraction of thinnings and may move 500 or more hoppus feet per day of tree-length material.

With all these machines the speed of extraction can result in stacking and conversion problems. Present studies indicate that extraction and conversion should proceed concurrently. A promising approach is the use of a grid on which the trees are dropped by the tractor for immediate crosscutting and stacking. The provision of a stacking device, front-mounted on the tractor, is an intended development.

Half-tracked Tractors

A Massey Ferguson 165 equipped with half-tracks, weight transfer mechanism and a Kombi double-drum winch is undergoing trials in a ground skidding rôle. The object is to determine the terrain limitations of half-tracked machines. The Kombi winch itself is provided with a low tower and may be used in a similar fashion to the Isachsen No. 1 double drum winch over a range of about 80 yards.

Lokomo Plough, Type NA 15

This is a Finnish deep draining plough which has been coupled to a B.T.D. 20 tractor with 36-in. wide track plates. In view of current drainage prescriptions, it is important to reduce costs to the minimum and, in Finland, outputs average 3 to 4 kilometres of drains per day, and costs are less than half those of hydraulic excavators. Studies have shown that draw-bar pulls needed in many of our conditions are likely to exceed those required in Finalnd; winch failures have been frequent. The mechanical winch has therefore been replaced by a hydraulic winch, and studies are being made to establish the draw-bar pulls needed to produce drains of different depths over different soils. The equipment is likely to find a place in the drainage of stiff, mineral soils with only a shallow covering of peat. It has no place at present on deep peat where the conventional deep-draining plough is the indicated equipment.

Chain Saws

The criteria for the selection of chain saws for different purposes have been established, and a detailed study has been made of noise effects upon operators. As a result of this study, it has become quite clear that ear protection is needed either by the use of approved ear muffs, fibreglass down or ear plugs. The best ultimate combination seems to be a safety helmet (which itself helps to reduce the noise intensity) to which are fixed adjustable ear muffs—reversed at will from the ears to rest on the helmet; a prototype has been developed.

Production Studies

Pulpwood and Boardmill Supplies

Work continued on the supply of logs to the Thames Board Mill Ltd. factory at Workington in Cumberland, and to Scottish Pulp and Paper Ltd. mill at Fort William, West Scotland. Standard times for the preparation of material to both factories were produced, together with standard times for the Isachsen double drum winch, the skidding arch and a pulpwood sledge.

Clear Felling

Clear felling, which poses problems of degree and possibly of kind, has been studied at Glenbranter Forest in Argyll, and is also now being studied at Kielder in the Borders.

Chain Saw Snedding

Snedding by axe accounts for 30 to 60 per cent of the time for thinning and converting. In the attempt to cut the costs of this operation, very detailed studies of chain saw snedding have been undertaken and the appropriate techniques and methods developed. The break-even in cost between axe snedding and chain saw snedding is reached when branches average $\frac{3}{4}$ to 1 inch in basal diameter; smaller branches are more expensive to sned by chain saw than axe but, for larger branches, the reverse is true. Additionally, however, time is saved for more production and this results in reduced labour on-costs. Taking the saving into account, the accepted break-even point is close to $\frac{3}{4}$-inch branch diameter, and the break-even branch diameter will tend to reduce still further as machine costs rise relatively less steeply than do labour costs. Lightweight chain saws are essential for this operation, and several months may be needed before an operator achieves full skill.

Brashing Studies

A team was set up to determine the degrees of brashing which give overall minimum costs, including those of marking, felling, conversion and extraction. This is a complex study which will need two years to completion.

L. C. TROUP

MECHANICAL DEVELOPMENT

The programme of work directed by the Mechanical Development Committee is at present concerned mainly with extraction and ploughing problems, and the equipment being covered includes tractors, cableways and winches, and drainage ploughs. Work Study are undertaking much of the field work involved, and their report covers those other major items on the Mechanical Development Committee programme that are not mentioned in this Report.

Tractors

A replacement for the Fordson Long Wide County (production of which has ceased) is being developed in conjunction with Messrs. Fowlers of Leeds. A Track Marshall 70 has been modified by extending the frame and widening the track gauge to enable 30-inch tracks to be fitted, to give a ground pressure only slightly higher than that of the Wide County. The tractor has now been delivered and is at present undergoing preliminary trials in North-east England Conservancy prior to being moved to South Scotland Conservancy for full field trials. It is too early at this stage to forecast the outcome, but the equipment looks promising. A Robur (Swedish) tail steering tractor, based on the Massey Ferguson 165, has now been received; it is to undergo extraction trials in various parts of the country.

Cableways and Winches

The investigation of various types of cableways and winches is being pursued. A limited demonstration has taken place with the Bamse system. This demonstration was not convincing and further investigation is needed before any decision can be made.

A Kombi winch is undergoing trials in the New Forest, prior to extended trials in Scotland. The delivery is awaited of a Baco winch from Switzerland for demonstration by a Swedish operator, also in Scotland.

The modification of the Isachsen winch to give hauls of up to 300 yards is also in hand. Comparative trials with the Baco are to be put in hand as soon as possible.

The radio-controlled Sepson winch has been modified for use in this country, and trials are also due to commence in Scotland.

A. J. COLE

TIMBER UTILISATION DEVELOPMENT

Properties of Home Grown Timber

The joint programme of research with the Forest Products Research Laboratory of the Ministry of Technology, Princes Risborough, on the properties of home grown timbers, continued. In the general programme, sampling in the forest was almost completed for work on a comparison of the timber properties of Scots pine and Corsican pine; the work will include the effect of log shape upon yield of sawn timber.

Field experiments on the prevention of blue stain in pines continued. An account of this work is given under Forest Pathology on page 72.

Other projects at the Forest Products Research Laboratory included an investigation into the pulping properties of the juvenile wood of Sitka spruce; the impregnation of green Scots pine poles with preservative, following boiling under vacuum; studies on the effect of the strength of solution and the length of dipping time on the extent of diffusion of boron preservatives in green timber; and an assessment of the wood structure of 'plus' trees selected by the Commission's Genetics Section. Studies on stem crack in *Abies grandis* are reported under Forest Pathology, page 71.

Economy Drier (Pre-drier) Development Project

The development of a simple low-cost timber drier at the Forest Products Research Laboratory was taken a stage further by the use of a specially designed oil heater which is placed inside the drier of kiln and gives a high degree of thermal efficiency.

Results so far have been encouraging; in one trial run, a load of two-inch Norway spruce was dried to a moisture content of 25 per cent in eleven days.

Fence Post Trials

These trials have now entered their eighth year in Scotland and seventh year in England and Wales. The experiment is a long-term one designed to evaluate the effect of site on the life of fence posts treated with various wood preservatives, and untreated posts. It is already clear that the untreated posts of species which are not naturally durable, have virtually failed within the period of 7–8 years. The survival rate of untreated posts varies between 16 and 21 per cent, although in Scotland about half the untreated Sitka spruce posts have survived.

In contrast, the posts treated with one of the wood preservatives have shown no failures whatsoever at any of the sites; and posts treated with the other (a water-borne preservative which is no longer marketed for use with wood in contact with the ground) show a survival rate of between 75 and 97 per cent.

The results to date clearly indicate that although site does affect the life to be expected from untreated posts of species that are not naturally durable, the effects of site are not of great practical importance in view of the much longer life which may be expected from posts treated with a wood preservative.

Telegraph Pole Trials with Japanese and Hybrid Larches

Trial telegraph poles of Japanese and Hybrid larch, together with controls of European larch, were delivered to the Post Office depot at Newport, Monmouthshire, where they were allowed to season for four months, before being creosoted under pressure. (European larch poles were used as controls because this species was already included in the G.P.O.'s telegraph poles specification; Japanese and Hybrid larch were not.)

Examination of the treated poles showed that in all three species the preservative had penetrated to a depth of between half and one and a quarter inches, and the net retention was 6·3 lb. per cubic foot.

The Post Office are now satisfied that there is no substantial difference between the permeability of these species, and in December 1965, Japanese larch and Hybrid larch were added to their specification for home-grown telegraph poles.

J. R. AARON

DESIGN AND ANALYSIS OF EXPERIMENTS

The functions of the Statistics Section have remained as before, namely:—

(a) To provide advice on the design and analysis of experiments and surveys to all Sections of the Research Branch, and to the Forest Commission in general;

(b) To undertake the analysis and interpretation of numerical data;

(c) To undertake research into the application of statistical methods and computing techniques to problems of forest research and management.

In the year under review, the Section has lost two members of its staff, Mr. H. G. M. Dowden having left to take up an appointment in Australia, and Mrs. B. E. Witts having left for family reasons. Replacements for these two members of the staff have not yet been found. The Section has also obtained permission to recruit an additional Scientific Officer, and this post has not yet been filled. The shortage of senior staff has necessarily limited the work of the Section. Several students from the Ministry of Aviation and other organizations have spent periods of up to six months in the Section, engaged on a wide variety of practical tasks as part of their industrial training on sandwich courses.

The Statistician attended the Second Conference of the Advisory Group of Forest Statisticians of Section 25 of the International Union of Forest Research Organizations in Stockholm during October 1965. This important conference presented an opportunity for discussions between the statistical advisers of many of the forest research organizations of the world, and it is gratifying to note that, as a result of the activities of this Advisory Group, several organizations have established their own Statistics Sections. The Statistician was also invited to visit Belgium to present two papers to the Adolph Quetelet Society in Brussels, and one paper to the Faculty of Sciences at the Institute Agronomique at Gembloux. Members of the Section also attended many conferences and meetings in Great Britain, and presented papers to some of these.

Designs and Analysis of Experiments and Surveys

Designs for experiments and surveys have been provided for about eighty investigations throughout the year. Some of these investigations were major projects, such as the Census of Woodlands, but most were for relatively small investigations on the research programme. Special attention has continued to be given to the problems of the design of Work Study investigations, and new genetic investigations have also been of some importance.

Nearly 20,000 separate analyses have been completed in the year under review. More than half of these analyses were complex studies of relationships between many variables, or applications of operational research techniques to practical problems of forest research and management. This increase in the proportion of complex analyses again demonstrates the value of electronic digital computers in making possible detailed interpretation of data from experiments and surveys. Few of these analyses would have been possible without the Section's own Sirius computer.

The research into the application of multivariate techniques to problems of forest research and management, reported over the past five years, has been widely exploited in the current year by applications to numerous ecological, taxonomic and classification studies. In addition, the Section has been consulted by many other organizations for advice on the application of these techniques in similar fields.

Computer Programming and Serviceability

The development of a full library of programmes for the Section's Sirius computer has continued, and more than 60 new programmes have been added in the year under review.

The computer itself has continued to be both reliable and productive—Table 13 gives details of the use of the machine for each month, and Table 14 summarises these details, using the criteria laid down by the Treasury for computer records. It is clear, from these tables, that the three criteria of 'serviceability', 'availability' and 'utilization' have all remained at a consistently high level. The particularly heavy usage of the computer during the months of April and May, representing long hours of overtime working, was concerned with the preparation of the management tables, and with the selection of the random co-ordinates to be used in the national census of woodlands.

Research into various methods of eliminating the manual punching of data has continued. Many of the devices that were thought to have some promise in the capture of field data have, however, now been rejected. Two methods have been retained for general use by the Research Branch. The first of these, the Lector Document Reader, requires the printing of special forms which, after being marked in the field, are scanned automatically, and the data converted to punched paper tape which can be read directly by the computer.

Very great care has been found to be necessary in the design and printing of the forms, and it is advisable to allow six weeks for this to be done, before data can be collected. The method is therefore most suitable for applications in which the collection of data can be planned well in advance. Nevertheless, about 80 per cent of the data collected by the Research Branch and by the Management Services Division can be captured by this method, and a case has been prepared for the purchase of a Document Reader by the Statistics Section. A number of forms have been designed, and are already in regular use, including those for nursery and forest experiments, the census of woodlands, fire reports, soil moisture readings, etc.

Most of the remaining data can conveniently be captured on I.B.M. Porta-Punch Cards, the data from which are then converted to punched paper tape by a card-to-tape converter, and the resulting tapes read directly by the computer. These cards need far less preparation, but are less suitable for large collections of data. A suitable card-to-tape converter has also been ordered by the Section.

International Union of Forest Research Organizations

The Statistics Section has continued to take an active part in the work of this Organization, and particularly in the Advisory Group of Forest Statisticians of Section 25.

Statistics Section Papers

The following Statistics Section Papers have been prepared in the year under review:—

96. Supplementary report on the FY 64 trials of the new nursery stock-taking procedure.

TABLE 13
DETAILS OF COMPUTER OPERATIONS

Month	No. of Faults	Production Time	Development Time	Idle	Repairs	Scheduled Maintenance	Supplementary Maintenance	External Causes
APRIL 1965	3	27972	1148	875	235	692	65	0
MAY 1965	1	44066	2058	65	230	551	215	0
JUNE 1965	3	17119	1155	63	30	888	0	60
JULY 1965	1	13216	1591	305	110	735	0	0
AUGUST 1965	2	9513	1412	25	105	978	0	0
SEPTEMBER 1965	0	8581	1048	18	0	902	0	0
OCTOBER 1965	0	9747	1857	69	0	1192	45	0
NOVEMBER 1965	0	9467	1244	2	0	784	0	0
DECEMBER 1965	1	9547	1452	250	34	1236	30	360
JANUARY 1966	1	16915	1931	33	0	1456	65	0
FEBRUARY 1966	1	14427	839	6	10	723	0	0
MARCH 1966	1	9539	1792	0	30	1143	0	0

Note: All times are in minutes.

TABLE 14

SERVICEABILITY OF COMPUTER

Month	Serviceability	Availability	Utilisation	Total Time Hrs.	Total Time Mins.
APRIL 1965	·992	·970	·971	516	27
MAY 1965	·995	·983	·999	786	25
JUNE 1965	·998	·952	·997	321	55
JULY 1965	·993	·947	·980	265	57
AUGUST 1965	·991	·910	·998	200	33
SEPTEMBER 1965	1·000	·914	·998	175	49
OCTOBER 1965	1·000	·907	·994	215	10
NOVEMBER 1965	1·000	·932	1·000	191	37
DECEMBER 1965	·997	·899	·978	215	9
JANUARY 1966	1·000	·928	·998	340	0
FEBRUARY 1966	·999	·954	1·000	266	45
MARCH 1966	·997	·906	1·000	208	24

97. Variation in leaf characters of *Thuja plicata*.
98. The case for Lector in the Forestry Commission Research Branch.
100. New stocktaking procedure.
101. Fence post trials.
102. Moisture content and specific gravity of fresh-felled conifers: analysis of unweighted billet values for specified size classes.
108. General analysis of non-orthogonal experiments.
109. Statistics Section 1970.
110. Nursery planning and production: a preview of a complex management problem.
111. Simulation by "Monte Carlo" methods.
113. A minimum distance problem.
114. Industrial Staff Register.
115. Calculation of life tables for insect populations.
116. Association analysis of ecological data.
117. Use of electronic digital computers in forest research and management —the new generation.

J. N. R. JEFFERS

Enquiries regarding any of these papers should be directed to the Statistics Section at Alice Holt.

PUBLICATIONS AND LIBRARY

Publications

The following twelve new publications were issued through Her Majesty's Stationery Office during the course of the year:—

Reports

Forty-sixth Annual Report of the Forestry Commissioners, 1965 (H.C. 97. Session 1966–67) (9s. 6d.).

Report on Forest Research for the year ended March 1965 (20s.).

Bulletins

No. 37. Experiments on Nutrition Problems in Forest Nurseries, by Miss Blanche Benzian. Vol. I. (50s.). Vol. II—Supporting tables (20s.).

Forest Records

No. 53. Studies on the Mineral Nutrient Status of Heather, *Calluna vulgaris*. By J. R. Aaron (2s.).

No. 54. Decay in Standing Conifers developing from Extraction Damage, by R. G. Pawsey and R. J. Gladman (3s. 6d.).

No. 55. Death of Pedunculate Oak and Variations in Annual Radial Increments related to Climate, by C. W. T. Young (3s.).

No. 56. Report of the International Advisory Group of Forest Statisticians, 1963, by J. N. R. Jeffers (1s.).

No. 57. The Relationship between Resin Pressure and Scolytid Beetle Activity, by A. R. Barlow (1s.).

Booklets

No. 13. Principal Butt Rots of Conifers, by R. J. Gladman and B. J. W. Greig (2s. 3d.).

No. 14. Rabbit Control in Woodlands, by E. V. Rogers (3s.).

No. 15. Know your Conifers, by H. L. Edlin (5s.).

Leaflets

No. 51. Chemical Control of Weeds in the Forest, by J. R. Aldhous (1s. 6d.).

In addition, twenty priced publications sold by the Stationery Office were reprinted, after varying degrees of revision.

Three unpriced publications were produced, mainly for internal circulation to the Commission's own staff. Copies are, however, available free of charge on application to the Publications Officer, Forestry Commission, 25 Savile Row, London, W.1. Their titles are:

Research and Development Papers

No. 27. Drainage Machinery for Forest Use, by E. F. Granfield.

No. 28. A Survey of the Literature on the Management Aspect of Large-scale Utilisation in Selected European Countries, by J. R. Aaron.

No. 29. Seed Identification Numbers. (A Formal Register of internal reference numbers for all seed lots used by the Commission from 1921 to 1956 inclusive.)

Twelve unpriced publications for general public issue were revised and reprinted during the year. Among them was the Stationery Office Sectional

List No. 31, entitled *Government Publications: Forestry Commission*, which is obtainable free of charge from the Publications Officer or the Stationery Office. This provides the latest published information on all available Commission publications, both priced and unpriced.

Books and periodicals issued by other British publishers, and currently on sale, were listed in the free pamphlet entitled *Books and Periodicals on Forestry and Allied Subjects*, available free of charge from the Publications Officer, Forestry Commission, 25 Savile Row, London W.1.

Library

Accommodation and Equipment

Towards the close of the year, the Library premises were extended into the main hall of the Research Station, providing five working rooms instead of four. The largest room of the Library suite was converted into an occasional conference room, which will, when not so used, offer more convenient and better lighted accommodation for students.

A Microfilm Reader was brought into use for the first time, the model now adopted being a Recordak Magnaprint Reader (Model HPE–1A). This has a print-out arrangement whereby photocopies can be made of any frame of film, very quickly and at reasonable cost.

So far the main use to which the reader has been put, has been the scanning of the microfilmed catalogue of the Commonwealth Forestry Institute at Oxford. The storage and servicing of any comparable catalogue of world forestry literature, by conventional means, is quite beyond the resources of our own small library. Microfilm makes it possible to have prompt access to this established catalogue, with its 220,000 entries, which can be stored in its microfilmed form within a small cabinet.

One minor technical difficulty was encountered, in that the reader, as supplied by the makers, could not display the whole area of each Oxford Catalogue frame. This has been overcome by a simple conversion lens outfit, designed and made by the Commission's Photographer and Workshop Officer.

Routine Work

The number of new books received during the year was 258. This included a number kindly presented to the Commission by Messrs. G. B. Ryle and J. Q. Williamson, for which our thanks are expressed.

The work of assembling a full collection of *past* issues in our main fields of "Forestry in the British Isles", and a useful working collection on related sciences, is nearly complete. Purchases now tend to be concentrated on *new* issues, as each appears. The specialist sections of the Research Branch are particularly keen to secure the latest published information in their respective fields.

As a result of measures taken to make the Library's existence better known, the number of loans increased substantially to a record figure of 1,476. It is noteworthy that 229 (or 15%) of these loans were made to "outside enquirers", who are not members of the Commission's own staff. The Library is thus fulfilling, to a greater degree than before, its function as a specialised centre of knowledge available to the general public.

Our borrowings from other libraries also rose sharply, to a record figure of

495. This is an expression of the need for knowledge in highly specialised fields of science, which a relatively small and generalised forestry library cannot hope to meet from its own resources alone.

The Library Review

To spread a knowledge of the library's services, and its store of information so readily available to all, the previous "Library Bulletin" was re-shaped and given a wider circulation. It is now printed, and is sent to all the Commission's professional, scientific and technical staff down to the Forester level. It is also exchanged with a number of research stations, including many overseas, which send us similar information. A typical issue of this "Review" lists all books recently acquired, and also papers by members of the Commission's staff; it may also carry a translated paper on some subject that has received little attention so far in Britain, or a reprint of a staff paper that merits wider circulation.

H. L. EDLIN

PART II

Research Undertaken for the Forestry Commission at Universities and other Institutions

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RESEARCH ON FOREST SOILS AND TREE NUTRITION

By J. B. CRAIG and H. G. MILLER

The Macaulay Institute for Soil Research, Aberdeen.

Work during the year continued along the same broad lines described in the previous report, though greater use is now being made of greenhouse investigations.

Nitrogen Nutrition

The nitrogen fertilizer experiments at the forests of Culbin (Morayshire), Broxa (Yorkshire) and Inshriach (Inverness-shire) described in earlier *Reports on Forest Research* for 1963, 1964 and 1965, have continued and there has been little change in the patterns of response so far reported. On the *Calluna* heathland sites at Broxa in Allerston Forest, Yorkshire, and Inshriach Forest in Inverness-shire, phosphate was included in this year's fertilizer applications following suggestions of a secondary phosphorus deficiency at the higher levels of applied nitrogen. As yet it is not known whether this has had any appreciable effect on growth.

In the nitrogen experiments laid down in 1961 and 1964 on young Corsican pine on the sand dunes of Culbin Forest (Morayshire), a high proportion of the trees are showing death of the buds and young shoots. Assessments reveal that this damage is closely correlated with repeated high nitrogen dressings, but as yet the direct cause is unknown. The symptoms do not appear to be typical of fertilizer scorch nor of induced water stress, which until recently had been the two most tenable hypotheses, and they now seem to show similarities to the types of damage resulting from either copper or boron deficiency in fruit trees and agricultural crops. The level of copper in the sand at Culbin is known to be extremely low and this suggestion is given added weight by the fact that in a few plots which are given dressings of copper and boron the incidence of bud death is low. Unfortunately the picture is confused by other somewhat conflicting evidence and so steps are being taken to investigate this matter further.

Investigations into the nitrogen nutrition of mature Scots pine on a river terrace at Alltcailleach forest (Aberdeenshire) have continued (*Reports on Forest Research* for 1963 and 1964). Preliminary results from an experiment laid out to assess the response to nitrogen in the presence of phosphate are given in Table 15. The fertilizers were applied in 1963 as urea and triple superphosphate and have resulted in appreciable increases in diameter growth, though there is little difference in response between the two upper levels of nitrogen.

Distribution and Movement of Nutrients within a Forest Ecosystem

In an experiment laid out in 1964, in a crop of Corsican pine planted in 1928 at Culbin, an attempt is being made to relate applied nitrogen to the natural movement and distribution of nutrients within a closed forest. As described in the *Report on Forest Research* for 1965, an intensive sampling of the ecosystem was carried out prior to the first application of fertilizers. Preliminary results from the analyses of the samples are given in Table 16. These results are to be supplemented by the analysis of the soil, and the calculation of the amount of nutrients represented by the thinnings; to date this has been completed only for nitrogen.

It was found that the amount of nitrogen within the top three and a half feet of soil was 1,370 kilograms per hectare, bringing the total quantity within the ecosystem to about 2,000 kg. per ha.—of which the trees represent only 13 per cent and the ground vegetation and forest floor a further 17 per cent. Thinnings are estimated to have removed 2,100 kg. of dry matter per ha. from the forest and resulted in the deposition of a further 800 kg. on the forest floor as "lop and top", the nitrogen contents of these being 2 and 3 kg. per ha. respectively. If the average annual incorporation of nitrogen by the crop is taken to be the nitrogen content of the trees and thinnings, divided by the age of the crop, a figure of 7·4 kg. per ha. per annum is obtained. This is less than 0·4 per cent of the total nitrogen within the ecosystem; ignoring the present crop, the rest of the ecosystem contains the equivalent of 245 times the average annual incorporation of nitrogen by the trees. Despite this, however, the trees when sampled were severely nitrogen-deficient as is demonstrated by the subsequent response of the crop to the application of nitrogen as sulphate of ammonia. The extent of this response is shown in Table 17 in terms of needle nitrogen concentration and the basal area growth during the second year of application.

In order to trace the movement of nutrients within this ecosystem, samples of the litter fall are collected on wooden trays and harvested every month. It was found that the application of nitrogen resulted in a reduction in the weight of litter falling during the first year. Between May 1964 and April 1965 the total accumulated weight of litter-fall in the control plots was 2,850 kg. per ha., whereas in the highest nitrogen treatment (N_4) it was reduced to 1,940 kg. per ha. over the same period—the corresponding quantities of nitrogen being 12 and 10·5 kg. per ha. respectively. During the following six months, however, the treated plots have shown a progressive increase in the rate of litter fall, due largely to a marked increase in the size of needle falling. Thus by October 1965, the weight of litter falling per month in treatment N_4 was 45 per cent greater than that in the control plots, and the weight of nitrogen falling in the litter was 130 per cent greater. This added increase was due to a rise in the nitrogen concentration of the needle litter, from 0·3 per cent for that in the control, to 0·7 per cent for that in the heaviest treatment. During the first 18 months of the experiment the total accumulated weight of litter fall amounted to 4,750 kg. per ha. in the control plots as against 4,200 kg. in treatment N_4, the corresponding nitrogen contents being 19 and 28 kg. per ha. respectively.

Satisfactory methods have now been developed for the collection and analysis of rainwater entering the forest. Preliminary results show that an appreciable quantity of nitrogen is returned from the trees to the forest floor *via* "leaching" of the crowns by rainwater, and that this quantity increases with increasing foliage nitrogen concentration resulting from applied nitrogen fertilizers.

Greenhouse Investigations

Experiments to test the effects of differing levels and forms of nitrogen on the growth of Corsican pine seedlings in the greenhouse suggest that maximum growth per plant is obtained with the nitrogen supplied in the ammonium form. With the nitrate form it was found that a greater concentration of nitrogen is required in the feed solution, and even then growth per plant never reached the level obtained with ammonium. Urea produced seedlings almost as large as those grown in ammonium nitrogen, but at a very much lower level of supply —14 p.p.m. as against 126 p.p.m. for maximum growth in the ammonium series. At levels of urea greater than 14 p.p.m. nitrogen, however, seedling growth fell off very rapidly and at all levels a high proportion of the seedlings was killed; similar deaths occurred in the high levels of the ammonium series. These investigations are being carried further.

Physical Studies

The field experiment at the Lon Mor, Inchnacardoch Forest, near Fort Augustus in Inverness-shire (*Report on Forest Research* for 1963) has continued. An assessment made in November 1965 showed that with increase in depth of drains, plant height, shoot length and percentage survival generally increased. All plots showed very significant increases in tree height compared with the corresponding 1964 heights. The 1965 shoot lengths were significantly greater than those for 1964 in the 10-centimetre, 30-cm. and 50-cm. drainage treatments. Each plot has now been divided into fertilized and unfertilized sections, and a botanical survey is to be made of the experiment each year.

A comparative study has been made of peat sampling on a volume and a weight basis, using different types of samplers. Samples were taken from a *Scirpus/Eriophorum* blanket peat in Inverness-shire, a *Calluna* hill peat in

TABLE 15

RESPONSE OF 80-YEAR-OLD SCOTS PINE TO NITROGEN IN THE PRESENCE OF PHOSPHATE. FERTILIZERS APPLIED IN SPRING OF 1963. ALLTCAILLEACH FOREST, ABERDEENSHIRE.

Treatment		N% in top whorl needles Oct. 1963	1964 Girth increment		N% in top whorl needles Oct. 1964	1965 Girth increment	
lb. P per acre	lb. N per acre		At breast height (ins.)	At 25 feet (ins.)		At breast height (ins.)	At 25 feet (ins.)
50	0	1·45	0·23	0·19	1·39	0·28	0·24
50	70	1·42	0·25	0·21	1·51	0·30	0·29
50	140	1·58	0·34	0·27	1·56	0·44	0·39
50	210	1·79	0·33	0·27	1·79	0·45	0·39

Kincardineshire, and a raised bog in Aberdeenshire. At each site the top 12 inches were sampled at 2-inch intervals. No significant difference in moisture content was found between the samples on a weight basis, using four different types of samplers, nor were there, excluding the surface samples, significant differences in moisture content and wet bulk density between the samples obtained on a volume basis, using two types of samplers. Although each was consistent in itself, the moisture content results on the weight basis, and on volume basis, give totally different impressions of the moisture profile. This is

TABLE 16

DISTRIBUTION OF ORGANIC MATTER AND MACRO-NUTRIENTS WITHIN A STAND OF 35-YEAR-OLD CORSICAN PINE.

(PLANTED IN 1928, ASSESSED IN 1964).

CULBIN FOREST, MORAYSHIRE.

Kilograms per hectare.

	Organic matter (oven dry weight)	Nitrogen content	Phosphorus content	Potassium content	Calcium content	Magnesium content	Sodium content
Trees—crowns	19,400	83	10	51	67	15	4
boles	77,400	60	6	40	64	15	4
stumps and roots	52,800	113	35	89	22	38	20
Total trees	149,600	256	51	180	153	68	28
Ground vegetation	1,000	8	1	3	2	1	0
Forest floor (L+F+H)	48,900	322	23	24	75	24	8
Totals*	199,500	586	75	207	230	93	36

*Totals exclude mineral soil (see text).

TABLE 17

FIRST AND SECOND YEAR RESPONSES OF A 35-YEAR-OLD CORSICAN PINE CROP TO ANNUAL APPLICATIONS OF NITROGEN.

(CROP PLANTED IN 1928).

(FERTILISERS FIRST APPLIED IN SPRING OF 1964, ASSESSMENTS MADE IN AUTUMN OF 1964 AND 1965.) CULBIN FOREST, MORAYSHIRE.

Treatment	lb. N per acre at each application	No. of applications per growing season	Total annual application lb. N per acre	N% in top whorl needles Oct. 1964	1965 Basal area increment (sq. ft. q. g. per acre)	N% in top whorl needles Oct. 1965
N_0	Control	–	0	0·9	0·8	0·9
N_1	75	1	75	1·1	2·6	1·3
N_2	150	1	150	1·3	3·0	1·7
N_3	150	2	300	1·9	3·5	2·0
N_4	150	3	450	2·0	3·8	2·3

because the moisture content by weight considers only the mass of water and peat, whereas the moisture content by volume is a function of the peat, water and pore space. Only in the unique case of zero pore space will the profiles of water content by volume, and water content by weight, be similar. Hence it would appear that a better picture is obtained of the moisture regime in peat by sampling on a volume basis.

SUMMARY

Investigations into the nitrogen nutrition of coniferous trees, in particular Corsican pine, have been continued. On the sand dunes of Culbin Forest heavily fertilized young Corsican pine are suffering from bud death and it is suggested that this may be due to a secondary deficiency of copper or boron. Determination of the nutrient content of a 36-year-old crop of Corsican pine and its associated forest floor produced the following values in kg. per ha.: N–586, P–75, K–207, Ca–230, Mg.–93, Na–36. From these results the average annual incorporation of nitrogen by the trees is calculated to be 7·4 kg. per ha. The annual application of 450 lb. of nitrogen per acre to this crop has more than doubled the needle nitrogen concentration and increased basal area growth by a factor of 4·5. It also resulted in an initial decrease in the weight and nitrogen content of the litter fall followed by a marked rise in the second year. Experiments in the greenhouse suggest that Corsican pine seedlings make maximum growth when nitrogen is supplied in the ammonium form. The application of nitrogen in the presence of phosphate to mature Scots pine is found to result in appreciable increases in growth.

Comparative trials of different methods of peat sampling have emphasised the value of sampling on a volume basis.

NUTRITION EXPERIMENTS IN FOREST NURSERIES

By BLANCHE BENZIAN, J. BOLTON, J. K. COULTER
and G. E. G. MATTINGLY,
Rothamsted Experimental Station, Harpenden, Herts.

Extracts from *Rothamsted Annual Report* for 1965.

Soil Factors and Root Development

Plots of Sitka spruce, Norway spruce and Japanese larch transplants were grown on three sites on different parts of a slope at the Wareham forest nursery. At the end of the growing season the roots of all species at two sites were almost completely confined to the 8-in.-deep cultivated (Ap) horizon. Most roots only just entered the top inch of the A_2 horizon, where even the strong tap root of Japanese larch then turned horizontally. Norway and Sitka spruce behaved similarly in 1964. The A_2 horizon is almost pure sand with no cracks, and its bulk density (1·49 g/cc) may be so large as to prevent roots from penetrating. Hidding and Van den Berg (*Proc. 7 Int.Congr. Soil Sci.* (1960) 1, 369) showed that roots do not penetrate sands with less than 40% pore space, i.e. bulk density of 1.56. Another reason may be that the A_2 horizon is often water-logged, for pits dug soon after heavy rain showed water flowing laterally through the A_2 over the top of the impermeable B/humus horizon. At one site, without any A_2 horizon, which was probably destroyed by deep digging, Japanese larch roots penetrated 30 in.

The shallow rooting imposed on small trees by these soils has the practical advantage that they can be lifted easily with whole root systems; but for other crops such an impermeable layer may be detrimental. Water probably flows through the A_2 after most showers, and soluble fertilizers may be washed down the slope, so interfering with experiments.

J. K. COULTER

Maximum Productivity

At Wareham nursery perennial ryegrass was sown in plots of 1 sq. yd., with basal dressings of magnesium ammonium phosphate and potassium metaphosphate. When 2 in. high the grass was top-dressed with "Nitro-Chalk" to supply amounts of N ranging from 0 to 320 lb./acre at each occasion. Similar dressings of N and a basal dressing of 107 lb/acre K were given after the first cut. Fertilisers were not given after the second cut, but were after the third, as after the first. The rainfall of 14·5 in. during the experiment was supplemented by 5 in. of irrigation (this need was calculated from preceding rainfall). Four cuts were taken, the first on 21 June, the last on 3 November. Dry-matter yields were increased by N dressings up to 672 lb/acre (given in three applications), but not beyond, and 960 lb/acre N depressed yield slightly. The largest total dry matter yield from the four cuts was 10,500 lb./acre. The amount of N applied had little effect on percentage K in grass at the first, second and fourth cuts; K. was not applied before the third cut, and its percentage in grass fell from about 1·8 with the smallest N dressing to 1·3 with the largest. The largest yields removed 230 lb./acre K, nearly three-quarters the amount applied as fertilizer. The sodium concentration in the grass increased with increasing dressings of N, and was particularly large, about 0·5%, in the third cut on plots given much N for earlier cuts. Altogether about 40 lb./acre of Na was recovered by grass dressed with the most N. Some of this must have come from rain, for the top 6 in. of Wareham soil contains only about 35 lb./acre of exchangeable Na. The N in the first cut ranged from 1·95% on plots without N to 5·34% on those with the largest amount, and grass from these latter plots contained free nitrate. Most N was recovered (41%) from plots given 576 lb./acre N.

J. K. COULTER

Seedbeds and transplant beds of Sitka spruce had basal fertilizer dressings of magnesium ammonium phosphate plus potassium metaphosphate, and ten incremental dressings of "Nitro-Chalk", ranging from none to a total of 60 g N/sq. yd. (about 640 lb. N/acre). The seedlings were 1·1 in. high on "no N" plots, 2·4 in. with the "low N" range, 2·6 in. in the middle range and 2·1 in. with most N. The corresponding values for transplants were: 6·3, 7·9, 7·5 and 6·7. The most dry matter produced by seedlings was 470 g/sq. yd. (5,000 lb./acre) and by transplants 450 g/sq. yd. (4,800 lb./acre). N in both seedlings and transplants ranged from 0·6% on the "no N" plots to 1·3 with the largest dressings. Ancillary tests showed that there was no response to the 5 in. of irrigation water supplied.

B. BENZIAN

Slow-release Fertilizers for Conifer Seedlings

The two experiments described last year were continued during 1965, when spring and early summer rainfall and leaching losses were less than in 1964. Responses to potassium for both height and dry matter were larger than in 1964. Table 18 shows that the standard soluble PK compound (made from superphosphate and potassium chloride), which was no better than superphosphate alone in 1964, trebled plant height in 1965, and that considerable further improvement was obtained by supplementing the PK compound with summer top-dressings of potassium nitrate. The slow-release fertilizer—potassium metaphosphate—was again superior to the soluble PK compound. Seedlings grown with any of the PK fertilizers contained similar % P, but % K increased in the same order as in 1964, i.e. PK compound alone, potassium dihydrogen phosphate, potassium metaphosphate, PK compound plus potassium nitrate.

A second experiment compared magnesium ammonium phosphate at rates 1, 2 and 4, plus potassium chloride, with the "standard fertilizer" consisting of "Nitro-Chalk", superphosphate, potassium chloride and kieserite. (Rate 1 supplied as much phosphorus as the "standard fertilizer".) To avoid the potassium deficiency caused in 1964 by early leaching, all four treatments were supplemented by summer top-dressings of potassium nitrate. A fifth treatment consisted of a compost made from bracken and hop-waste, used in conjunction with "standard fertilizer". The plants grown with magnesium ammonium phosphate (differences between rates were small) were all larger than those grown with "standard fertilizer", but did not quite equal those with standard fertilizer plus compost.

B. BENZIAN, J. BOLTON AND G. E. G. MATTINGLY

TABLE 18

THE EFFECTS OF P AND K FERTILIZERS ON 1-YEAR SITKA-SPRUCE SEEDLINGS AT WAREHAM IN 1965.

	Rates applied (g. element/sq. yd.)		Height (in.)	Dry matter of tops (mg/ plant)	Colour score*	P % (in dry matter)	K % (in dry matter)
	P	K					
No fertilizer	0	0	0·4	27	Severe	0·19	0·28
Superphosphate only	9	0	0·5	35	Severe	0·28	0·20
PK compound (from super + KCl)	9	9	1·4	117	2	0·22	0·32
Potassium dihydrogen phosphate	9	12	1·1	84	1	0·23	0·57
PK compound + KNO_3	9	15	1·7	158	0	0·21	1·12
Potassium metaphosphate	9	12	1·6	131	0	0·21	0·70

*For the purple and yellow discoloration typical of K-deficiency (O = no discoloration.)

Effects of Nitrogen and Potassium Concentrations in Conifer Seedlings on Frost Damage

Top-dressings of nitrogen and potassium were applied to conifer seedbeds at Wareham Nursery so late in the season that nutrient concentrations were increased in the seedlings without further increasing their growth. Frost damage during December, in the form of needle browning, was decreased by increasing % N in Sitka spruce and Western hemlock and was almost eliminated by increasing % K in Sitka spruce. (Table 19).

TABLE 19

NITROGEN AND POTASSIUM CONCENTRATIONS IN SEEDLINGS OF SITKA SPRUCE (PICEA SITCHENSIS) AND WESTERN HEMLOCK (TSUGA HETEROPHYLLA) IN RELATION TO FROST DAMAGE.

	N concentration (% in dry matter)		Score for frost damage*	
	Low	High	N% Low	N% High
Experiment A				
Sitka spruce	0·94	1·78	2·2	1·2
W. hemlock	0·79	1·99	2·8	2·2

	N concentration (% in dry matter)		K concentration (% in dry matter)		Score for frost damage*			
	Low	High	Low	High	N low K low	N high K low	N low K high	N high K high
Experiment B								
Sitka spruce	0·82	1·58	0·42	1·01	3·4	1·0	0·0	0·5

*The higher the score the larger the number of seedlings damaged by frost.

Sitka spruce seedlings at Kennington Extension Nursery, and on the Reference Plots at Woburn (see *Rothamsted Report* for 1961, pp. 51–52), on "no K" plots showed browning resembling the symptoms of the "low K" seedlings at Wareham, though much more severe. Seedlings on plots given potassium were almost completely free from symptoms.

B. BENZIAN

Calcium as a Plant Nutrient for Sitka Spruce

Some of the concentrated fertilizers now commonly used contain little or no calcium, so calcium deficiencies in crops are more likely to occur than previously —especially on very acid soils. At Wareham nursery, on a site with pH values (in $CaCl_2$ solution) of 3·3–3·5, Sitka spruce seedbeds received increasing dressings of calcium (2½, 5, 10, 20 g Ca/sq.yd.) applied as calcium sulphate. The basal NPKMg manuring consisted of calcium-free fertilizers: Ammonium nitrate ("Nitram"), potassium dihydrogen phosphate and kieserite. Seedling heights, which ranged from 1·5 in. on "no calcium" plots to 2·2 in. with the most calcium, followed the rates of dressing closely. pH values at the end of the growing season were unchanged, even by the largest calcium sulphate dressings.

B. BENZIAN AND J. BOLTON

INFLUENCE OF LEAF-CHARACTERS AND GROWTH HABIT ON THE PRODUCTION OF DRY MATTER BY FOREST TREES

By D. R. CAUSTON AND P. F. WAREING,
Botany Department, University College of Wales, Aberystwyth.

A study is being made of the effect of various morphological characters on the rate of production of dry matter in hardwood trees. Since the productivity of a tree will be markedly affected by its total leaf area, it is important to study the influence of various morphological characters determining the leaf area of the crown, viz. (1) the number of leaves, (2) the area of individual leaves, and (3) the branching habit. Two species, sycamore (*Acer pseudoplatanus*) and birch (*Betula pubescens*), have been chosen because of their contrasting habits in respect of these three characters. In a field experiment with first-year seedlings of sycamore and birch, the effect of decapitation and de-branching has been studied by comparison of seedlings so treated with normal seedlings, using the methods of growth analysis. The results with these first year seedlings must be regarded as preliminary and subject to confirmation by the results to be obtained in the second year.

De-branching (i.e. removal of lateral shoots) of birch seedlings, which normally show considerable natural branching, markedly reduced the total number of leaves per plant, but there was a corresponding increase, within certain limits, of the size of the individual leaves of plants so treated. Moreover, the net assimilation rate (NAR) of the de-branched seedlings was higher than in the untreated ones, and consequently the overall dry weight of the treated plants was not significantly different from that of the normal seedlings. Since first-year seedlings of sycamore normally show little branching, removal of lateral shoots had little effect on seedlings of this species. On the other hand, decapitation had little effect on the production of laterals in birch seedlings since the normal seedlings are already highly branched, whereas this treatment considerably increased the number of laterals of the sycamore seedlings and hence increased the total number of leaves per plant. However, the area of the individual leaves was decreased by this latter treatment and the total dry weight of the decapitated seedlings, at the end of the growing season, was not significantly different from that of the normal seedlings. The effects of these various treatments on the leaf-area ratios and relative growth rates have also been followed.

It would seem from these preliminary results that birch and sycamore seedlings have compensatory mechanisms to counteract the effects of the treatments applied, so that, for example, a reduction in leaf number is compensated by increased leaf area and increased net assimilation rate in birch seedlings. It would appear, therefore, that the maximum photosynthetic capacity of the leaves is not being fully exploited in normal seedlings of birch.

PATHOLOGY EXPERIMENTS ON SITKA SPRUCE SEEDLINGS

By G. A. SALT,
Rothamsted Experimental Station, Harpenden, Herts.

The Effect of Seed-borne Fungi on the Viability of Sitka Spruce Seed

It is often found that far fewer Sitka spruce seedlings emerge in nursery beds than would be expected from germination tests with seeds in the laboratory. Several species of the fungus *Pythium* are known to cause considerable loss in some years in some nurseries, but losses of 50% or more are frequently recorded in seedbeds that have been treated with a formalin drench, or other partial sterilants. This suggests that the importance of seed-borne fungi needs investigating.

Germination tests are usually done at temperatures near 25°C, whereas seed sown at the usual time in mid-March has to survive several weeks at much lower temperatures before germination begins. To test whether moist, cool conditions affect germination, seed having a germination of 81% in laboratory tests was sown on moist, cellulose-free, material in petri dishes at the rate of 50 seeds per dish, and incubated at 10°C for 0, 3, 5, 7, 17 and 32 days. Then they were transferred to a temperature of 20°C until no more seeds germinated. Seed dusted with 50% thiram was compared with untreated seed and there were four replicates of each treatment. Seed that failed to germinate was cut in half in a 25% solution of 'Chloros' (sodium hypochlorite), the embryo and endosperm plated on PDA, incubated at 5°C for a week and then at 20°C until overgrown by fungi.

TABLE 20

EFFECT OF INCUBATION AT 10°C. ON GERMINATION AT 20°C.

Days at 10°C.	Per cent germination		Per cent ungerminated seed yielding:							
	Untreated	Thiram	Bacteria		Penicillia		P.S. Fungus		Other Fungi	
	–	T	–	T	–	T	–	T	–	T
0	82	84	30	45	50	15	5	10	5	5
3	72	78	15	75	35	5	20	10	30	10
5	68	73	20	75	25	0	20	5	40	15
7	65	84	0	65	60	5	20	20	35	5
17	63	78	15	0	5	0	45	17	10	5
32	40	72	0	5	10	0	50	30	15	0

Table 20 shows that germination at 20°C without pretreatment at 10°C agreed with the 81% obtained in the seed testing laboratory. Ungerminated seed yielded mainly bacteria and *Penicillia*; treatment with thiram increased the bacteria and greatly decreased the *Penicillia* without any effect on germination. Seed incubated at 10°C lost viability faster when untreated than when treated with thiram. This loss was associated with substantial increases in numbers of an unidentified, slow-growing, fungus with a coarse mycelium giving an orange-brown colony with blue-green irregular margins on potato-dextrose agar. This fungus is provisionally called the psychrophilic seed fungus* (P.S. fungus) because it occurs on seed kept cold. Bacteria, *Penicillia* and the P.S. fungus accounted for most of the isolates from ungerminated seed, but whereas the first two became fewer with increasing time of incubation at 10°C, the P.S. fungus became more abundant. From a total of 250 ungerminated seed, 69 produced bacteria, 55 the P.S. fungus, 43 *Penicillia*, 7 *Cylindrocarpon*, 5 *Rhizoctonia solani*, 4 *Verticillium*, 3 *Ceratobasidium*, 2 *Mucor*, 1 *Gliocladium roseum* and 13 sterile or unidentified fungi.

In another experiment the effect on germination of incubation at 10°C for 24 days was measured on 15 different seed lots which had been in cold storage for several years and differed greatly in their germination.

TABLE 21

EFFECT OF INCUBATION AT 10°C. ON GERMINATION OF SITKA SPRUCE OF DIFFERENT ORIGINS.

Ident. Number	Per cent germination at 20°C. Pretreatment		Per cent ungerminated seed yielding: P.S. Fungus		Gliocladium	
	Nil	24 days at 10°C.	–	10°	–	10°
57 (7114)	52	2	5	50	0	
59 (7111)	40	16	5	60	0	20
58 (7116)	74	78	0	10	0	10
57 (7986)	12	10	0	30	0	40
57 (7117)	10	16	0	0	0	
56 (127)	18	14	0	0	0	
56 (7116)	50	78	0	0	0	30
58 (7971)	74	92	0	0	0	
57 (7951)	70	56	0	0	0	
57 (7985)1	30	52	0	0	0	
57 (7111)	60	60	0	0	0	60
57 (7971)	68	58	0	0	0	40
57 (7972)	44	68	0	0	0	30
57 (7952)	40	48	0	0	0	
58 (7985)3	36	80	0	0	0	

Table 21 shows that the 10°C treatment substantially decreased germination of only two lots of seed, both of which were infected with the P.S. fungus. With little or none of this fungus, incubation at 10° either had no effect on germination or increased it. The P.S. fungus was not found on seed of which only a very small proportion germinated, and so it is unlikely to cause deterioration of dry seed during storage. Such seed was usually contaminated with moulds of the genera *Rhizopus*, *Mucor*, *Penicillium* and *Chaetomium*. *Gliocladium* was isolated frequently only from ungerminated seed that had been incubated at 10°C, and was not associated with any germination loss in this experiment. Other fungi isolated only occasionally were *Cylindrocarpon*, *Fusarium*, *Epicoccum*, *Alternaria*, *Stemphyllium*, *Trichoderma*, *Phialophora*, *Aspergillus* and *Humicola*.

*See Epners, *Canad. J. Bot.*, 1964.

The effect on germination of various fungi isolated from seed was tested at 20°C, with and without pretreatment for three weeks at 10° and 5°C. The seed, with a germination of 81%, was surface sterilized in 25% Chloros before sowing in small pots of quartz grit and in Petri dishes of water agar, both having been inoculated with agar discs of the test fungi. The P.S. fungus failed to grow and had to be omitted. Death of seeds and seedlings was sometimes associated not with the added inoculum but with other fungi that had probably survived surface sterilization of the seed, or may have arrived as aerial contaminants. These deaths were largely associated with the presence of *Rhizoctonia solani*, the P.S. fungus, *Cylindrocarpon*, *Gliocladium roseum*, and bacteria. Fungi of the following genera did not affect germination or were not recovered from dead seeds or seedlings: *Rhizopus*, *Penicillium*, *Aspergillus*, *Trichoderma*, *Mortierella*, *Mucor*, *Phialophora*, *Cladosporium* and *Coniothyrium*. *Epicoccum* and *Phoma* did not decrease germination but were often recovered from dead seeds.

Fungi showing varying degrees of pathogenicity are recorded in Table 22.

TABLE 22

PATHOGENICITY OF FUNGI ISOLATED FROM SEED

Inoculated Fungus	Per cent germination at 20°C. after incubation at			Recovery of inoculated fungus	Other fungi recovered
	20°C.	10°C.	5°C.		
Nil	80	73	35	—	P.S. ††
Gliocladium roseum	40	33	60	†††	—
Gliocladium roseum	68	62	60	†	—
Cylindrocarpon	52	35	65	†††	—
Cylindrocarpon	70	32	90	††	
Cylindrocarpon	80	42	58	†††	P.S. †
Rhizoctonia solani	70	0	30	†††	
Fusarium avenaceum	72	72	95	††	
Fusarium sp.	60	70	70	†	
Phoma	72	62	48	††	P.S. ††
Phoma	95	68	88	†††	
Phoma	60	22	80	†††	P.S. ††
Epicoccum	68	75	80	†††	

Notes: † Recovered occasionally.
†† „ frequently.
††† „ from almost every seed or seedling.

Incubation at 5°C nearly always affected germination less than incubation at 10°C, except in the uninoculated control where poor germination after 5°C treatment was associated with the presence of the P.S. fungus. Of the two isolates of *Gliocladium*, one was moderately pathogenic, the other only slightly. The three isolates of *Cylindrocarpon* were more pathogenic at 10°C than at 5°C or 20°C. *Rhizoctonia* killed all seeds at 10°C, whereas at 20°C most seeds germinated and the radicles were killed later. The two *Fusaria* had little effect on germination but were reisolated from diseased radicles.

Germination Losses in Nursery Seedbeds

Seed from the same source as that used in the laboratory experiments was sown early in April at Wareham and Old Kennington nurseries. The seed sown on one half of each plot was treated with red lead, and on the other half with 50% thiram dust. Plots were sampled 3, 4 and 5 weeks after sowing by removing blocks of soil measuring 2 inches by 9 inches and 2 or more inches deep. Seed extracted by washing through sieves was separated into "germinated" and "not germinated", and the viability of the latter was tested on moist quartz grit at 20°C. Seed that had failed to germinate after 7 to 10 days incubation was cut and the contents plated on potato dextrose agar as before.

TABLE 23

VIABILITY OF SEED RECOVERED FROM SOIL.

	Kennington K.102			Wareham W.82		
Weeks after sowing	Number recovered	Per cent germinated	Per cent viable	Number recovered	Per cent germinated	Per cent viable
3	384	7	67	623	62	83
4	747	42	82	619	86	94
5	580	79	87	670	89	90

Table 23 shows that in neither soils was there any loss of viability, as there had been in laboratory experiments at 10°C. Under these conditions thiram seed dressing had little effect and increased the percentage of viable seed by a mean of only 3%.

Many ungerminated seeds yielded no micro-organisms; of 200 recovered from Wareham soil 44% were sterile, 19% produced bacteria, 28% the P.S. fungus, and 14% produced other fungi including *Cylindrocarpon*, *Fusarium*, *Trichoderma*, *Cladosporium*, *Zygorhynchus*, *Coniothyrium*, *Varicosporium* and *Phialophora*. Similarly, of 330 ungerminated seed from Kennington soil, 34% were sterile, 22% produced bacteria, 22% the P.S. fungus, 23% other fungi including *Cylindrocarpon*, *Fusarium*, *Phoma* and *Penicillia.*

Germination was not affected by seed-borne fungi in these two experiments because all the viable seed sown germinated, but this might not be so in other years with different seedbed conditions. However, losses occurred soon after germination because only 60% of the viable seed emerged at Kennington and 70% at Wareham, representing 1,076 and 1,254 seedlings per square yard respectively. There were no losses after emergence at Wareham, but at Kennington more than 100 died, on average, per square yard. Germinating seeds with diseased radicles at Kennington and Wareham both yielded several species of *Pythium*, but a reliable measurement of the damage done by this fungus was not obtained because infected seedlings rotted rapidly and only a few were found on any one occasion. In contrast, species of *Cylindrocarpon* and *Fusarium* were less lethal than *Pythium* and were isolated from many apparently healthy as well as diseased roots. Thus, in these two experiments, losses occurred mainly after germination and before emergence, and were caused not by seed-borne fungi but by soil-inhabiting fungi, of which *Pythium* was the principal pathogen.

A different result was obtained in two other experiments at Kennington and Ringwood nurseries. The same seed as used in the other experiments was compared with poor quality seed having a germination of only 18%. Although the two lots of seed were sown at different rates to give 1,800 viable seed per square yard, the good seed at Ringwood yielded 1,408 seedlings and thiram seed dressing had no beneficial effect, whereas the poor seed yielded only 602 seedlings and thiram increased emergence by 69% to give 1,019 seedlings per square yard. A similar result was recorded at Kennington where thiram increased the emergence of poor seed by 31%. The increases in emergence were similar in untreated soil and in soils partially sterilized with formalin or dazomet. This suggests that seed-borne pathogens were largely responsible for losses in poor quality seed, but this could not be confirmed because the detailed sampling and plating of diseased seeds, as was done in the other experiments, could not be repeated.

Growth of Seedlings in Partially Sterilized Soil

At Ringwood Nursery, soil sterilants last applied in December 1962 substantially increased survival and growth of Sitka spruce sown in April 1965. In untreated soil 1,380 seedlings survived and grew to an average height of 1·11 inches compared with 1,476, 1,569 and 1,574 seedlings measuring 1·70, 2·35 and 1·82 inches in plots previously treated with formalin, metham-sodium and dazomet respectively. The ectoparasitic nematode *Hoplolaimus uniformis*, abundant in untreated soil, was still rare in soil treated three years previously with sterilants, whereas the numbers of isolates of root-infecting fungi, mainly *Pythium*, *Cylindrocarpon* and *Fusarium* were similar in all plots.

Fallowing half the plots in 1964 had no effect on numbers of seedlings in 1965, but it increased heights by a mean of 23% in untreated soil, and by 19% in soils treated with sterilants three years ago. Fallowing had no effect on numbers of *H. uniformis* or isolates of root-infecting fungi, and the growth response was probably a nutritional effect.

SUMMARY

The following fungi isolated from Sitka spruce seed were associated with germination failure and were reisolated consistently from dead seeds or seedlings:—*Rhizoctonia solani*, *Cylindrocarpon*, *Gliocladium roseum* and an unidentified psychrophilic fungus. Losses were greater when seed was incubated at 10° than at 20° or 5°C, and were decreased by treating seed with a 50% thiram dust.

In seedbeds at Wareham and Old Kennington Nurseries, all the viable seed sown germinated, losses occurred mainly before emergence and were associated with several different species of *Pythium*. The losses were less in the acid Wareham soil than in the near-neutral soil at Kennington.

Growth responses to formalin, methan sodium and dazomet applied to seedbeds at Ringwood in December 1962 were recorded on Sitka spruce sown in April 1965, and were associated with the control of parasitic nematodes.

FIRES IN FOREST AND HEATHLAND FUELS

By A. J. M. HESELDEN and M. WOOLLISCROFT,
Ministry of Technology and Fire Offices' Committee Joint Fire Research Organization, Boreham Wood, Herts.

Last year a theory was described by Thomas and Law (1966) which could predict the rate of fire spread in deep fuel beds, both in still air conditions and in a wind. The rate of fire spread in shallow fuel beds with a wind is more difficult to predict, but a theory has now been formulated (Thomas, 1965) which may form the basis for correlating experimental data.

In parallel with this work, further field measurements have been made during controlled burns to relate experimental and theoretical work to practical conditions. The Forestry Commission has also begun to make a systematic collection of data from controlled burns carried out throughout Great Britain.

Theoretical Study

A study has been made of the contribution of flame radiation to fire spread in forests (Thomas, 1965). If the heating of unburnt fuel ahead of a steadily moving fire front is by radiation from the flames above the fuel bed and by radiation transmitted through the fuel bed, there are two possible rates of spread. In one the flames above the fuel bed do not radiate well as they are optically thin and the fire spread is then slow, and is controlled by radiation passing through the fuel bed. In the other, the flames are optically thick and the fire spread, which is rapid, is controlled by radiation from the flames above the fuel bed.

Between these two rates of spread there is an unstable state. Some calculations have been made which suggest that rapid spread is only possible for fire fronts wider than about 10 metres (33 feet).

Data from Controlled Burns

A preliminary analysis of the thirty-nine data cards received from the Forestry Commission in 1965, has been made to see how far relationships found from laboratory experiments can be applied to field data and particularly, to find the most profitable methods of analysing future information. The analysis has shown that the flame length calculated from flame height and deflection from the vertical gives a more reliable measure of burning rate per unit cross-sectional area of the fuel bed, than that calculated from the measured rate of fire spread and fuel bulk density. But the variation in the results between different fuels and different observers is large and the expected correlations must await more results before they can be checked.

Field Work—Joint Fire Research Organization Measurements

Measurements were made by a team from the Fire Research Station at controlled burns in the New Forest in March 1966. Those from two fires in different fuels burning into the wind (backing fires) were comparable with measurements obtained in 1965 and with the theory for still air conditions, showing that for fires burning into the wind the heat transfer is not predominantly from the flames.

This may be contrasted with the results from two fires burning with the wind (head fires) in which the rate of fire spread in a light wind was significantly greater than could be accounted for by radiation through the fuel bed alone, so that heat transfer from the flames above the fuel bed must be a significant or even controlling factor. A head fire in mixed fuel consisting of dwarf gorse, cross-leaved heath and fine grass was particularly interesting. Measured values of heat flux, flame length and residence time were more consistent with a model in which grass was regarded as the effective fuel for spread, even though some of the other thicker fuel had burnt.

These data are also being analysed to derive values for the minimum width of fire-break which could stop a fire, assuming the fire-break was produced by wetting down the fuel. For backing fires, or fires in still air, a value can be derived from the reduction in intensity of radiation passing through the fire-break, assuming that the heating of the flames above the fuel bed can be entirely neglected. The widths of fire-breaks for the heather and gorse fuels were calculated to be about 90 cm. (3 ft.) and 35 cm. (14 in.) respectively.

An estimate has been made of the width of fire-break required for head fires, which are more important, from the configuration factor and radiative properties of the flame and the energy required to ignite the fuel. Typical values for an average wind speed of about 3½ m/s (8 mile/h), for live and dead heather were calculated as about 3 m. (10 ft.) and 5½ m. (18 ft.) respectively, i.e. several times greater than for a backing fire. These figures must be regarded as subject to revision for, as yet, no allowance has been made for the effect of burning brands carried by the wind.

REFERENCES

THOMAS, P. H., and LAW, Margaret. 1966. Experiments on the spread of fire. *Report on Forest Research*, 1965. London, 1966. H.M. Stationery Office.

THOMAS, P. H. 1965. The contribution of flame radiation to fire spread in forests. *Joint Fire Research Organization F.R. Note* No. 594/1965. November 1965.

VOLES AND THEIR PREDATORS

By J. D. LOCKIE,
Department of Forestry and Natural Resources, University of Edinburgh.

Studies on the Predators of Voles

The study area at the west end of the Carron Valley Forest was abandoned owing to the closure of much of the canopy and a new study area set up in young plantations at the east end. Unfortunately, weasels, stoats and voles remained scarce during the year and, for this reason, an additional study area in Midlothian was chosen.

The following aspects have been investigated:

(i) *Territoriality in Male Weasels.* This was confirmed as was the fact that male territories are held throughout the year.

(ii) *Territoriality in Female Weasels.* A female weasel is accepted into the territory of a male and defends a small area within the larger territory against the resident male and against intruding males and females. The female defends her small territory most vigorously in late pregnancy and when the young are in the nest. Even so her presence in the male's territory is dependent on his acceptance of her, which in turn is dependent on his level of aggressiveness. Shortage of food and also a high density of weasels are two factors which can increase the aggressiveness of male weasels, sometimes to the extent of their not accepting females. Both factors may be important in explaining why female weasels survive often less well than males. The practical aspect of this is that if a weasel population can be adversely affected by factors unrelated to the food supply (for example, high population density, *per se*), these predators will at such times be inefficient as a controller of their prey.

Territoriality in weasels has been written up and will shortly appear in the proceedings of a symposium held in 1966 at the Zoological Society of London.

Studies on Field Voles, Microtus agrestis

The big gap in knowledge of field voles, and therefore in the understanding of their fluctuations, is their social organization. This is difficult to follow with the standard Longworth trap since short-tailed field voles do not enter this trap readily.

A technique was therefore developed in which an animal is caught, one toe removed and the animal released. Wooden tunnels are laid out in the study area connecting with the runway system of the voles in the grass. The tunnels contain smoked paper, or paper with an ink pad, or paper treated with a talcum powder preparation, in order to record the individual footprint. The technique has the advantage that the natural daily movement of the animal is not prevented by its being held in a trap until released. The technique is not yet finalised but it does show promise.

A paper on the predation by weasels, stoats and short-eared owls on voles is in preparation.

VIRUS DISEASES OF FOREST TREES

By T. W. TINSLEY,
Commonwealth Forestry Institute, University of Oxford.

Work has continued on Poplar Mosaic virus and there are indications that a complex of viruses may be involved. Collections have been made in the field of different symptom types from a wide range of poplar clones. These are being studied in the glasshouse on herbaceous hosts, chiefly *Nicotiana glutinosa*.

Grafting stocks of a range of important forest tree species have been planted in the Bagley Wood Nursery and some should be ready for the 1966 season.

APPENDIX I

Main Experimental Projects and Localities

NURSERY EXPERIMENTS

Benmore Nursery, near Dunoon (Argyll)
Bush Nursery, near Edinburgh
Fleet Nursery, Gatehouse of Fleet (Kirkcudbright)
Inchnacardoch Nursery, near Fort Augustus (Inverness)
Kennington Nursery, near Oxford

Newton Nursery, near Elgin (Moray)
Sugar Hill Nursery, Wareham Forest (Dorset)
Tulliallan Nursery, near Alloa (Fife)

AFFORESTATION EXPERIMENTS ON PEAT

Achnashellach Forest (Wester Ross)
Beddgelert Forest (Caernarvon)
Clocaenog Forest (Denbigh)
Inchnacardoch Forest (Inverness)
Kielder Forest (Northumberland)

Naver Forest (Sutherland)
Strathy Forest (Sutherland)
Watten (Caithness)
Wauchope Forest (Roxburgh)

AFFORESTATION EXPERIMENTS ON HEATHLAND

Allerston Forest, Harwood Dale (Yorkshire)
Clashindarroch (Aberdeenshire)
Inshriach Forest (Inverness)
Land's End Forest, Croft Pascoe (Cornwall)
Millbuie, Black Isle Forest (Easter Ross)

Taliesin Forest (Cardigan)
Teindland Forest (Moray)
Wareham Forest (Dorset)

FOREST NUTRITION

Allerston Forest, Broxa (Yorkshire)
Arecleoch Forest (Ayrshire)
Clocaenog Forest (Denbigh)
Culbin Forest (Moray)
Exeter Forest (Devon)

Inchnacardoch Forest (Inverness)
Selm Muir (Mid and West Lothian)
Shin Forest (Sutherland)
Tarenig Forest (Cardigan)
Teindland Forest (Moray)

Wareham Forest (Dorset)
Wilsey Down Forest (Cornwall)

SOIL MOISTURE STUDIES

Aldewood Forest (Suffolk)
Alice Holt Forest (Hampshire)
Bernwood Forest (Oxfordshire)
Bramshill Forest (Hampshire)
Inchnacardoch Forest (Inverness)

New Forest (Hampshire)
Queen Elizabeth Forest (Hampshire)
Swaffham, Thetford Chase, Forest (Norfolk)

PROVENANCE EXPERIMENTS

Scots pine:	Findon, Black Isle, Forest (Easter Ross) Thetford Chase (Norfolk)
Corsican pine:	Brighstone Forest (Isle of Wight) Cotswold (Gloucestershire) Thetford Chase (Norfolk) Wareham Forest (Dorset)
Lodgepole pine:	Achnashellach Forest (Wester Ross) Allerston Forest, Wykeham (Yorkshire) Brendon Forest (Somerset) Ceiriog Forest (Denbigh) Clocaenog Forest (Denbigh) Forest of Deer (Aberdeen) Millbuie, Black Isle Forest (Easter Ross) New Forest (Hampshire) Taliesin Forest (Cardigan)
European larch:	Coed y Brenin (Merioneth) Mortimer Forest (Herefordshire) Savernake Forest (Wiltshire)
European and Japanese larches:	Clashindarroch Forest (Aberdeen) Drummond Hill Forest (Perth) Fetteresso Forest (Kincardine) Lael Forest (Wester Ross)
Douglas fir:	Glentress Forest (Peebles) Land's End Forest, St. Clement (Cornwall) Lynn Forest, Shouldham (Norfolk) Mortimer Forest (Shropshire) Rheidol (Cardigan)
Norway and Sitka spruces:	Brendon Forest (Somerset) Cannock Chase (Staffordshire) Forest of Dean (Gloucestershire) Newcastleton Forest (Roxburgh) The Bin Forest (Aberdeen)
Silver fir (Abies alba):	Radnor Forest (Radnor) Thetford Chase (Norfolk)
Sitka spruce:	Clocaenog Forest (Denbigh) Coed Morgannwg (Glamorgan) Glendaruel Forest (Argyll) Kielder Forest (Northumberland) Mynydd Ddu Forest (Monmouth) Radnor Forest (Radnor) Ratagan Forest (Wester Ross) Taliesin Forest (Cardigan) Wark Forest (Northumberland) Wilsey Down Forest (Cornwall)

Western hemlock:	Allerston Forest, Wykeham (Yorkshire) Benmore Forest (Argyll) Brecon Forest (Brecon) Brendon Forest (Somerset) Clocaenog Forest (Denbigh) New Forest (Hampshire) Rheidol Forest (Cardigan) Thetford Chase (Norfolk) Wareham Forest (Dorset)
Western Red cedar:	Alice Holt Forest (Hampshire) Benmore Forest (Argyll) Cannock Chase (Staffordshire) New Forest (Hampshire) Radnor Forest (Radnor) Thetford Chase (Norfolk)
Beech:	Queen Elizabeth Forest (Hampshire) Savernake Forest (Wiltshire) Wendover Forest (Buckinghamshire)
Oak:	Forest of Dean (Penyard) (Herefordshire)

CONVERSION OF COPPICE

Alice Holt Forest, Marelands (Hampshire)
Cranborne Chase (Dorset and Wiltshire)
Forest of Dean, Penyard and Flaxley (Herefordshire and Gloucestershire)
Hursley Forest (Hampshire)

PLANTING EXPERIMENTS ON CHALK DOWNLANDS

Friston Forest (Sussex)
Queen Elizabeth Forest (Hampshire)

CULTURE OF OAK

Tintern Forest, Crumbland Wood (Monmouth)
Dymock Forest (Gloucestershire and Hereford)
Forest of Dean (Gloucestershire and Hereford)

DRAINAGE EXPERIMENTS

Bernwood Forest (Oxford and Buckinghamshire)
Forest of Ae (Dumfries)
Halwill Forest (Devon)
Hartland Forest (Devon)
Hafren Forest (Montgomery)

Kershope Forest (Cumberland)
Kielder Forest (Northumberland)
Lennox Forest (Stirlingshire)
Loch Ard Forest, Flanders Moss (Stirling)
Orlestone Forest (Kent)
Towy Forest (Cardiganshire)

POPLAR TRIALS AND SILVICULTURAL EXPERIMENTS

Alice Holt Forest (Hampshire)
Bedgebury Forest (Kent)
Blandford Forest (Dorset)
Creran Forest (Argyll)
Dyfnant Forest (Montgomery)

Forest of Dean (Gloucestershire)

Greskine Forest (Dumfries-shire)
Lynn Forest, Gaywood (Norfolk)
Quantock Forest (Somerset)
Rogate Forest (Hampshire)

South Yorkshire Forest
Stenton Forest (East Lothian)
Wentwood Forest (Monmouthshire)
Wynyard Forest (Durham)
Yardley Chase (Bedfordshire and Northamptonshire)

ARBORETA

National Pinetum, Bedgebury (Kent)
Westonbirt Arboretum (Gloucestershire)
Whittingehame (East Lothian)

MAJOR COLLECTIONS OF SPECIES PLOTS

Bedgebury Forest (Kent)
Brechfa Forest (Carmarthen)
Crarae, near Minard (Argyll)
Kilmun, Benmore Forest (Argyll)
Thetford Chase (Norfolk and Suffolk)

SPECIES COMPARISIONS IN RELATION TO SPECIAL SITES

Achnashellach (Wester Ross)
Aldewood Forest (Suffolk)
Beddgelert Forest (Caernarvon)
Bodmin Forest (Cornwall)
Brendon Forest (Somerset)

Brownmoor (Dumfries)
Caeo Forest (Carmarthen)
Cairn Edward Forest (Kirkcudbright)
Clashindarroch (Aberdeen)
Coed Morgannwg (Glamorgan)

Dovey Forest (Merioneth and Montgomery)
Forest of Ae (Dumfries)
Forest of Dean (Gloucestershire)
Garadhban Forest (Stirling)
Glentress Forest (Peebles)

Glentrool Forest (Kirkcudbright)
Glen Urquhart Forest (Inverness)
Gwydyr Forest (Caernarvon)
Inchnacardoch Forest (Inverness)

Kielder Forest (Northumberland)
Kirroughtree Forest (Kirkcudbright)
Land's End Forest (Cornwall)
Micheldever Forest (Hampshire)
Mynydd Ddu (Brecon and Monmouth)
Naver Forest (Sutherland)

New Forest (Hampshire)
Pembrey Forest (Carmarthen)
Rockingham Forest (Northamptonshire)
Rosedale, Allerston Forest (Yorkshire)
Teindland Forest (Moray)

Thetford Chase (Norfolk)
Tintern Forest (Monmouth)
Wareham Forest (Dorset)
Wykeham, Allerston Forest (Yorkshire)

RE-AFFORESTATION EXPERIMENTS

Culloden Forest (Inverness)
Culbin Forest (Moray)
Drumtochty Forest (Kincardine)
Forest of Ae (Dumfries)
Kielder Forest (Northumberland)

Kirkhill (Aberdeenshire)
Lennox Forest (Stirling)
Michaelston, Coed Morgannwg (Glamorgan)
Newcastleton Forest (Roxburgh)
Radnor Forest (Radnorshire)

Redesdale Forest (Northumberland)
Thetford Chase (Norfolk and Suffolk)

WEED CONTROL

Alice Holt Forest (Hampshire)
Bramshill Forest (Hampshire)
Brendon Forest (Somerset)
Forest of Dean (Gloucestershire)
New Forest (Hampshire)

Rogate Forest (Hampshire)
Wareham Forest (Dorset)

WIND STUDIES

Hafren Forest (Montgomery)
Myherin Forest (Cardinganshire)
Mynydd Ddu (Brecon and Monmouth)
Radnor Forest (Radnorshire)

MENSURATION

The following are experiments in which permanent sample plots are used as assessment units and which are of interest for growth and yield studies. Replicated experiments are marked with an asterisk (*).

SPACING

Scots pine:	Thetford Chase (Suffolk and Norfolk) Roseisle Forest (Moray) Tintern Forest (Monmouthshire) Ebbw Forest (Monmouthshire)
Corsican pine:	Aldewood Forest (Suffolk)
European larch:	Mortimer Forest (Hereford) Forest of Dean (Gloucestershire) Radnor Forest (Radnor) Fleet Forest (Kirkcudbright)
Japanese larch:	Bodmin Forest (Cornwall) Dalbeattie Forest (Kirkcudbright) Drumtochty Forest (Kincardine) Rheola, Coed Morgannwg (Glamorgan) Crychan Forest (Brecon) Ebbw Forest (Glamorgan) Caeo Forest (Carmarthen) Brechfa Forest (Carmarthen)
Norway spruce:	Monaughty Forest (Moray) Clocaenog Forest (Denbigh, Merioneth) Kerry Forest (Montgomery) Rheola, Coed Morgannwg (Glamorgan)

Sitka spruce:	Allerston Forest (Yorkshire) Brecon Forest (Brecon) Rheola, Coed Morgannwg (Glamorgan) Gwydyr Forest (Caernarvon) Clocaenog Forest (Denbigh, Merioneth)
Douglas firs:	Allerston Forest (Yorkshire) Ystwyth Forest (Cardigan) Brechfa Forest (Carmarthen)

THINNING

Scots pine:	Aldewood Forest (Suffolk) Thetford Chase (Suffolk and Norfolk) Swaffham Forest (Norfolk) New Forest (Hampshire) Cannock Chase (Staffordshire) Edensmuir Forest (Fife)* Crown Estates, Fochabers, near Speymouth Forest, (Moray and Banff)
Corsican Pine:	Aldewood Forest (Suffolk and Norfolk) Thetford Chase (Suffolk and Norfolk) Sherwood Forest (Notts.)* Swaffham Forest (Norfolk) New Forest (Hampshire) Culbin Forest (Moray) Pembrey Forest (Carmarthen)
European larch:	Forest of Dean (Gloucestershire) Murthly Estate (near Strathord Forest, Perthshire)
Japanese larch:	Bodmin Forest (Cornwall) Stourhead Estate (Wiltshire) Glentress Forest (Peebles) Drumtochty Forest (Kincardine) Brechfa Forest (Carmarthen) Rheola Forest (Glamorgan)
Norway spruce:	Kershope Forest (Cumberland) Bowmont Forest (Duke of Roxburgh's Estate, Roxburghshire)* Bennan, Cairn Edward Forest (Kirkcudbright) Monaughty Forest, near Elgin (Moray) Tintern Forest (Monmouth)
Sitka spruce:	Brendon Forest (Somerset) Dovey Forest (Merioneth)* Forest of Ae (Dumfries) Ardgartan Forest (Argyll) Loch Eck Forest (Argyll)*
Picea omorica:	Bedgebury Forest (Kent)
Douglas fir:	Wensum Forest (Norfolk) Alice Holt (Hampshire)* Glentress Forest (Peebles) Mynydd Ddu (Brecon, Monmouth) Gwydyr Forest (Caernarvon)
Noble fir:	Dovey Forest (Merioneth, Montgomery)
Beech:	Nettlebed Estate (Buckinghamshire) Hampden Estate (Buckinghamshire)
Oak:	Micheldever Forest (Hampshire) Forest of Dean (Gloucestershire) Wensum Forest (Norfolk) Hazelborough Forest (Northamptonshire)

UNDERPLANTING

European larch underplanted with various species:	Dymock Forest (Gloucestershire) Haldon Forest (Devon)
Oak, underplanted with Western hemlock:	Micheldever Forest (Hampshire)

MIXTURES

Oak/beech:	Tintern Forest (Monmouth)
Sitka spruce/Japanese larch *Sitka spruce/Lodgepole pine*	Beddgelert Forest (Caernarvon)

GENETICS

PROPAGATION CENTRES

Alice Holt Forest (Hampshire)
Bush Nursery (near Edinburgh)
Grizedale Nursery (Lancashire)
Teindland Forest (Moray)
Wauchope Nursery (Roxburgh)

TREE BANKS

Alice Holt Forest (Hampshire)
Bush Nursery (near Edinburgh)
Newton Nursery (Moray)

SEED ORCHARDS

Alice Holt Forest (Hampshire)
Bradon Forest (Wiltshire)
Drumtochty Forest (Kincardine)
Forest of Dean (Gloucestershire)
Keillour Forest (Perthshire)

Ledmore Forest (Perthshire)
Lynn Forest (Norfolk)
Newton Nursery (Moray)
Stenton Forest (East Lothian)
Whittingehame (East Lothian)

PROGENY TRIALS

Alice Holt Forest (Hampshire)
Allerston Forest (Yorkshire)
Ardross Forest (Ross-shire)
Benmore Forest (Argyll)
Bramshill Forest (Hampshire)

Clocaenog Forest (Denbigh)
Chillingham Forest (Northumberland)
Coed-y-Brenin Forest (Merioneth)
Devilla Forest (Fife and Clackmannan)
Elchies Forest (Morayshire)

Farigaig Forest (Inverness)
Forest of Dean (Gloucestershire)
Glenlivet Forest (Banffshire)
Gwydyr Forest (Caernarvon)
Inchnacardoch Forest (Inverness-shire)

Kilmichael Forest (Argyll)
Kilmory Forest (Argyll)
Saltoun Forest (East Lothian)
Speymouth Forest (Moray)
Stenton Forest (East Lothian)

Teindland Forest (Moray)
Thornthwaite Forest (Cumberland)
Torrie Forest (Stirling)
Westonbirt (Gloucestershire)

TREATMENT OF SEED STANDS

Culbin Forest (Moray and Nairn)
Thetford Chase (Norfolk and Suffolk)

PATHOLOGICAL RESEARCH AREAS

ELM DISEASE TRIALS

Alice Holt Forest (Hampshire and Surrey)

TOP DYING OF NORWAY SPRUCE

Knapdale Forest (Argyll)
Coed Morgannwg Forest (Glamorgan)

FOMES ANNOSUS

Bramshill Forest (Berkshire and Hampshire)
Clocaenog Forest (Denbigh)
Kerry Forest (Montgomery)
Lael Forest (Ross)
The Bin Forest (Aberdeen)
Thetford Chase (Norfolk and Suffolk)

ARMILLARIA MELLEA

Alice Holt Forest (Hampshire and Surrey)
Bramshill Forest (Berkshire and Hampshire)

BACTERIAL CANKER OF POPLAR

Aldewood Forest, Fen Row Nursery (Suffolk)
Alice Holt Forest (Hampshire and Surrey)
Blandford Forest (Dorset)
Cannock Chase (Staffs)
Creran Forest (Argyll)
Dean Forest (Gloucester, Hereford and Monmouth)
Dyfnant Forest (Montgomery)
South Yorkshire (Yorks)
Stenton Forest (East Lothian)
Wynyard Forest (Durham)

DIDYMASCELLA (KEITHIA) THUJINA ON WESTERN RED CEDAR

Alice Holt Forest (Hampshire and Surrey)
Bramshill Forest (Berkshire and Hampshire)
Tair Onen Nursery (Glamorgan)

CRUMENULA SORORIA ON PINE

Ringwood Forest (Hampshire and Dorset)

BLUE STAIN IN PINE

Thetford Chase (Norfolk and Suffolk)

ENTOMOLOGY

PINE LOOPER MOTH: BUPALUS PINIARIUS

Cannock Chase (Staffordshire)

LARCH SAWFLY: ANOPLONYX DESTRUCTOR

Drumtochty Forest (Kincardine)
Mortimer Forest (Hereford and Shropshire)

SPRUCE APHID: ELATOBIUM ABIETINUM

Alice Holt Forest (Hampshire)
Bramshill Forest (Hampshire)
Dovey Forest (Merioneth and Montgomery)
Forest of Ae (Dumfries)
Inverliever Forest (Argyll)
New Forest (Hampshire)

APPENDIX II

Staff Engaged in Research and Development

As at 31st March 1966

FOREST RESEARCH STATION: Alice Holt Lodge, Wrecclesham, Farnham, Surrey.
Tel.: Bentley 2255

Director	J. R. Thom, B.Sc.
Conservator	R. F. Wood, B.A., B.Sc.
Administration and Finance Officer	T. D. H. Morris
Director's Secretary	Miss O. A. Harman

SILVICULTURE (SOUTH)

R. M. G. Semple, B.Sc., Head of Section
J. R. Aldhous, B.A.
J. M. B. Brown, B.Sc., Dip.For. (Ecologist)
A. I. Fraser, B.Sc.
J. Jobling, B.Sc.
A. F. Mitchell, B.A., B.Agric.(For.)
M. Nimmo

Office:
R. G. Harris: Miss E. Burnaby, A. R. Taggart, F. H. Khawaja

Research Foresters		*Centre*
South East England Region	R. Hendrie	Alice Holt
South East England Area	P. W. W. Daborn J. B. H. Gardiner, R. W. Genever, A. J. A. Graver, A. C. Hansford, B. G. Howland, C. J. Large, P. Marsh, A. C. Swinburn	Alice Holt
Wareham Area	E. E. Fancy, B.E.M. L. A. Howe, A. M. Jenkin, F. S. Smith	Sugar Hill Nursery, Wareham Forest
Bedgebury Area	A. W. Westall R. E. A. Lewis	Bedgebury Pinetum
South West England Region	D. A. Cousins	Bristol
South West England Area	K. F. Baker, J. E. J. White	Exeter
Dean and South Wales Area	F. Thompson R. M. Keir, M. L. Pearce	Dean Dean
Westonbirt Area	E. Leyshon D. J. Rice	Westonbirt Arboretum

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North Wales Region	G. Pringle	Betws-y-Coed
North Wales Area	G. A. Bacon, C. W. Webber	Betws-y-Coed
Mid-Wales Area	D. G. Tugwell P. A. Gregory, D. J. Williams	Knighton, Radnorshire
East England Region	W. G. Gray, B.E.M.	Kennington,
Kennington Area	F. R. W. Stevens, H. C. Caistor	Nr. Oxford
East England Area	R. M. Ure G. F. Farrimond	Santon Downham Nr. Thetford

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EDINBURGH: Government Buildings, Bankhead Avenue, Sighthill, Edinburgh, 11.
Tel.: Craiglockhart 4010.

SILVICULTURE (NORTH)

R. Lines, B.Sc., Acting Head of Section
J. Atterson, B.Sc.
A. J. Low, B.Sc., Ph. D.
S. A. Neustein, B.Sc.
G. G. M. Taylor, B.Sc.

Office:
P. Hunter: T. T. Johnston, A. D. McKenzie, Miss M. E. Grant, Miss E. P. Beattie, Mrs. M. J. Pedder

Research Foresters		*Centre*
North Scotland Region	A. Macdonald	Fort Augustus
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FOREST RESEARCH STATION: Alice Holt Lodge, Wrecclesham, Farnham, Surrey

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R. Kitching, B.Sc., A.R.C.S., Ph.D.

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Miss J. M. Cowie (Edinburgh)

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Miss J. M. Davies, B.Sc.
Miss J. J. Rowe, B.Sc. (Mammals and Birds)
J. T. Stoakley, M.A.

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Working Plans and Census:
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Field Parties—Scotland
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A. R. Sutton, B.Sc. (Brecon)
A. Whayman (Hawick)
W. O. Wittering (Olney, Beds.)
R. B. Ross, A.M.I.Mech.E. (Alice Holt)
W. S. Mackenzie (Kielder)

Foresters:
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S. E. Baggs: R.D. Duncan

ENGINEERING

R. G. Shaw, A.M.I.C.E. (London), Head of Section
R. Branford (Alice Holt)

HARVESTING AND MARKETING

B. W. Holtam, B.A. (London, Marketing)
J. R. Aaron, M.A. (London, Marketing)

APPENDIX III

List of Publications by Staff Members

Aaron, J. R.	Studies on the Mineral Nutrient Status of Heather, *Calluna vulgaris*. *For Comm. Forest Record* 53, 1965.
Aldhous, J. R.	Outline of Forest Nursery Management. *Journal of Chartered Land Agents Soc.* Vol. 64, 1965 (324–333).
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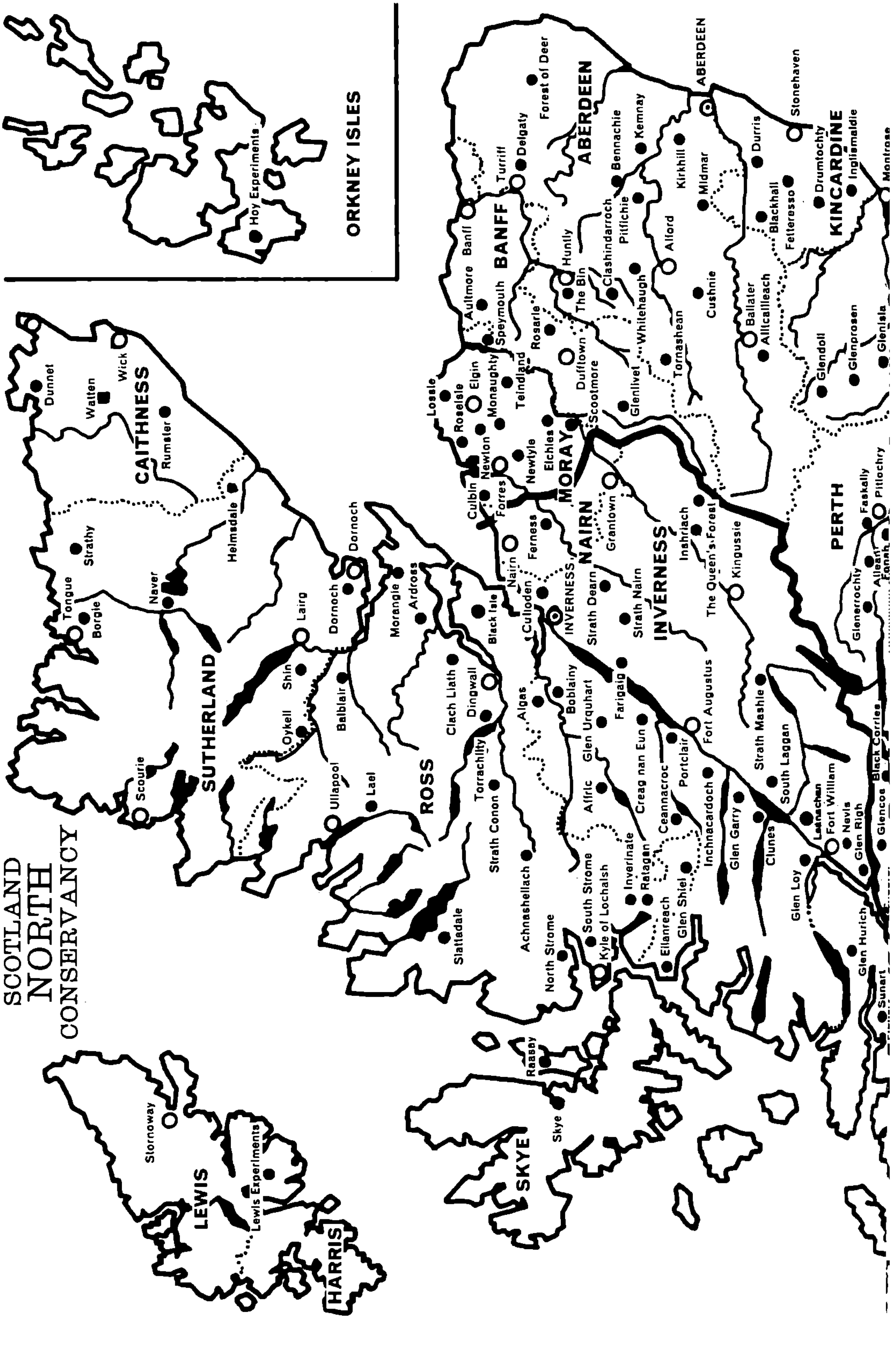
MAPS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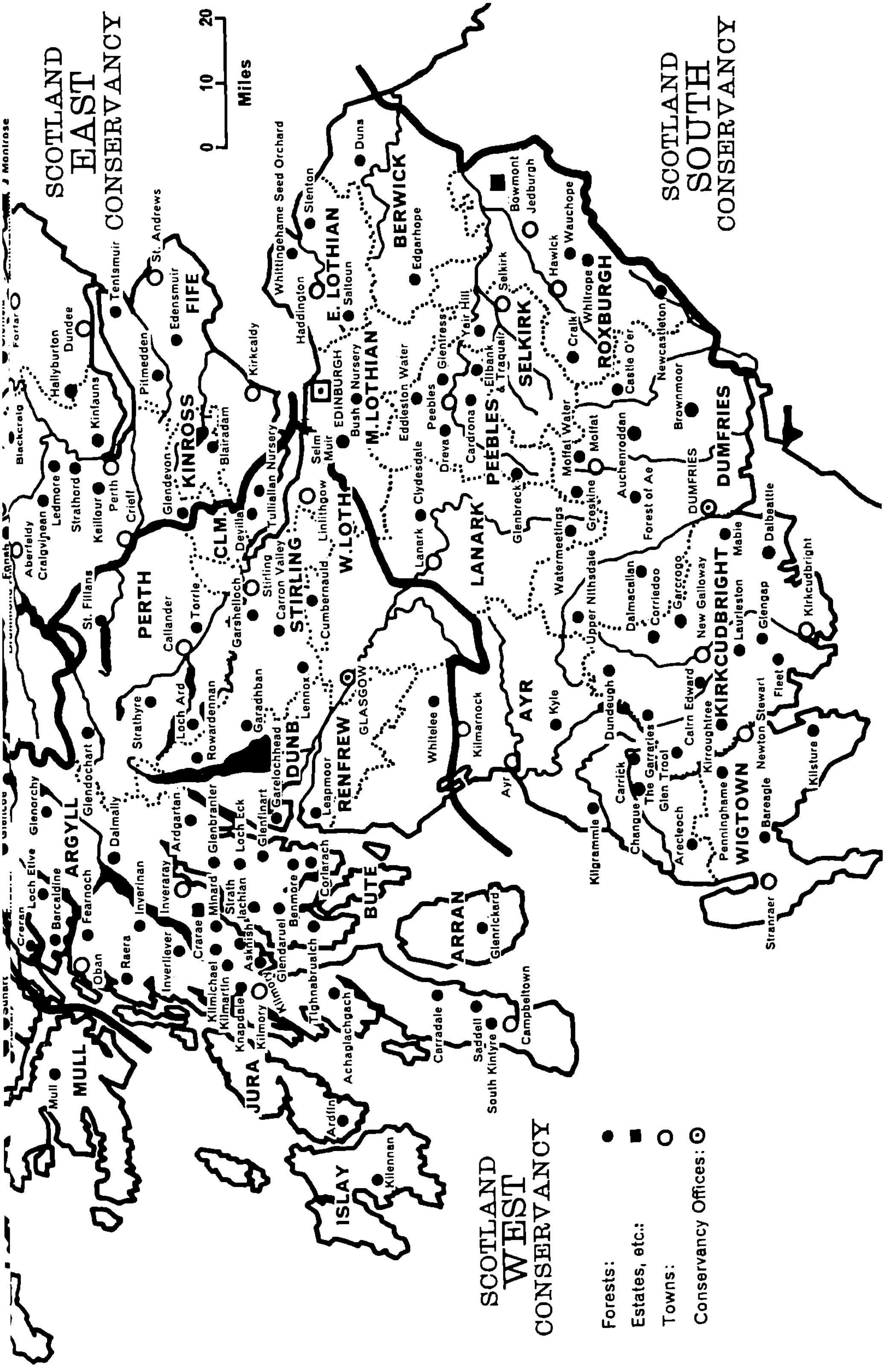
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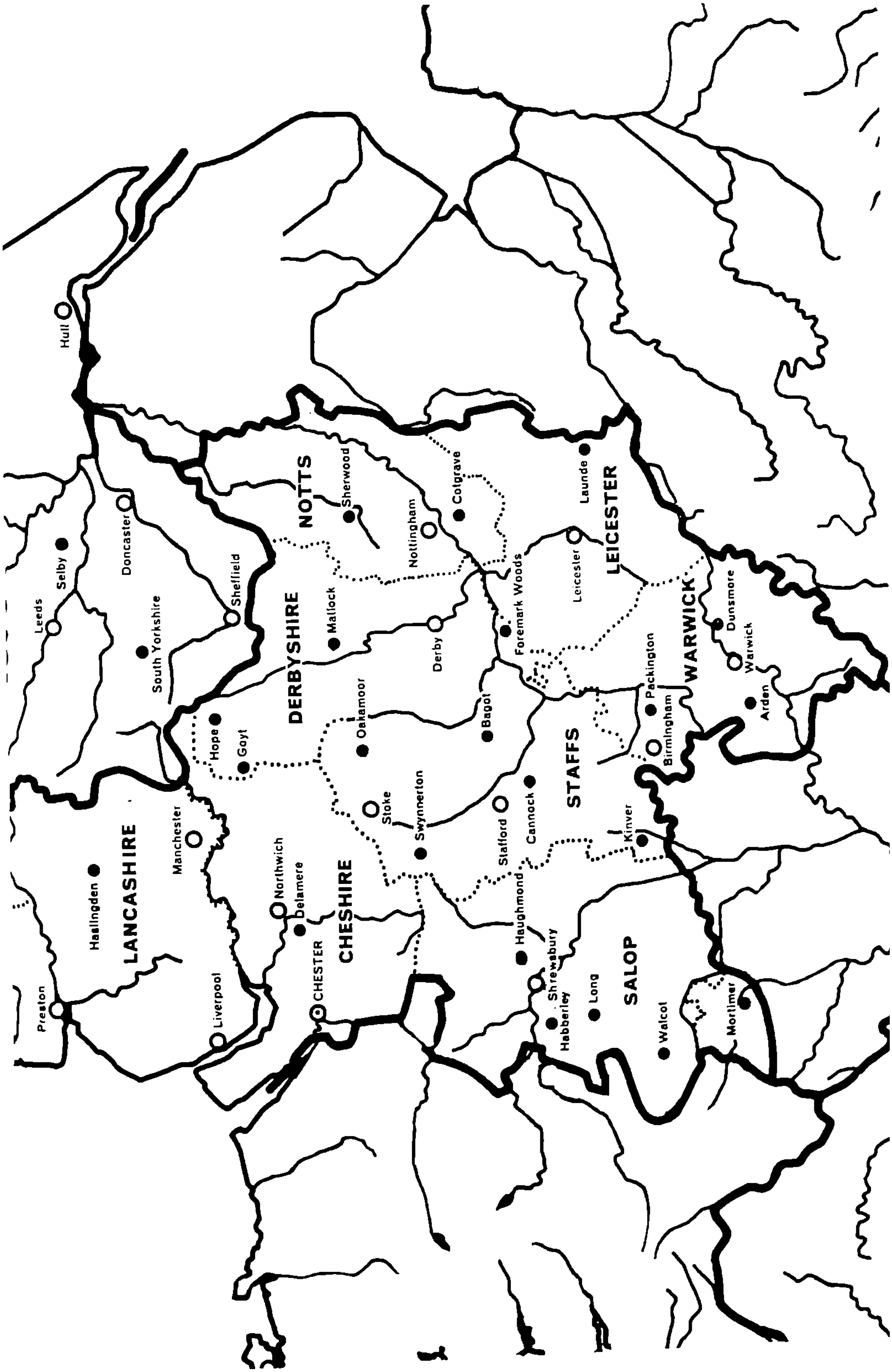
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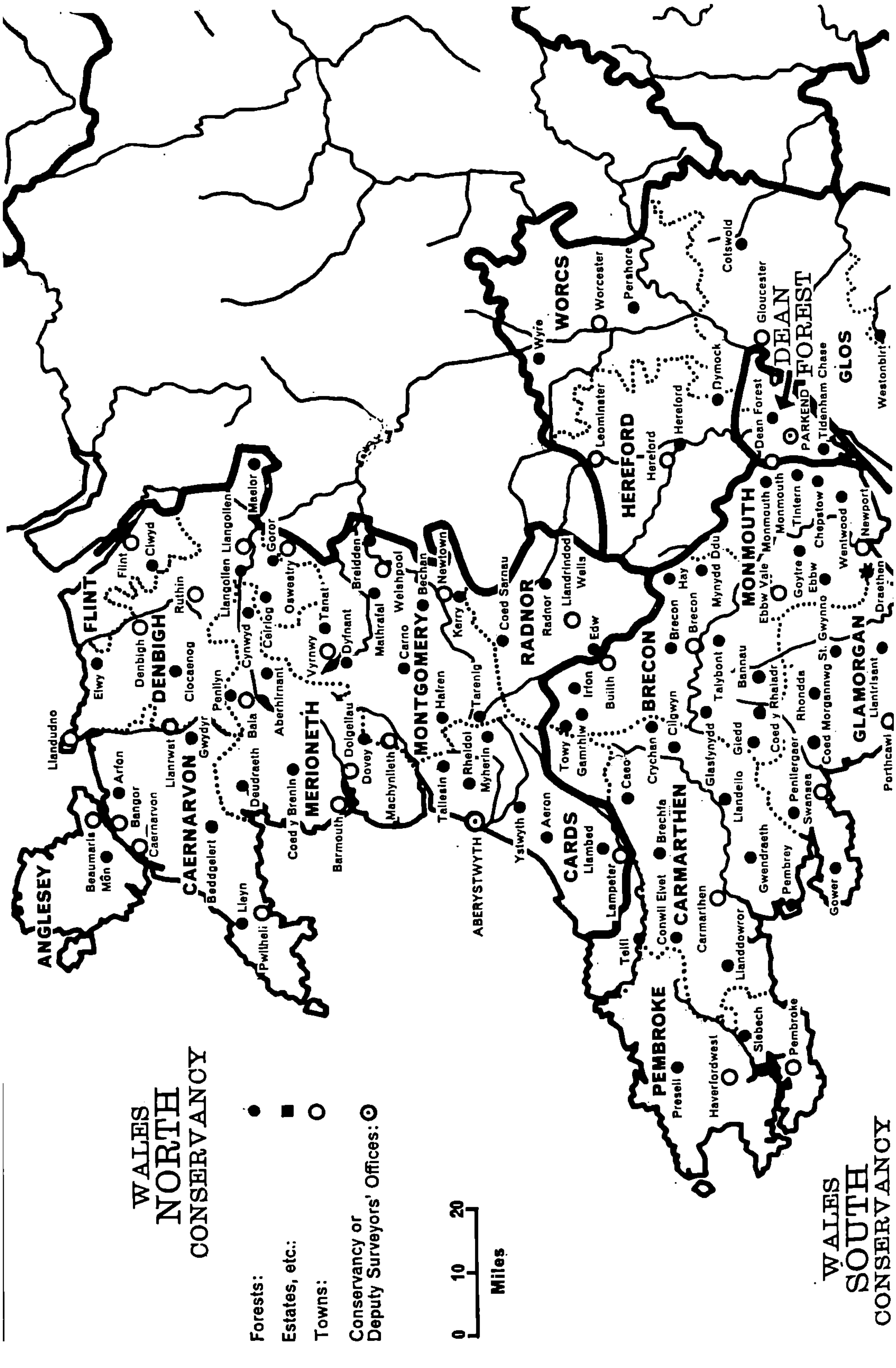
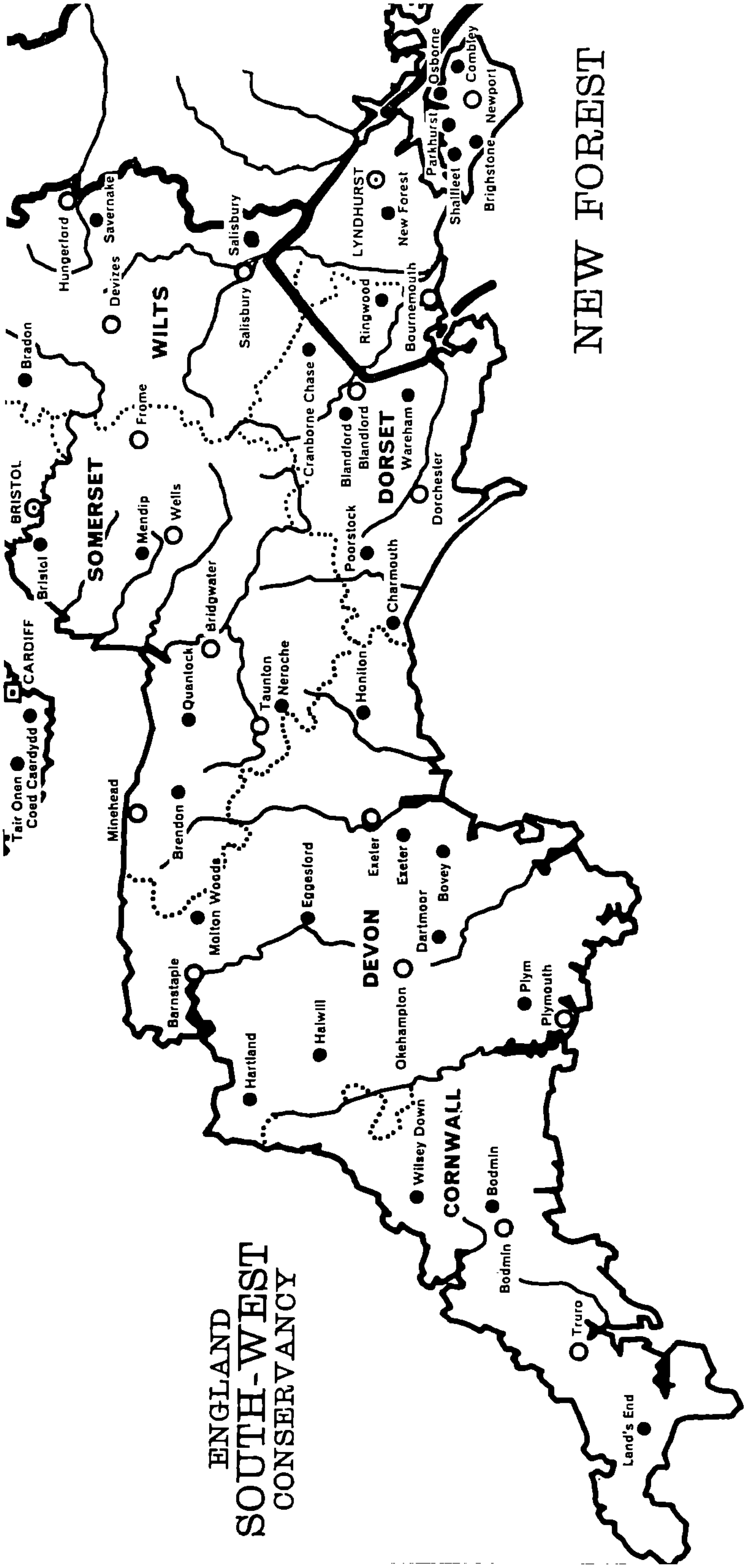
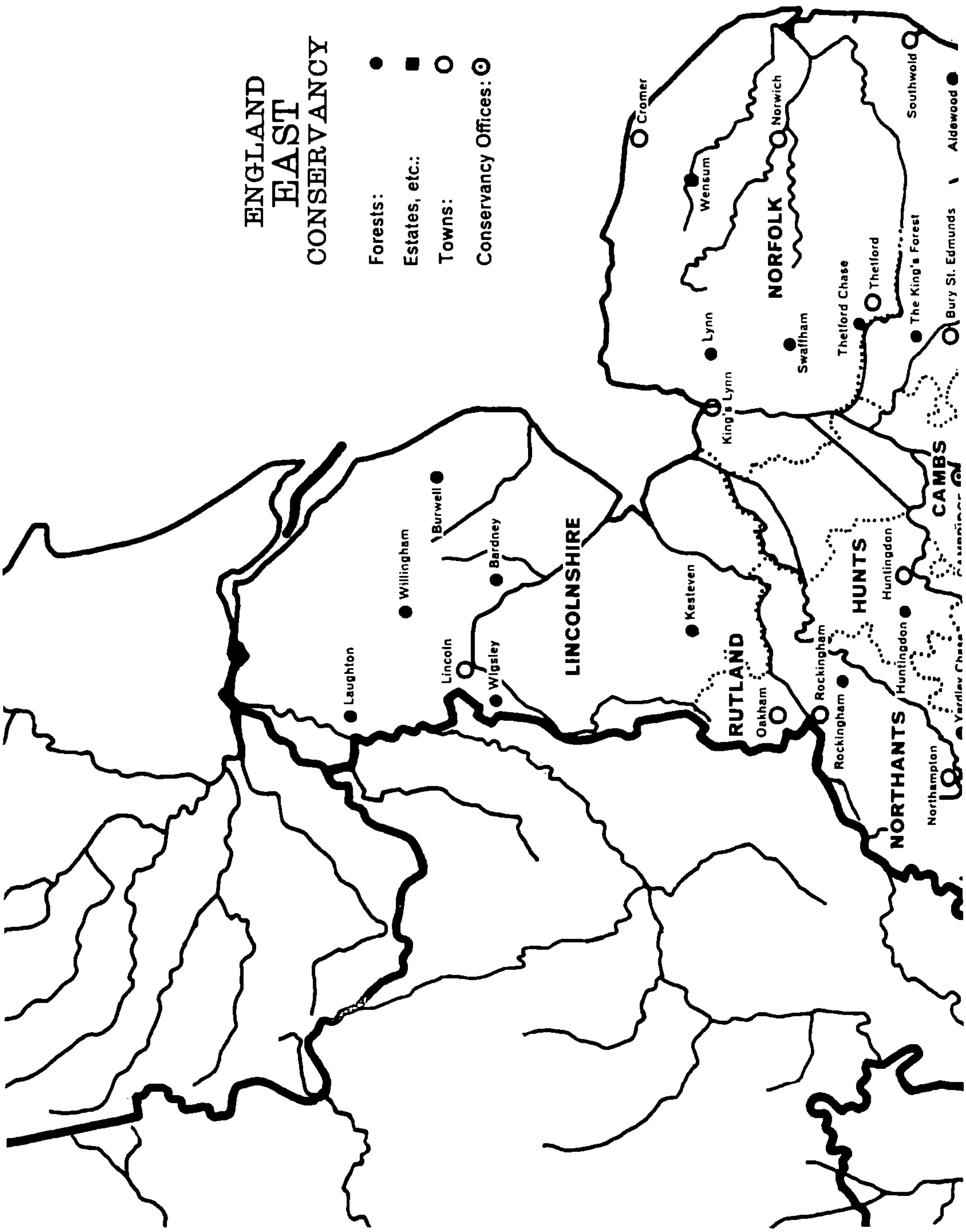
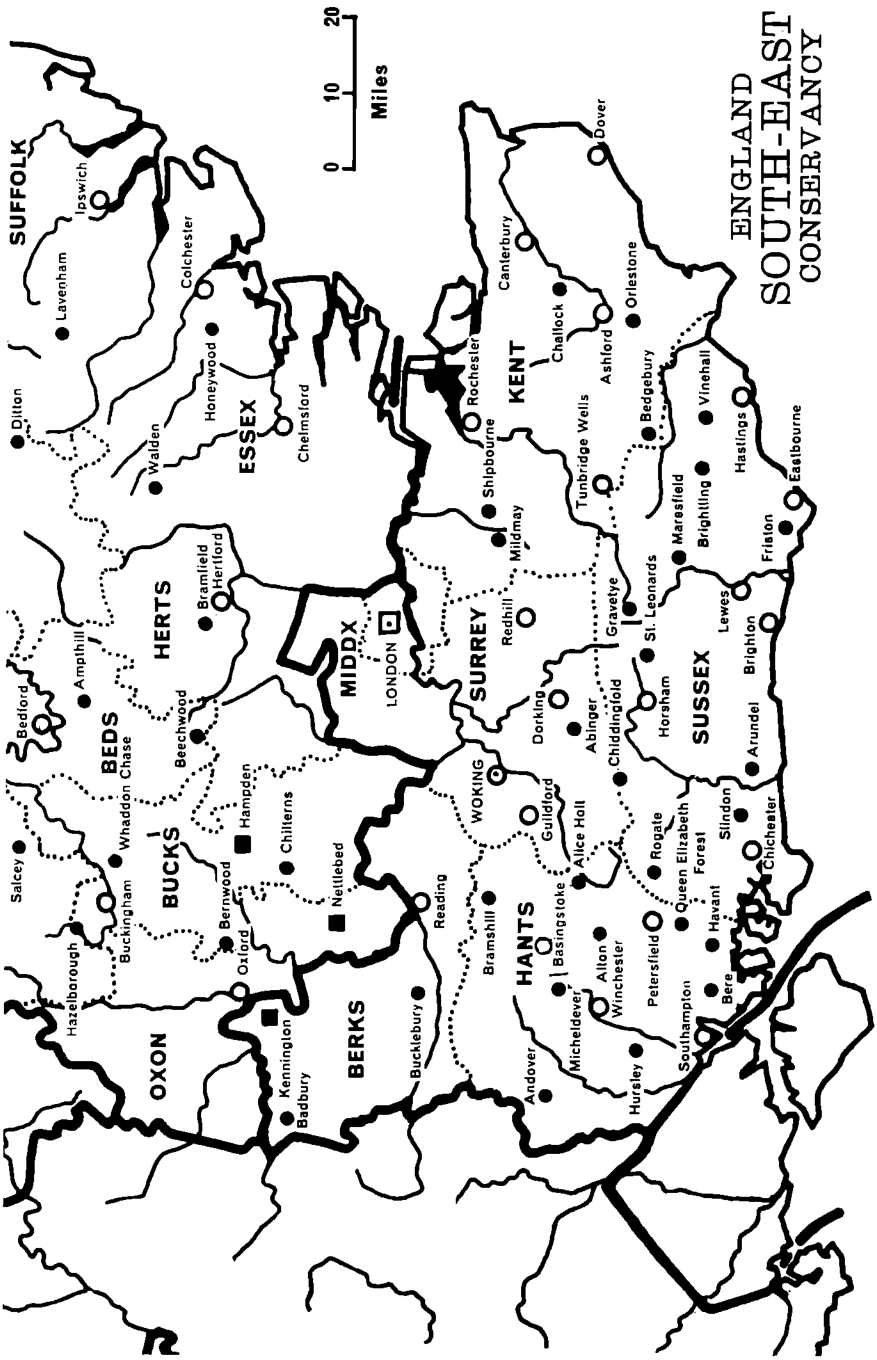

WALES NORTH CONSERVANCY
Forests:
Estates, etc.:
Towns:
Conservancy or Deputy Surveyors' Offices:
0 10 20
Miles
WALES SOUTH CONSERVANCY
ANGLESEY
CAERNARVON
FLINT
DENBIGH
MERIONETH
MONTGOMERY
RADNOR
CARDS
BRECON
CARMARTHEN
PEMBROKE
GLAMORGAN
MONMOUTH
HEREFORD
WORCS
GLOS
DEAN FOREST
Llandudno
Beaumaris
Môn
Bangor
Arfon
Caernarvon
Beddgelert
Lleyn
Pwllheli
Llanrwst
Gwydyr
Elwy
Denbigh
Clocaenog
Flint
Clwyd
Ruthin
Llangollen
Maelor
Goror
Oswestry
Ceiriog
Cynwyd
Penllyn
Bala
Aberhirnant
Deudraeth
Coed y Brenin
Dolgellau
Dovey
Machynlleth
Barmouth
Vyrnwy
Tanat
Dyfnant
Breidden
Welshpool
Mathrafal
Carno
Bechan
Newtown
Kerry
Coed Sarnau
Hafren
Tarenig
Rheidol
Myherin
Taliesin
ABERYSTWYTH
Ystwyth
Aeron
Llambed
Lampeter
Radnor
Llandrindod Wells
Edw
Builth
Irfon
Towy
Gamrhiw
Caeo
Crychan
Cilgwyn
Brecon
Hay
Mynydd Ddu
Talybont
Glasfynydd
Bannau
Coed y Rhaiadr
Rhondda
Gledd
Llandeilo
Brechfa
Conwil Elvet
Carmarthen
Teifi
Llanddowror
Slebech
Pembroke
Haverfordwest
Preseli
Gwendraeth
Pembrey
Penllergaer
Swansea
Gower
Coed Morgannwg
St. Gwynno
Llantrisant
Porthcawl
Glamorgan
Ebbw Vale
Ebbw
Goytre
Wentwood
Newport
Draethen
Chepstow
Tintern
Monmouth
Hereford
Leominster
Dymock
Wyre
Worcester
Pershore
Cotswold
Gloucester
Dean Forest
PARKEND
Tidenham Chase
Westonbirt


NEW FOREST
ENGLAND
SOUTH-WEST
CONSERVANCY
Hungerford
Savernake
Devizes
WILTS
Salisbury
Salisbury
LYNDHURST
New Forest
Osborne
Combley
Parkhurst
Newport
Shalfleet
Brighstone
Ringwood
Bournemouth
Bradon
Frome
Cranborne Chase
Blandford
Blandford
DORSET
Wareham
Dorchester
BRISTOL
Bristol
SOMERSET
Mendip
Wells
Poorstock
Charmouth
Bridgwater
CARDIFF
Quantock
Taunton
Neroche
Honiton
Tair Onen
Coed Caerdydd
Minehead
Brendon
Exeter
Exeter
Bovey
Molton Woods
Eggesford
DEVON
Dartmoor
Barnstaple
Okehampton
Plym
Plymouth
Hartland
Halwill
Wilsey Down
CORNWALL
Bodmin
Bodmin
Truro
Land's End


ENGLAND
EAST
CONSERVANCY
Forests:
Estates, etc.:
Towns:
Conservancy Offices:
Cromer
Norwich
Southwold
Aldewood
Wensum
NORFOLK
Lynn
Swaffham
Thetford Chase
Thetford
The King's Forest
Bury St. Edmunds
King's Lynn
CAMBS
Burwell
Willingham
Bardney
LINCOLNSHIRE
Kesteven
Laughton
Lincoln
Wigsley
RUTLAND
Oakham
Rockingham
Rockingham
HUNTS
Huntingdon
Huntingdon
NORTHANTS
Northampton


ENGLAND
SOUTH-EAST
CONSERVANCY
0
10
20
Miles
SUFFOLK
Ipswich
Lavenham
Colchester
Ditton
Honeywood
Walden
ESSEX
Chelmsford
Canterbury
Dover
Orlestone
Challock
Ashford
KENT
Rochester
Shipbourne
Tunbridge Wells
Bedgebury
Vinehall
Hastings
Eastbourne
Brightling
Maresfield
Friston
Mildmay
Bramfield
Hertford
HERTS
Ampthill
Bedford
BEDS
Whaddon Chase
Beechwood
MIDDX
LONDON
SURREY
Redhill
Gravetye
St. Leonards
Lewes
Brighton
SUSSEX
Horsham
Arundel
Dorking
Abinger
Chiddingfold
Salcey
BUCKS
Buckingham
Hazelborough
Hampden
Chilterns
Bernwood
Oxford
Nettlebed
Reading
WOKING
Guildford
Alice Holt
Rogate
Queen Elizabeth Forest
Slindon
Chichester
Bramshill
Basingstoke
HANTS
Alton
Winchester
Petersfield
Havant
Bere
Southampton
Hursley
Micheldever
Andover
OXON
Kennington
Badbury
BERKS
Bucklebury