O.F.I. OCCASIONAL PAPERS

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NO. 37

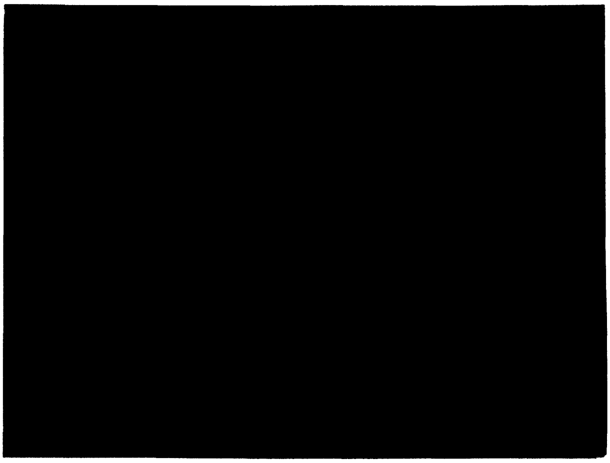
NATIONAL HARDWOODS PROGRAMME

REPORT OF THE EIGHTH MEETING
and Second Meeting of the
UNEVEN-AGED SILVICULTURE GROUP
7 January 1988

edited by
P.S. Savill

1988

OXFORD FORESTRY INSTITUTE
Department of Plant Sciences
UNIVERSITY OF OXFORD



Note: The proceedings of meetings 1-6 were published separately by OFI on behalf of the National Hardwoods Programme. Details of those still available are obtainable from OFI. Reports of the seventh and subsequent meetings are published within the OFI Occasional Papers series.

The paper by Jim Dewar on 'The storm of 16 October 1987' which was presented at the 1988 meeting is omitted from this publication but planned for inclusion in a future Occasional Paper. However, an additional paper which it is believed will be of interest to participants has been included: Peter Mitchell's translation from the French of a paper by L. Lanier on 'Weeding and cleaning of broadleaved high forest'.

The report of the First Meeting of the Uneven-aged Silviculture Group was not published, but details of papers presented may be obtained from Dr P.S. Savill at OFI.

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ISBN 0 85074 107 6
ISSN 0269-5790

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Report of the Combined Meeting of the

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UNEVEN-AGED SILVICULTURE GROUP

Thursday 7 January 1988

INTRODUCTION

PROFESSOR J D MATTHEWS, Department of Forestry, University of Aberdeen

This is the eighth occasion on which research workers and practising foresters have met at the Oxford Forestry Institute to discuss ways of increasing the use of hardwoods in Britain. The presence of so many people from all sections of our industry indicates that interest continues undiminished. This year Peter Savill has joined with Rodney Helliwell in devising a joint programme which includes uneven-aged silviculture.

There are three reasons why this is appropriate. The first is that the 1979-82 Census of Woodlands in England and Wales revealed that the area of broadleaved high forest has increased since the end of the last war. In particular, woodland made derelict by war time fellings has since been planted or become colonised by hardwoods, and other areas classed as scrub in the 1947 Census have since developed, either naturally or with management, into mixed broadleaved high forest. There are now several thousand hectares of woodland containing ash, birch, cherry and sycamore - in addition to beech and oak - that could be converted into productive stands using systems of uneven-aged silviculture.

The second reason why this joint programme is timely is the appearance of the report 'Beyond 2000' produced by the Forestry Industry Committee of Great Britain. This is the most optimistic appraisal of the forestry industry that I have read for a long time. After recounting the success of coniferous forestry in the uplands it lays particular stress on the need for a policy that will arrest the decline and ensure the expansion of broadleaved forestry, especially in the lowlands of Britain.

The third reason derives from the objects of the National Hardwoods Programme and the Uneven-aged Silviculture Group. All foresters appreciate the beauty of hardwoods and recognise their importance in the landscape and in our wood-using industries. Re-reading many of the papers that have been presented at past meetings held here makes it clear that the knowledge and expertise required to make broadleaved high forest profitable as well as beautiful certainly does exist in Britain. We must make sure that the best examples of hardwood silviculture become more widely known and are available for study.

Two systems of uneven-aged silviculture appear important for the future, namely, group selection and irregular shelterwood. These will be discussed today. I am sure that the Institute of Chartered Foresters and the two Royal Forestry Societies will continue to take an active interest in the development of these two systems in Britain, in addition to working with the Forestry Commission in formulating the policy for broadleaved forestry.

BRITISH UNEVEN-AGED SILVICULTURAL SYSTEMS

A POORE, The Parnham Trust, Beaminister, Dorset

INTRODUCTION

The objectives of this paper are to examine the basic practical features of the relatively small number of irregular systems which are likely to be applied widely in Britain, to consider their applications and to look at some aspects of definition and nomenclature.

Most managed uneven-aged stands in Britain have arisen by the promotion or the cutting and planting of groups in even-aged stands, or in stands subjected to heavy exploitative fellings. In addition, a number of irregular stands have resulted from heavy thinning of even-aged stands designed both to provide opportunities for regeneration and to stimulate the increment of existing stems. These two approaches taken during the conversion phase towards an irregular structure give a useful distinction between systems using group-working on the one hand and a system which I shall call irregular shelterwood on the other. The following sections consider these two types of system in turn.

Both silviculture (the art of growing trees at the level of the stand) and forest management (the organisation and volume control of fellings designed to achieve the required objectives at forest level) are important in the simple classification proposed.

GROUP WORKING

Group Characteristics

In silvicultural terms all group systems involve the use of a compact even-aged collection of stems as the basic unit. The minimum size and preferred shape and alignment of the these groups will be determined by the requirements of the particular species for light and final crop canopy space. The maximum size may be determined silviculturally, eg by seed dispersal considerations in naturally regenerated stands or by the problems of using large coupes on heavy clays, although non-silvicultural factors such as landscape are often involved. The actual size and shape of the group in non-mature stands is crucially affected by the distribution of 'stems-with-a-future'.

Stands managed consistently under group-working will resemble either a mosaic of discrete squarish units whose boundaries are adjusted at each final felling, or a series of coalescing concentric rings radiating out from initial focal groups. The former is probably the more common in current British practice.

Group Felling and Group Selection

From the forest management point of view, group-working involves two distinct types of approach and I shall use this to separate group felling systems on the one hand and group selection on the other.

Forest mangement is concerned partly with the organisation of tending and felling operations, an important factor being the scale on which such operations must take place in order to be economically viable. The nature of the felling out-turn (in terms of the range and proportion of sizes) produced by this organisation is another important consideration. In addition a forest management system usually requires a system by which stand structure can be manipulated towards a stated objective and may require the means to control the volume removed.

Consider in the first place the situation where each self-contained intervention or job, whether final felling or thinning, takes place at the scale of the 'silvicultural group'. In this case each group can be managed as a separate even-aged mangement unit, yield regulation can be achieved by using the Forestry Commission's yield tables and stand structure can be manipulated by area. In addition the range of sizes in the out-turn of such a management unit will be relatively restricted. In effect, the management system is the conventional one operated at a small-scale. This system, when applied to group-working, I shall call group felling.

When, on the other hand, each self-contained intervention or job involves more than one group, each at a different stage of development, the position is very different. Each felling may combine removing large sawlogs and short logs from final fellings in mature and middle-aged groups with fencing and pulp/firewood from the tending of pole-stage groups. The silvicultural group ceases, therefore, to be the unit of intervention and management. Manipulation of the stand structure by area breaks down and alternative yield regulation methods must be adopted. This system I propose to call group selection.

The choice between group selection and group felling is critically determined by the minimum size of area over which a job is viable. This minimum size will vary with the type of forest enterprise, stocking and growth rates, the type of machinery used and the nature of the felling. In the case of, for example, a lowland estate with a high road density, intensive marketing and relatively cheap machinery, the minimum viable intervention unit for a final felling might be as low as 0.4 ha. An upland forest manager operating an extensive system with few roads using processors and forwarders would have a such larger minimum unit size of say 4 ha. In both cases silvicultural or landscape considerations might determine a group size of 0.8 ha. On the lowland estate a group felling system could be adopted as 0.8 ha is large enough for each group to be treated as a separate management unit. On the upland estate, however, a group selection system would be required since 5 or 6 groups would have to tackled at once in order to produce a viable job.

Group Selection and the Bradford Plan

In group selection the difficulties of felling and extraction without damaging the younger age-classes and of controlling the stands, particularly if normality is the objective, are clearly greater than with group felling. The desire to overcome these problems was the impetus behind the development of the Bradford Plan. In this system small groups are established on a regular pattern in such a way that the full range of age-classes occur in a spacially predictable way. Hence felling and extraction is easier, the required objective of normality is assured and the adoption of a yield regulation system based closely on the yield table system is possible (Hutt, undated).

As applied at Lord Bradford's Tavistock Woodlands Estate each group (called a plot) is designed to produce one final crop tree. However, apart from increased distances to the main extraction racks, there is no reason why larger plots designed to produce two or more crop trees could not be adopted particularly if more light demanding species were used.

Application of Group-Working

Group-working has been successfully applied to beech using groups down to 0.1 ha both for planting and natural regeneration. The constraint of ensuring that felling takes place within each group by setting a minimum diameter for the group of twice the height of the mature trees would suggest a minimum nearer to 0.3 ha (Workman, 1986). With light-demanders such as oak, ash and cherry larger groups of 0.5 ha plus are likely to be more successful, particularly during the early stages of conversion when the initial groups are surrounded by even-aged stands. The *ad hoc* application of this system in broadleaved woods has been encouraged by the Forestry Commission's Broadleaved Policy with its presumption against large coupes in ancient, semi-natural stands (Forestry Commission, 1985). Further practical advice on the application of the system is given in Fairbairn (1963) and Garfitt (1984).

The application of group-working to conifer stands is less well developed in Britain. A successful example at Glentress forest, described in a later paper by Dr Malcolm, was begun in 1952 in middle-aged stands of Scots pine, larch and Norway spruce with group sizes of 0.1 to 0.25 ha now being preferred for the establishment of a range of species. Another trial was initiated in the early 1950's at Corrour (Malcolm, 1971) at similar elevations (380-460 m) in middle-aged and maturing stands of mixed conifer species dominated by spruce. Again the group size ranged up to an average near to 0.2 ha, with Sitka spruce as the main species being established. The potential for group-working in well-managed mature conifer stands in the lowlands is demonstrated on estates such as Stourhead (Western).

The possibility of introducing group-working into the more uniform pole-stage conifer stands which have arisen since the war is more speculative. The problem of windthrow following the cutting of groups in conventionally managed stands in the uplands was clearly shown in trials in Dumfries in 32-35 year old Sitka spruce (Neustein, 1964). In the lowlands, however, there may be more scope for using group systems in handling neglected stands of a potentially windfirm species such as Douglas fir or Corsican pine which will also respond to thinning. In such stands the distribution of final crop trees is often uneven and areas of general understocking are present. Conventional thinning practices are often ruled out as being too expensive, given the take-down problems, the poor quality of the small roundwood and the possible lack of a fully-stocked mature stand. The combination of clear-felling in groups of say 0.1-0.2 ha with thinning as in the best areas offers the means of making the most of the existing stand, improving the worst areas and introducing an element of irregularity, whilst showing a surplus on the operation. Some windthrow around the initial groups will be inevitable but this should decline as further groups are cut beside the thinned areas. The prospects for applications in young and middle-aged pure spruce stands in the lowlands are less good. Where spruce is mixed with semi-suppressed broadleaves, however, as in the case of neglected oak/spruce line mixtures, the deep live crowns of the spruce may allow the adoption in some form of the group system used in Belgium, where groups are initiated by cutting thin strips which are subsequently enlarged amongst adjacent areas prepared by crown thinning (Penistan, 1960).

IRREGULAR SHELTERWOOD

Some Aspects of Shelterwood Systems in General

A common feature of all shelterwood systems is the retention of an over-storey for a period, from which and amongst which a new age-class develops. In terms of stand diversity, however, systems vary greatly. At one extreme is the uniform system, an essentially even-aged system in which regeneration takes place over the whole compartment during a short period. Beech managed on a 140 year rotation, for example, may be under regeneration for 20-30 years and then 'revert' to a one-storey structure. At the other extreme the selection system in its ideal form envisages regeneration occurring at each intervention, scattered about the compartment producing a permanently irregular stand in which all age-classes are represented at compartment level. In between these two extremes there are systems in which regeneration occurs more sporadically over time than under the ideal selection system, but over a more extended period than under the uniform system. In most of these 'intermediate' systems a multi-age class structure persists but with a degree of spacial separation of the age-classes not found in the ideal selection system. A normal structure, where it is aimed for at all, is achieved at the scale of the working circle. These later systems are best termed irregular shelterwood.

The above distinctions are made clearer by examining the nature of the fellings undertaken in shelterwood systems. In general such fellings can be separated into three types according to their function, as follows:

1. Pure thinnings - designed to favour an existing age-class.
2. Pure regeneration fellings - designed to initiate and establish a new age-class.
3. Combined fellings - designed to both favour an existing age-class and promote the next.

Under the uniform system, pure thinnings are followed by more or less pure regeneration fellings, whilst under the selection system all fellings can be described as 'combined'. Under the irregular shelterwood system all three types of fellings occur, sometimes during the same intervention.

Stand Development in Irregular Shelterwood

An example of how the conversion of an even-aged stand to Irregular Shelterwood might proceed in Britain is given in Table 1. The initial stand is assumed to be 15 year old Douglas fir in which prolific seeding starts at around 35 years. The rotation of individual crop trees is 60 years and the felling cycle is five years. Table 1 shows the age of each age-class just before each intervention and the type of felling used at that intervention is indicated.

During Period 1 pure thinnings are undertaken to increase the windfirmness of the stand and to produce an overstorey of good quality stems. In Period 2 combined fellings start in the form of heavy thinnings. It is assumed that four successive combined fellings produce two new age-classes. At the beginning of this period the emphasis lies on adding increment to the best stems in the overwood as well as providing space for regeneration. As the regeneration develops, however, the need to 'follow' it will reduce the opportunities for favouring the overstorey until Period 3 is reached, during which pure regeneration fellings occur, designed to favour age-classes B and C (and complete the harvesting of age-class A). Since no stems in age-classes B or C are at a seeding stage, planting would be required to establish age-class

TABLE 1: Theoretical example of the conversion of a 15 year old Douglas fir stand to Irregular Shelterwood: ages are those of each age-class just before each intervention and type of felling employed (for assumptions see text).

Years	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	
Age-class																														
A	15	20	25	30	<u>35</u>	<u>40</u>	<u>45</u>	<u>50</u>	55*	60*																				
B							(8)	(13)	18	23	28	33	38	43	<u>48</u>	<u>53</u>	58*	63*												
C									(8)	(13)	18	23	28	33	<u>38</u>	<u>43</u>	<u>48</u>	<u>53</u>	58*	63*										
D											(5)	(10)	15	20	25	30	<u>35</u>	<u>40</u>	<u>45</u>	<u>50</u>	55*	60*								
E																	(8)	(13)	18	23	28	33	38	43	<u>48</u>	<u>53</u>	58*	63*		
F																			(8)	(13)	18	23	28	33	<u>38</u>	<u>43</u>	<u>48</u>	<u>53</u>	58*	63*
G																					(8)	(13)	18	23	28	33	<u>38</u>	<u>43</u>	<u>48</u>	53
H																											(8)	(13)	18	23
I																														(8)

Period 1 2 3 4 5 6 7

Type of felling: (8) = no felling, 15 = pure thinning, <u>35</u> = combined felling, 58* = regeneration felling

D. In Period 4 pure thinnings predominate again and no regeneration takes place. Here it is assumed that no new age-classes are created or accepted until two age-classes in the existing stands are at seeding stage. Period 5 represents the beginning of another regeneration period which lasts for 30 years during which three new age-classes develop. Note that in years 105 and 110 all three types of felling occur simultaneously. Period 6 begins with pure regeneration fellings in age-class D. Given the structure of the stand, however, no regeneration occurs until year 135 when two seeding age-classes occur again and a further regeneration period (Period 7) begins.

The result of this theoretical conversion is the creation of a permanently irregular structure oscillating between 3 and 4 age-classes with periods of regeneration alternating with those in which thicket and pole-stage age-classes predominate. Over the 120 years from year 40 to year 155 (twice the nominal rotation age), active regeneration occurs for around 75 years.

Application of Irregular Shelterwood

A promising type of irregular shelterwood system has been introduced on a substantial scale at Longleat by John McHardy in well-managed stands of Douglas fir, larch, western red cedar and western hemlock. Combined fellings begin between 30 and 40 years with a felling cycle of about 6 years. During periods of regeneration new age-classes are accepted every 10 years or so by selective control of bracken which dominates the ground flora. The nominal rotation for final crop trees is 40 to 50 years with an older 'monarch' age-class of 80 year plus stems being retained at densities of about 12 per ha for the production of extra-large sawlogs (for which a premium exists for Douglas fir and larch), and for amenity (Poore, 1986). This extra age-class serves a particularly useful purpose in landscape terms during periods when the younger age-classes predominate and in other circumstances could provide an senescent age-class for nature conservation purposes.

The achievement of the four age-class structure projected in Table 1 is dependant on the assumption that four combined fellings, followed by two regeneration fellings are feasible without shading out the younger age-classes. In addition the distribution of seeding stems in relation to the regeneration gaps must be compatible, although the assumption that two age-classes must be at the seeding stage before regeneration occurs may be sufficient. Whether these assumptions are correct with Douglas fir remains to be seen. Clearly the use of very light-demanding species such as larch will result in the reduction of the number of combined fellings since the need to open up the regeneration at a faster rate will reduce the opportunities for favouring the overwood. Hence the number of regeneration gaps will be less, producing fewer age-classes in the fully-converted stand. Such a situation occurs in Switzerland where irregular shelterwood systems are applied to mixed stands of oak, larch, ash, beech and sycamore. A very informative account of these systems is given in Jeffrey (1956). It should be stressed that even though the emphasis between increment thinnings and regeneration fellings lies towards the latter because of the light-demanding nature of the species involved, the structure of the converted stand is permanently irregular.

In general the irregular shelterwood system is likely to rely on natural regeneration. Success will depend on the timing of the regeneration being regular and on the its reliable occurence following the opening of the canopy. A further requirement is that the species used should be capable of becoming windfirm if well thinned during its early stages. These considerations are likely to restrict the use of irregular shelterwood in Britain to coniferous stands of Douglas fir, larch, western red cedar and western hemlock whilst, among broadleaves, sycamore appears to be the only, but possibly an ideal, suitable species.

Irregular Shelterwood and Group Selection

From the silvicultural viewpoint the distinction between these two systems is clear during the conversion phase. Group selection involves the establishment of a group structure consciously from the beginning, whilst irregular shelterwood starts with an overall heavy thinning. As the irregular structure develops, however, the distinction becomes less clear since both systems involve the use of spatially distinct age-classes. The distinctive feature of irregular shelterwood is the emphasis on the use of combined fellings part of whose purpose is to add increment to existing age-classes. Consequently group size in irregular shelterwood will tend to be more fluid than that under group selection where the exclusive reliance on pure thinnings and final fellings gives rise to a more pre-determined and inflexible group as the basic unit.

In forest management terms the systems are very similar since both involve carrying out a range of treatments in more than one age-class at any one intervention. In addition both require 'non-conventional' systems of stand control and yield regulation.

IRREGULARITY

The 'convential' British approach to forest management and yield regulation pays little or no heed of the requirements of achieving sustained yields at the forest level which has played such an important role in continental practice. In Britain the timing of final felling depends not on the imperatives of attaining a normal structure, and an ideal growing stock volume and then cutting the increment, but on the performance of individual stands judged according to standards of maximum volume production, maximum net discounted revenue or objectives linked to cash flow and tax requirements. The role of yield regulation is restricted to controlling thinning intensity and predicting future yields.

The application of irregular systems in Britain will have to accommodate to this overall environment both in terms of stand control and yield regulation. The major point is that the objective of obtaining a normal structure at forest or working circle level in the medium-term (say one average rotation) will often be inappropriate. In many cases the costs associated with premature and delayed final fellings will be too high, particularly where the impetus behind the introduction of irregularity is the desire to make the most of existing stands. Partial irregularity will be the most commonly encountered reality and in many cases this will be an entirely appropriate objective. Where nature conservation has a high priority, the achievement of a normal structure may have great advantages for the sustained production of habitats for the many woodland species with poor powers dispersal. Even here, however, a compact block in the process of conversion to a normal structure might be incorporated within a woodland which consists of areas of partial irregularity and of even-aged stands. This is the situation at Hooke Park, a 140 ha wood in west Dorset, where high forest stands (some 125 ha) are allocated to one of three working circles, each with a different objective as regards the degree of irregularity aimed for. A compact group of largely pole-staged broadleaves of variable quality, amounting to 50 ha, is allocated to a working circle in which the aim is to achieve a full range of age-classes within an average rotation of 80 years using a group felling system based on group size of 0.5-0.9 ha. Initial regeneration groups are cut in areas largely devoid of crop trees, and hence the costs of premature final fellings are likely to be low. A further 20 ha of variable stands of conifers, broadleaves and mixtures are allocated to a working circle managed under a group selection system with a group size of 0.1-0.2 ha in which partial irregularity at stand level is the stated objective. The remaining 55 ha of uniform coniferous high forest are managed within an even-aged working circle along conventional lines.

As was observed earlier, stand control under the group felling and Bradford Plan systems is by area and yield regulation, where applicable for forecasting and silvicultural purposes, can make use of yield tables. In the case of group selection where normality is the aim the main pre-occupation is likely to be the condition of the stand structure. Of particular importance is the relationship between the mature and youngest age classes, given the tendency under this system to cream the best of the former and to achieve an insufficient density of the latter. A simple method of assessing such stands is proposed in Garfitt (1987) in which yield class is assessed for each species, and yield tables are used to generate a series of age-classes expressed in terms of mean top height. A general stem number frequency is then obtained for each height class in terms of the number of stems required to produce one mature tree. For example, assuming the stand is composed of yield class 10 beech, every mature stem (of average top height 34 m) will require 1.5 stems in the 32 m class (equivalent to the 81-100 years age-class), 2.5 stems in the 29 m class (equivalent to the 61-80 years age-class), 5 stems in the 24 m height class (41-60 years age-class), 17 stems in the 16 m height class (21-40 years age-class) and 40 in the 0 to 11 m regeneration class, if a balanced normal structure is to be achieved. Assuming that, ideally, one-sixth of the stand should be covered by each of the 6 height classes, the target stem numbers for a 1 ha stand would be 18 mature stems, 27 in the 32 m class, 46 in the 29 m class etc (assuming a fully-stocked even-aged mature stand of 110 stems per ha). A series of sample plots can be used to check the actual proportions of the height classes in the stand with these target figures.

In the case of the group selection and irregular shelterwood stands, where a normal structure is not the objective, the <u>degree</u> of irregularity aimed for could be defined in a broad way by the ratio of the regeneration period to the target rotation age of mature stems. Regeneration period is defined as the period during which regeneration occurs in <u>some</u> part of the stand. In the example given in Table 1 the regeneration periods occupy 60 per cent of the 120 years (twice the target rotation) from the start of the first combined fellings. A continuum of irregularity exists between stands with a ratio of around 33 per cent (below which the stand is unlikely to be permanently irregular) and those with 100 per cent in the case of stands with a normal structure. A more rigorous objective could be set by aiming for a structure in which a specific number of age-classes is always present. For example, in the case of the yield class 10 beech stand referred to above, the objective might be to perpetuate three age-classes out of the possible six, each ideally covering a third of the area. In terms of stand control the question becomes: is each third sufficiently stocked, given its particular height class, to produce a fully-stocked stand in due course? This question can be answered using the same approach as outlined above for normal stands. Assuming that at the particular point in time the three age-classes present in the beech stand were the mature class (34 m height class), the 21-40 year age class (17 m) and the regeneration class (0-11 m), the target stem numbers for each height class are equal to the number of stems in an even-aged stand of one third the area of the stand, ie 36 per ha for the mature class, around 612 for the 17 m height class and 1440 per ha for the regeneration class. The proportion between the classes is the same as in the normal stand but each class covers twice the area. The two examples of this approach applied to a normal stand,

and a three age-class stand along with a further example in a four age-class stand are summarised in Table 2.

TABLE 2: Derivation of target stem density numbers for a 1 ha irregular beech stand (yield class 10) with a) normal structure, b) a 3 age-class and c) a 4 age-class structure (after Garfitt, 1987).

Age-class	Mean top height	Stems per ha in even-aged stand		Target stem numbers in 1 ha irregular stand					
				Normal		3 Age-class		4 Age-class	
(yrs)	(m)	(no.)	(ratio)	(no.)	(ratio)	(no.)	(ratio)	(no.)	(ratio)
1-20	0-11	4400	40	720	40	1440	40	-	-
21-40	17	1870	17	306	17	612	17	465	11.3
41-60	24	550	5	90	5	-	-	137	3.3
61-80	29	275	2.5	45	2.5	-	-	68	1.6
81-100	32	165	1.5	27	1.5	-	-	41**	1
101-120	34	110	1	18	1	36*	1	-	-

* = 110 ÷ 3, ** = 165 ÷ 4

In irregular shelterwood and group selection stands, yield regulation for forecasting purposes will require the use of permanent sample plots. Accurate results are likely to be expensive and difficult to obtain.

CONCLUSIONS

1. The classification of uneven-aged systems which are likely to be widely applied in Britain is relatively simple. In silvicultural terms there are group systems (group felling, group selection and Bradford Plan) on the one hand and irregular shelterwood on the other. In forest management terms group felling (a small scale conventional system) lies on one side, with group selection and irregular shelterwood on the other, and the Bradford Plan aiming for a compromise solution.

2. Group-working is likely to be most suitable for broadleaved stands and may also have applications in neglected pole-stage stands of Douglas fir or Corsican pine, and windfirm mixed stands. Irregular shelterwood appears to be a suitable system for well managed stands of potentially windfirm, prolific seeding species such as Douglas fir, larch, western red cedar and sycamore.

3. The adoption of partial irregularity may often be a reasonable objective. A practical or financial inability to achieve a full range of age-classes should not be seen as a reason for rejecting an irregular structure completely.

REFERENCES

Fairbairn, W.A. 1963. Some observations on group regeneration. Forestry 36, 113-123.

Forestry Commission. 1985. Guidelines for the management of broadleaved woodland. Forestry Commission, Edinburgh.

Garfitt, J.E. 1984. The group selection system. Quarterly Journal of Forestry 78, 155-158.

Garfitt, J.E. 1987. Yield control of irregular woodlands. Quarterly Journal of Forstry 81, 181-184.

Hutt, P. undated. Bradford Plan continuous cover forest. An experiment in uneven-aged forestry. Tavistock, Woodlands Estate (unpublished).

Jeffrey, W.W. 1956. Swiss femel-coupe working. Bulletin of the Forestry Dept, University of Edinburgh, No 2.

Neustein, S.A. 1964. Windthrow on the margins of various sizes of felling areas. Report on Forest Research 1964, 166-171, HMSO, London.

Malcolm, D.C. 1971. Corrour management trial. Scottish Forestry 25, 262-269.

Penistan, M.J. 1960. Forestry in the Belgian uplands. Forestry 33, 1-7.

Poore, A. 1986. Association of Professional Forester's regional meeting at Longleat. Association of Professional Forester's Newsletter 1986, 44-48.

Workman, J. 1986. Experience in the management of beech woodlands. Proceedings of 1st meeting Discussion Group on Uneven-aged Silviculture held at Pershore College of Horticulture, 29th October 1986, 17-19.

DYNAMIC MODELLING OF TREE GROWTH IN A MIXED-DECIDUOUS WOODLAND: ITS SIGNIFICANCE FOR RESEARCH AND MANAGEMENT

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INTRODUCTION

The productivity, course of development, nutrient cycling and processes maintaining soil fertility in any mixed deciduous woodland are likely to be influenced by many factors, such as species composition, site quality, climatic conditions, thinning, selective felling, coppicing and, as is increasingly being recognised, pollutant inputs. The complexity and dynamic nature of mixed deciduous uneven-aged woodlands makes the prediction of the long-term impacts of these factors extremely difficult, for each factor may change, sometimes discontinuously with time and the factors may exhibit complicated interactions. So much so, that present assessments of the long-term impacts of the various factors on the these woodlands are reliant on a mixture of intuition and limited empiricism (Dyck, Messina and Hunter, 1986). The fragmentary and often short-term nature of much of the applied research data available on the development and functioning of deciduous woodlands does not help this situation.

To predict the impacts of environmental and management factors on woodland development and soil fertility as it affects tree productivity, it is necessary both to consider a woodland as an integrated system and to understand the dynamic processes governing its functioning. Potentially at least, computer modelling offers not only an approach for dealing with the complex processes involved in woodland growth and functioning, but also can aid our understanding of the impacts of perturbations brought about by management practices and the more insidious effects of environmental changes or low level pollution, by allowing their simulation.

Several computer models have been proposed for forest ecosystems (see Agren, 1986). One such model which produces outputs on biomass of mixed deciduous uneven-aged woodland growth, changes in species composition, organic matter decomposition and nutrient cycling and offers some opportunities to investigate impacts of environmental factors and management, is FORTNITE developed by Aber and Melillo (1983). This model has been based on the large amount of data accumulated from the Hubbard Brook Forest studies (e.g. Whittaker et al., 1974). The model has been used to explore the impacts of various clear-felling regimes on changes in surface litter layers on the soil, potential for nitrogen leaching and the subsequent natural regeneration of the mixed deciduous forest. The outputs have been partially validated using data for the studied and other sites.

One of the major problems with the use of computer models is the difficulty of obtaining a large enough base of reliable information and appropriate data for validation (Dyck et al., 1986). This problem is particularly relevant to work in the UK for there are possibly only two mixed deciduous woodland sites for which there are sufficient information on tree productivity, soil and nutrient cycling data, for modelling and some degree of model validation. One of these sites is the Oak-Ash-Birch woodland near ITE Merlewood at Meathop, Cumbria. The research data were obtained by intensive studies conducted during the 1960's and 70's as part of the International Biological Programme.

In early 1986, we obtained a disk-mounted copy of the FORTNITE model and got it working readily on a VAX 8600 computer, initially using the American data set. Very soon after we, as soil scientists engaged in nutrient cycling research rather than foresters, tried collating the relevant data for Meathop Wood and applying the model to it, with we think reasonable success for a preliminary attempt (Harrison and Ineson, 1988). As a result of this, we have subsequently gone on to upgrade the model in a number of ways. With the objective of widening the discussion on long-term management of mixed deciduous woodlands in the UK about which there are many reports (see e.g. Anon, 1982; Crowther,1980; Holmes,1984; Kirby, 1984; Peterkin,1981) and the hope that it will stimulate more research, we are therefore outlining in this paper the present (end 1987) state of our developments on and application of this model.

FORTNITE MODEL

The FORTNITE model as developed by Aber and Melillo (1983) for uneven-aged mixed deciduous woodland comprises two basic modules (Figure 1) a tree production module based on the JABOWA forest growth simulator (Bodkin et al., 1972) and a forest floor decomposition simulator (Aber et al., 1978; 1979). The tree production module simulates the growth of several tree species, each individually, in relation to its responses to site moisture status (expressed as actual evapotranspiration, AET), temperature (expressed as accumulated degree days ^{o}F, DEGD), available nitrogen, (regression constants and coefficients N1-N5 from Aber, Bodkin and Melillo, 1979 relating foliar N concentration, tree productivity and available N based on the Mitchell and Chandler fertiliser experiments) and light intensity (the lower threshold for fraction of full sunlight below which the species fails to reproduce itself, LMAX), and the degree of tolerance to shade (a relative growth factor calculated using equations from Bodkin et al., 1972, A1-A3). Tree biomass changes are derived from a suite of constants and coefficients from equations relating tree stem diameter at breast height (dbh) to tree height (B2 and B3), stem dry weight (SA and SB), branch dry weight (BA and BB), root biomass (RA and RB) and crown width (SLTA and SLTB) for each species. The maximum leaf dry weight produced (g M^{-2}) the root/stem biomass ratio (RTST), the maximum likely stem dbh (DIMX) and age (AGMX), and the numbers of regenerating saplings $100M^{-2}$ (SAPN) under optimum conditions are also required for each tree species. New stem entrance is calculated from SAPN and computed environmental conditions within the stand. Tree mortality is computed as a random function related to AGMX or a minimum annual stem diameter increment threshold (DINC).

The litter input to the decomposition module is a function of both tree mortality and live tree biomass. Leaf litter biomass is calculated from the leaf weight per unit canopy area and litter from each tree species is classified into one of six categories according to its chemistry and decomposition rate. Annual fine root litter has been assumed to be broadly 1.3 times leaf litter input, but adjusted for the root/stem ratio and changes in the forest floor biomass. Annual twig litter input is calculated from a regression relating it to stem basal area. Large woody litter input is

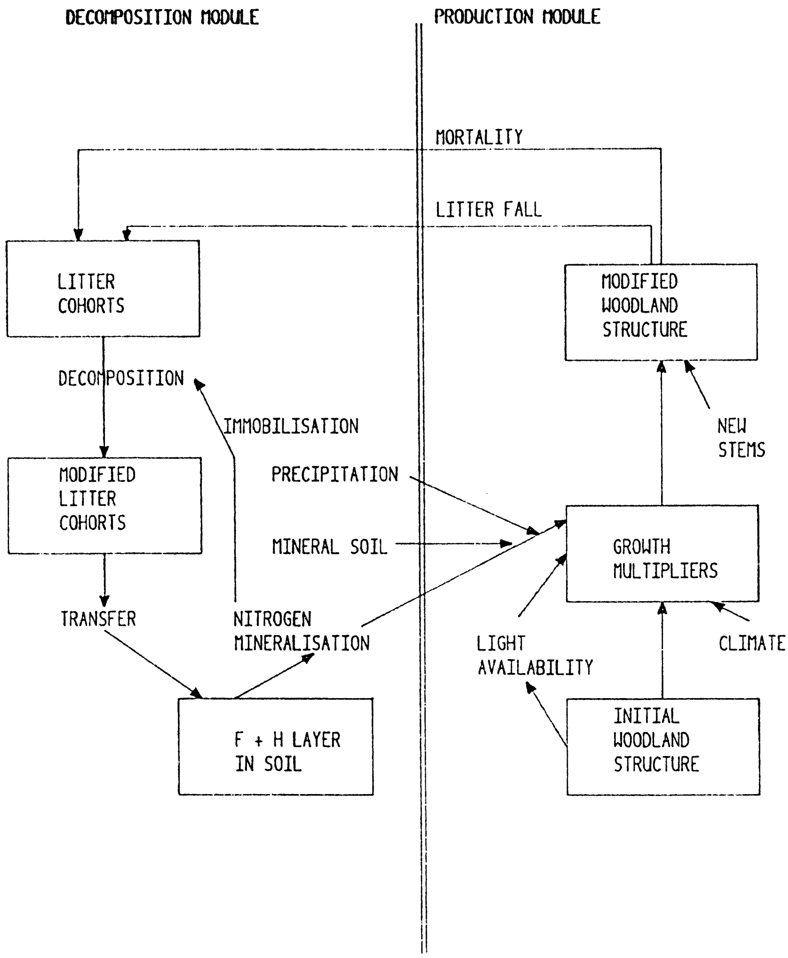

Fig. 1. A simplified diagram of the FORTNITE model structure, based on Aber and Melillo (1983).

assumed to be related to tree death and is distributed into 10 size classes according to dimension equations (Whittaker et al., 1974). For each of the potential 19 classes of litter, information required is the fraction of initial weight as nitrogen, decomposition expressed as the fractional weight loss per year, the grams N immobilised per gram weight loss, the fraction of weight loss of litter when it is transferred from the original litter compartment to the F+H material compartment. Inputs from precipitation, mineral soil and fertilisers are then combined with the net release of N through the litter decomposition to be fed into the tree production module, so completing the cycle.

MEATHOP WOOD

The site is a mixed deciduous coppice-with-standards woodland, located on the northern edge of Morecambe bay (Grid Ref. SD 435795) with an oceanic climate, the average annual temperature and rainfall being c. 8°C and 1250 mm respectively. The tree species comprise oak (Quercus petraea Matt. Liebl.), ash (Fraxinus excelsior L.), birch (Betula pubescens Ehrh. and B. pendula Roth.), sycamore (Acer pseudoplatanus L.) with an understorey of hazel (Corylus avellana L.). The site was last fully coppiced (but leaving some oak standards) in 1939 and its tree age structure partially reflects this management. The site has had a history of coppice and charcoal burning for at least 3 centuries (Satchell, 1984). Illicit use of the woodland for winter grazing continued until 1966, and has reoccurred from time to time within the last 10 years. The soil is an acid (pH 4.3-7.0) brown earth, averaging 13.5 cm depth, derived from Silurian slates and shales, overlying Carboniferous limestone.

The research data were mostly obtained from a 'type hectare' within the woodland, though tree dimension measurements requiring felling were necessarily obtained outside this area. Data used in the initial runs of the model, most of which was derived from the IBP studies, are presented elsewhere (Harrison and Ineson, 1988). Specific details about the sensitivity of growth and seedling generation to light intensity and on growth responses to nitrogen fertilisation as determined by Mitchell and Chandler (1939) are not available for the tree species at Meathop. Appropriate equations were selected (Bodkin, Janak and Wallis, 1972; Aber et al., 1979) based on generalised tree responses (Helliwell and Harrison, 1978; Evans, 1984; 1986). Information on the environmental limits with respect to AET and DEGD for each of the species were determined from the geographical distribution of each species (Jalas and Suominen, 1976) in conjunction with meteorological data for the sites nearest to the limits of spread (Muller, 1982).

INITIAL MODEL RUNS

We originally got the model up and running on a VAX 8600, but we now have transferred it to the ITE Merlewood microVAX, after the addition of graphics facilities.

We ran the model for Meathop Wood starting from the 1939 coppicing. The runs of the model showed the outputs to be reasonably realistic, with the predictions of total tree biomass and their components (stems, roots etc) and biomass by species for the years 1962-1972 agreeing with field estimates. Also the predictions for the litter masses of different classes of 1972 i.e. leaf litter, branch litter, twigs etc, concurred fairly well with the field measurements (Table 1). The longer-term developmental changes within the woodland predicted by these runs are given in Figures 2, 3, 4 and 6.

As part of our preliminary examinations of the potential of the model, we ran it to simulate the effects of the removal of sycamore stems (representing about 3% of the stem biomass) at year 52 after the last coppicing from the woodland. In broad terms, the model predicted that the oak and ash would show some improved growth and this improved growth is paralleled by slight increases in nitrogen availability (Figures 5 and 6). It is likely that the growth increases in the oak and ash predicted by the model would have been 'influenced' by changes in the light penetrating the canopy which the model computes, but which are not made extrinsic by the computer program.

MODIFICATIONS TO THE COMPUTER PROGRAM

During the initial trials of this model, we noted a number of points where

Table 1 Comparison of predicted (P) and estimated (E) biomass values for the studied hectare in Meathop Wood, 1962 - 1972

Forest Component	1962		1967		1972	
	P	E	P	E	P	E
Species						
Oak	58	68	74	78	100	88
Ash	56	46	61	53	69	63
Birch	20	16	16	18	13	20
Sycamore	8	5	12	6	15	7
Hazel	15	10	10	18	7	19
Tree component						
Total tree	158	146	173	173	204	198
Stems + Branches	97	88	104	108	121	124
Rootsystem	57	58	65	65	79	74
Basal area	23	18	22	23	24	25
Litter layer						
F + H					20.2	28.2
Branch wood					5.4	2.03*
Dead wood in canopy					10.9	5.47*
Root wood					1.2	N.A.
Fine root					1.9	6.6
Leaf litter					1.9	1.6
Twig litter					1.4	2.73

* From Swift et al 1976.

Estimated tree biomass figures provided by J M Sykes and R G H Bunce
Biomass is expressed as t ha-1 and basal area as m2 ha-1

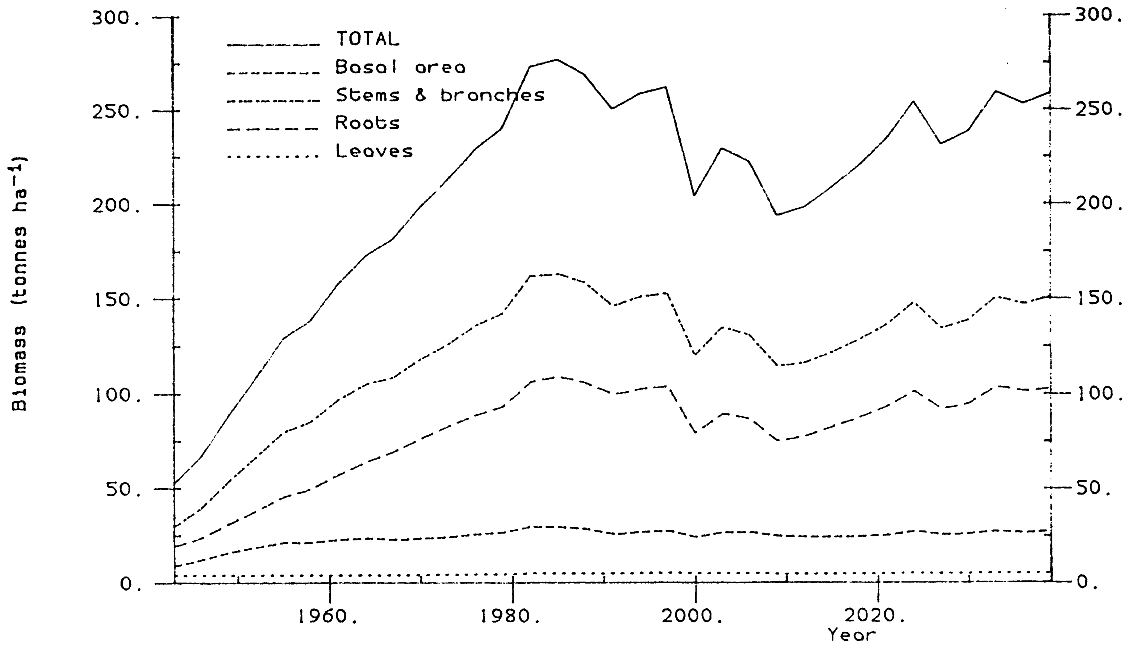

Fig. 2. Trends in the biomass of all tree species combined and tree components in Meathop Wood, predicted using FORTNITE.

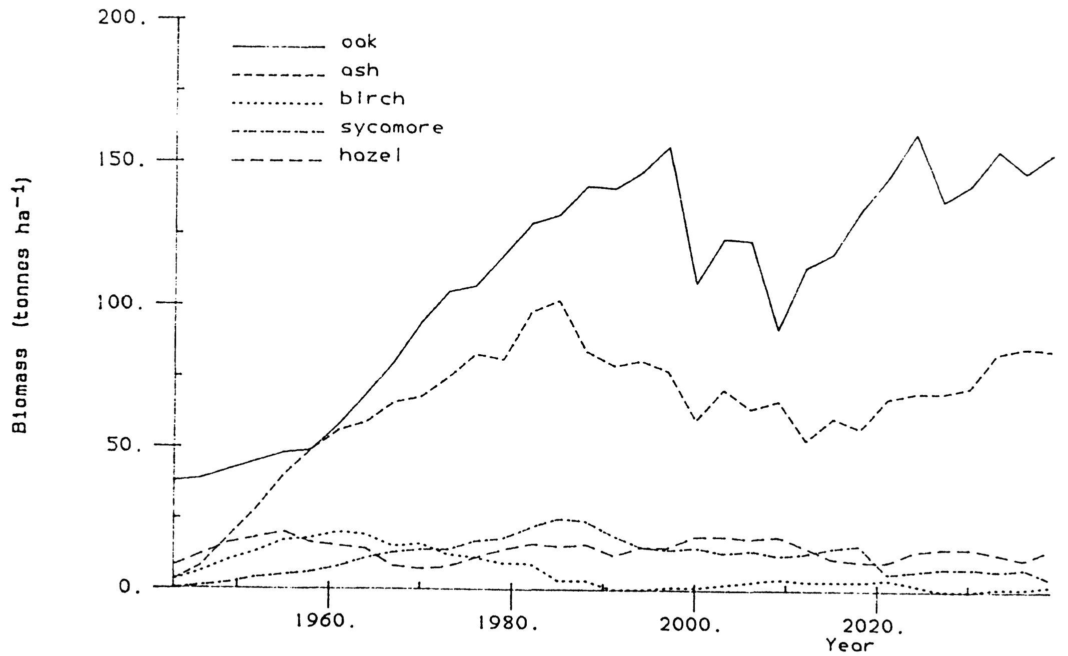

Fig. 3. Trends in total biomass of each tree species in Meathop Wood, predicted using FORTNITE.

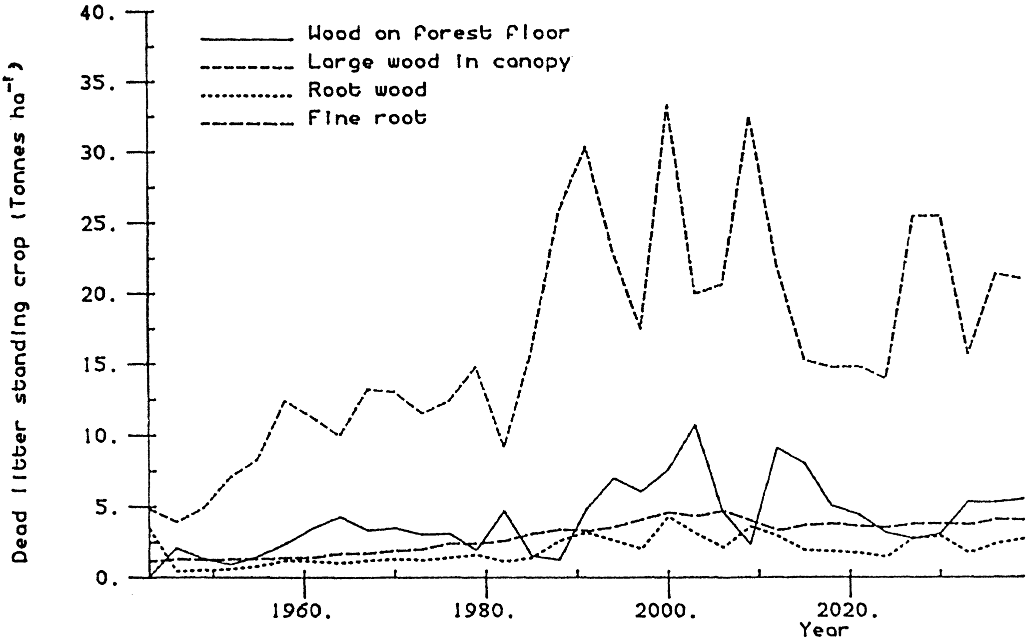

Fig. 4. Trends in litter layer components and dead wood in the canopy of Meathop Wood, predicted using FORTNITE.

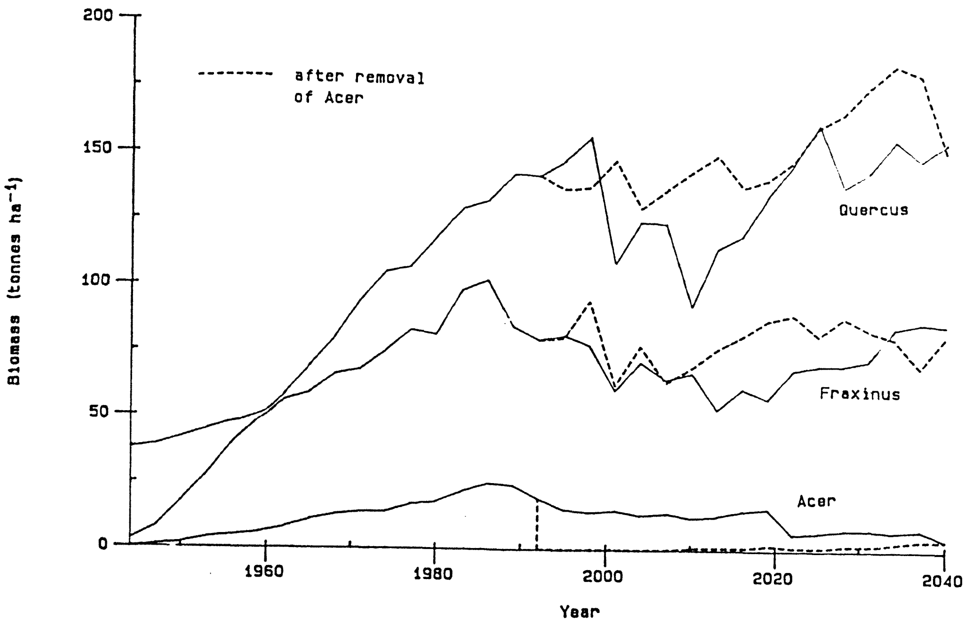

Fig. 5. Effects on the biomass of oak and ash of the removal of sycamore stems, predicted using FORTNITE.

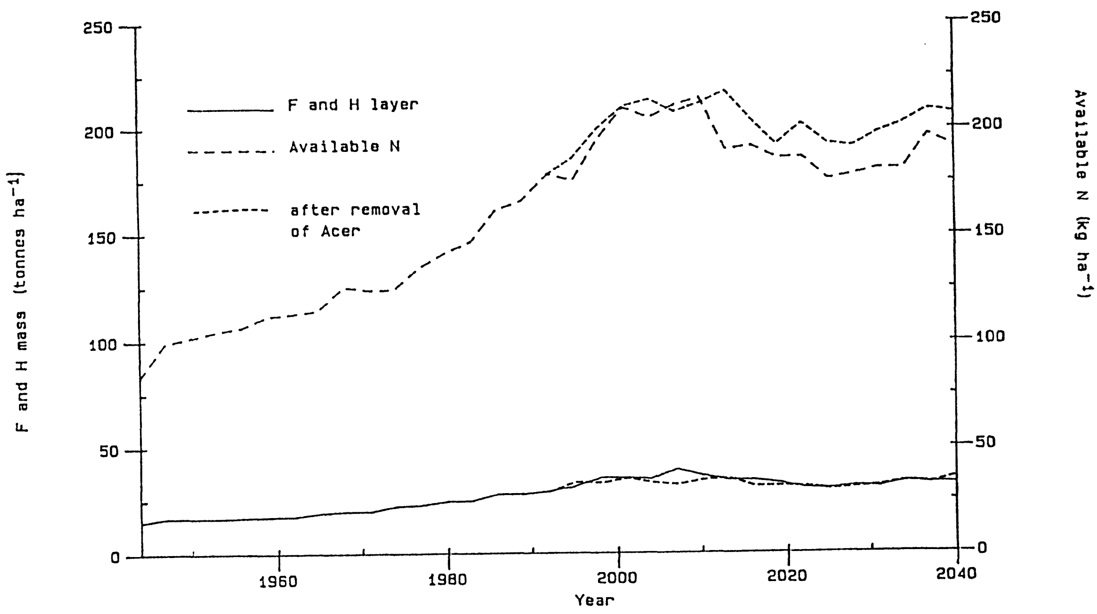

Fig. 6. Effects on the mass of F+H layer material and 'available' nitrogen of the removal of sycamore stems, predicted using FORTNITE.

modifications were either necessary or desirable. We have therefore implemented some of the changes. We want to emphasise that the modifications we have made, apart from the one made earlier (Harrison and Ineson, 1988), do not affect the conceptual basis of the simulations of the biological processes of the FORTNITE model. These modifications affect the computer operations and the accessibility of computed data generated during the model runs; the data outputs are however, altered quite significantly in specific ways, as indicated below.

Variability in outputs

a) Random number generation

During the initial running of the model, two problems have been identified which relate to the random elements used within the model. The first concerns the situation when the model is used to simulate a tree cut i.e. a selective removal or clear cut. When a cut is introduced, the model gives quite a different output for the years leading up to the time of the cut i.e. it seems to anticipate the tree removal. We have not only found this problem running our Meathop wood data (Figure 7), but also when re-running the original model with the published American data (Aber and Melillo, 1983): in the latter publication and previous studies (Aber, Bodkin and Melillo, 1979) graphical outputs of runs for period prior to a cut are not presented.

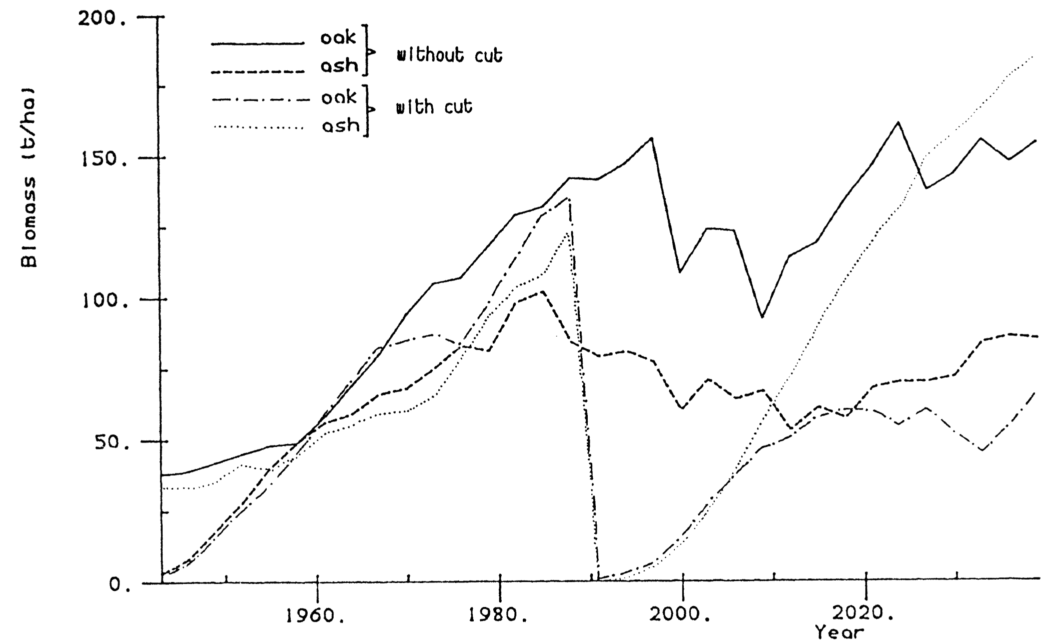

Fig. 7. Effects of an introduction of a clear-fell at year 50 on the biomass output prior to year 50, induced by change in accessing of the random numbers generated by the FORTRAN call RAN in the original FORTNITE model; simulation for Meathop Wood.

This effect was pinned down using the 'debug' facility on the microVAX to a problem relating to the way in which the computer program generates and uses random numbers. The model uses random numbers generated intrinsically by the Fortran call RAN, producing the same series of random numbers whenever it is used. However, the order in which the numbers were called differs according to whether a cut has or has not been specified; this results in the differences in output noted above. This was overcome by generating series of random numbers and depositing them into an array at the commencement of the program run. The numbers were then accessed in a sequential manner as required by the model and always in the same order.

b) Number of iterations

We then found that the form of seed used to generate the random numbers caused a fair amount of variation in the predicted value for any particular parameter between runs, when only 25 iterations were executed for each run as in Aber and Melillo (1983). In their model as published, only one arbitrarily chosen seed was used. The practical reality of this was that the form of seed used could have a greater affect on the model output values than adjustments to the input data. It was found that it was necessary to perform

200 iterations for each run to achieve stability of output values and to ensure output was independent of the form of seed used to generate the random numbers.

We consider the effects of the way that the random numbers were generated and the use of a single arbitrary seed are important weaknesses in the model operation. They could have had some unexpected effects in any tree harvesting applications of FORTNITE, which could invalidate conclusions drawn. This point requires further clarification.

Graphics

The output generated by the original model is in digital form which makes the interpretation of the outputs quite a slow process. We have now arranged for the output matrix to be coupled up to a colour graphics program based on the NERC written GRAFIX (GKS-based) package, for almost instantaneous transfer to a plotter. A further modification was to menu selected graphical output for the various biomass components (e.g. tree biomass by tree component, tree biomass by species, forest floor components and F+H layer and available N) to be outputted separately to a range of plotters e.g. HP7475 or VDU screens. Output of any run can now be ready for graphical assessment within about five minutes.

Additional management options

The published model allows three types of clear-fell (removal of stems only, all above ground biomass or wholetree), selective felling of trees of each or all species above a particular diameter class and additions of fertiliser, to be simulated either individually or in combination. In the light of management practices operated in UK woodlands, it was thought useful to introduce two additional options, namely those of thinning and coppicing. These options were integrated into the computer program by the simple addition of a few lines into the program. For thinning, this was achieved by setting a lower limit of dbh below which stems are removed, as well as a lower limit of dbh above which stems are removed when selective felling is implemented. For coppicing related to hazel, multiple stems were generated instead of one, the number per stool being determined at random from the normal distribution of stem numbers per stool found in Meathop wood.

Woodland heterogeneity

As part of the data-base required to run the model, the species of trees and their dbh on a single 'start plot' are required. This has therefore to be related to an average situation. The situation regarding the acquisition of data for Meathop wood, where a single 'uniform' area was studied, matched this requirement. However, woodlands in general are notoriously variable sometimes being divisible into subtypes, so the use of a single 'start plot' is hardly possible. We have therefore developed a variant of the model, which has multiple 'start plots' and integrates the resultant computations generated to provide an overall output.

Extraction of tree size class distribution

The model as published provides predictions of the changes with time in tree biomass, expressed either in terms of tree components stems, roots, leaves, etc or the individual tree species comprising the woodland. An important aspect of a woodland, particularly regarding its management, conservation and timber value, is the size distribution of the trees. This information is computed during the running of the model, but it is not made available in the output. We have included a subroutine (Sizdis) for doing this. The output from this has been included in the selection menu at the beginning of the program and has been coupled up to graphics to provide a colour histogram distinguishing three size classes, though digital output is also made available for more precise comparisons. The size classes can be altered easily to any predetermined values.

FURTHER MODEL RUNS ON MEATHOP WOOD DATA

Having integrated the subroutine for accessing tree size class distribution, we ran the model for Meathop Wood to examine this output. Unfortunately when we did this, the output did not match the size classes as determined during the 1967-72 period; no saplings and few small dbh trees were generated by the model although they were present on the site. It is important to realise here that failure to generate saplings and small trees does not markedly effect the total biomass predictions, but it is likely to have a significant influence on the predicted long-term woodland development. Similarly, a mismatch between predicted and observed stem distribution was also noted by Bodkin, Janak and Wallis (1972) with the JABOWA model. Broadly there are two possibilities which can account for this i) either the model has some structural defect - Bodkin et al., (1972) suggested there may be a need to modify the way tree mortality rates are computed or ii) some of the input data values used are not precise enough, for some of the parameters are rough estimates due to lack of specific information. We chose to investigate the latter. We found by varying the maximum potential seedling number (SAPN), light sensitivity threshold values (LMAX), the maximum growth rate (G) and some of the dbh values for individual stems on the startplot, from those initially included in the data matrix FORT.DAT, we have been able to generate a stand structure more closely in line with those observed in the 'type hectare' in Meathop Wood (Table 2). However, when this was attained, the predicted tree biomass values for 1962-72 significantly deviate from those for the woodland (Table 1). From our experience to date, a closer approximation both could perhaps be achieved by further fine-tuning of these parameters; unfortunately we are unable to harden SAPN, LMAX or start plot values due to lack of specific data.

A further complication is that Meathop Wood has been subjected to illicit sheep grazing until 1966 (this factor has definitely influenced seedling regeneration but these effects have not been investigated), so attempts to model the stem size distribution in Meathop Wood as determined for 1972, may lack precision until grazing effects can be accomodated in the model. The model, though, could be run with the 'thinning' regime operative, setting a very low stem diameter limit to achieve a specified seedling removals at defined intervals, to simulate a grazing effect. It may be possible to adjust stand structure by implementing a grazing regime in this way, rather than modifying the SAPN, LMAX and start plot data, and we are now exploring this.

SENSITIVITY OF MODEL PARAMETERS

During the course of our examination of the model for Meathop Wood, we have found some of the parameters used to be particularly sensitive to change. Perhaps the most sensitive we have discovered is that of the decomposition

Table 2 Comparison of predicted (P) and determined (D) stem size distribution of trees in the studied hectare of Meathop Wood, 1972

Tree species	Stem size class (cm)	Observed	Predicted Number of Stems	
			Initial data	Modified data
Oak	0 - 4	6	12	16
	4 - 15	212	12	208
	> 15	118	148	180
Ash	0 - 4	17	12	12
	4 - 15	143	8	100
	> 15	110	64	140
Birch	0 - 4	1	0	4
	4 - 15	61	0	16
	> 15	52	24	52
Sycamore	0 - 4	7	0	0
	4 - 15	22	0	32
	> 15	8	52	32
Hazel	all	985	264	288

rate of tree fine roots. The decomposition of the F+H layer material on the soil surface, the low light intensity threshold for sapling growth and reproduction (LMAX), the responses of the trees to variation in nitrogen availability and the potential for sapling regeneration (SAPN) are also quite sensitive.

Clearly all these factors require particular attention in research studies. Fine root decomposition rate is very variable (Persson, 1978; Deans, 1983; McClaughtery, Aber and Melillo, 1984) and there are intrinsic difficulties in the methodology for measurement of this parameter. Some success has been acheived in determining the turnover rate of F+H layer material by use of the bomb-^{14}C incorporation technique used in Meathop Wood (Harkness, Harrison and Bacon, 1986). The low light intensity threshold for sapling growth can possibly be investigated using shading techniques (Helliwell and Harrison, 1978) or growth under experimental conditions under a woodland canopy (Shaw, 1981). For tree responses to nitrogen availability, extensive fertiliser trials, as conducted by Mitchell and Chandler (1939) and Evans (1986) are required for deciduous tree species. The potential for sapling regeneration and the assessment of the damaging effects of grazing may require more permanent exclosures to be established in woodlands to exclude grazing animals (Piggott, 1983).

TRANSFERABILITY OF FORTNITE

From the progress we have made in applying the FORTNITE model, originally developed on the Hubbard Brook Forest, to Meathop Wood, we are convinced that it has the potential for general application to UK woodlands. Clearly there is the major problem of the availability of adequate data-bases for the common tree species. However, this can provide a logical and justifiable incentive for diverse but integrated woodland research programmes in the future.

A further attribute of the model, is that it and its data files are easily accessed, as we have shown, to make the adaptations necessary to meet particular research requirements or practical woodland situations.

Though the development of mathematical models is still in the early stages (Dyck et al., 1986), they offer opportunities to i) integrate data acquired in different research projects, ii) identify important gaps in knowledge and thus stimulate research in these areas and iii) produce scenarios on the potential effects of management practices and environmental factors such as pollution and possibly pest damage, on changes in woodland growth and productivity.

Our preliminary studies in applying FORTNITE to a data-base for Meathop Wood, Cumbria show that this model can produce reasonable predictions of the trends with time in total tree biomass, biomass of each of the tree species, and litter layer materials. After some important modifications to the computer program, we consider the model has the potential for application to woodlands in the UK, for the production of scenarios on the effects of management and environmental factors on the long-term development of woodlands. It is recognised that much of the data needed for this activity are at present not available. However, we see this model as providing an objective and logical basis for i) stimulating further integrated research programmes on woodland growth and functioning and ii) integrating the differing conservation, timber and research interests.

References

Aber, J.D. and Melillo, J.M. (1983). FORTNITE: A Computer Model of Organic Matter and Nitrogen Dynamics in Forest Ecosystems. Research Bulletin No. R3130, pp 1-36. University of Wisconsin, Madison.

Aber, J.D., Bodkin,D.B. and Melillo, J.M. (1978). Predicting the effects of different harvesting regimes on forest floor dynamics in northern hardwoods. Canadian Journal of Forestry Research 8, 306-315.

Aber, J.D., Bodkin, D.B. and Melillo, J.M. (1979). Predicting the effects of different harvesting regimes on productivity and yield in northern hardwoods. Canadian Journal of Forestry Research 9, 10-14.

Agren, G. (Editor) (1986). Predicting the Nutritional Consequences of Forest Harvesting on Site Productivity. Swedish University of Agricultural Science, Dept. Ecology and Environmental Research Report No. 26 pp 1-205.

Anon (1982). Workshop on Research Needs in Forestry. Report of Workshop held at University College, London 29-30 March. pp 105, Natural Environment Research Council, Swindon.

Bodkin, D.B., Janak, J.F. and Wallis, J.R. (1972). Some ecological consequences of a computer model of forest growth. Journal of Ecology, 60, 849-872.

Crowther, R.E. (1980) Lowland broadleaved woodlands and silvicultural. research. In: Research Strategy for Silviculture. Edited by D.C. Malcolm, pp 68-73. Institute of Chartered Foresters, Edinburgh.

Deans, J.D. (1983). Dynamics of coarse root production in a young plantation of Picea sitchensis. Forestry 54, 139-155.

Dyck, W.J., Messina. M.G. and Hunter. I.R. (1986). A Review by the Managing Agent of IEA/FE Project CPC-10. In: Predicting the Nutritional Consequences of Forest Harvesting on Site Productivity. Edited by G. Agren. Swedish University of Agricultural Science, Dept. Ecology and Environmental Research Report No. 26 pp 9-29.

Evans, J. (1984). Silviculture of broadleaved woodland. Forestry Commission Bulletin No. 62. HMSO: London.

Evans, J. (1986). Nutrition experiments in broadleaved stands: 1. Pole-stage ash and oak. Quarterly Journal of Forestry 80, 85-94.

Harkness, D.D., Harrison, A.F. and Bacon, P.J. (1986). The temporal distribution of 'bomb' ^{14}C in a forest soil. Radiocarbon 28, No. 2A 328-337.

Harrison, A.F. and Ineson, P. (1988). Nitrogen cycling in a Quercus/Fraxinus (oak/ash) woodland in northern England, examined using the computer model FORTNITE. In: The Temperate Forest Ecosystem. Edited by Yang Hanxi, Wang Zhan, Jeffers, J.N.R. and Ward, P.A., pp 115-123. ITE: Grange-over-sands.

Helliwell, D. R. and Harrison, A.F. (1978). Effects of light and weed competition on the growth of seedlings of four tree species on a range of soils. Quarterly Journal of Forestry 73, 160-171.

Holmes, G.D. (1984). Broadleaves in Britain. Report of a Policy Review Group Published by the Forestry Commission as a Consultative Paper, pp 64. Forestry Commission.

Jalas, J. and Suominen, J. (1976). Distribution of Vascular Plants in Europe. Salicaceae to Balanophoraceae. Atlas Florae Europaeae vol. 3. pp 128. Committee for Mapping the Flora of Europe and Societas Biologica Fennica Vanamo, Helsinki.

Kirby, K.J. (1984). Forestry Operations and Broadleaf Woodland Conservation. Report No. 8, pp 1-59, Nature Conservancy Council.

McClaugherty, C.A., Aber, J.D. and Melillo, J.M. (1984). Decomposition dynamics of fine roots in forested ecosystems. Oikos 42, 378-386.

Muller, M.J. (1982). Selected Climatic Data for a Global Set of Standard Stations for Vegetation Science, pp 1-306. Junk: London.

Peterkin, G.F. (1981). Woodland Conservation and Management, pp 1-328, Chapman and Hall, New York.

Piggott, C.D. (1983). Regeneration of oak-birch woodland following exclusion of sheep. Journal of Ecology 71, 629-646.

Satchell. J.E. (1984). A History of Meathop Woods. Pt 2 - The middle ages to the present. Transactions of the Cumberland and Westmorland Antiquities and Archeological Society 84, 85-98.

Shaw, M.W. (1981). Woodland regeneration with examples drawn from investigations of oak woodland. In: Forest and Woodland Ecology. Edited by F. Last & A. Gardiner, pp 24-28. Cambridge: Institute of Terrestrial Ecology.

Whittaker, R.H., Bormann, F.H., Likens, G.E. and Siccama, T.G. (1974). The Hubbard Brook ecosystem study: forest biomass and production. Ecological Monographs 44, 233-254.

THE ECOLOGY AND SILVICULTURE OF LIMES (TILIA spp.)

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Two species of lime are native in western Europe, including Britain. The small-leaved lime (*Tiliia cordata*) is native as far north as latitude 65°N on the coast of Norway, latitude 62°-63°N in Sweden and Finland, and eastwards it extends to beyond the Urals. Its southern limit is more or less along the northern boundary of the Mediterranean zone. The species is characteristically a member of the lowland summer-green deciduous woodlands of the European plain, where it is commonly associated with oaks (*Quercus robur* or *Q. petraea*) and hornbeam (*Carpinus betulus*).

The large-leaved lime (*Tilia platyphyllos*) has a more southerly natural distribution. It is absent from Norway and Finland and has a single locality in southern Sweden; it extends eastward to Poland and the western Ukraine but further southward than *T. cordata* into northern Greece, southern Italy and central Spain. It is a tree of hills, growing in beech woods, or on cliffs and in ravines associated with sycamore (*Acer pseudoplatanus*) and wych elm (*Ulmus glabra*).

In the British Isles, *T. cordata* is much the commoner and more widespread species. It is native almost throughout England and Wales, but introduced and planted rarely in Scotland and Ireland. It now has a patchy distribution, being locally abundant in some regions and strangely rare in others.

The belief that *T. cordata* generally occurs on limestone is erroneous and the species has a wide tolerance of soil conditions and will grow on podzols, brown earths, brown calcareous soils and rendzinas. In the English Midlands, southern England and East Anglia, it usually grows on brown forest soils and stagnogleys, developed over non-calcareous or weakly calcareous clays and silty loams. It is almost absent from soils developed directly over chalk and oolite. Where it is abundant it seems to be the combination of impeded drainage in winter and desiccation in summer which particularly favours the species.

To the north and west in regions of higher rainfall (> 850 mm per annum), *T. cordata* occurs on both acid soils and on shallow soils over limestone (for analyses see Pigott and Huntley, 1978; Table 3). It shows a similar extension on to limestone in areas of higher rainfall in central Europe and the Alps.

By contrast, *T. platyphyllos* is a much rarer species in Britain, now shown by pollen analysis to be certainly native, but confined to a few scattered localities in England and Wales (Pigott, 1981a). As on the continent it usually grows on soils which are typically rendzinas and which have been derived directly from limestones or basic igneous rocks. In south-east England and the Welsh borderland it grows with beech, ash, sycamore and yew, and in the Pennines and east Yorkshire with ash, sycamore, wych elm and a varied assemblage of calcicolous shrubs. The presence of rare apomictic species of *Sorbus* is a feature of some of its localities.

The native distribution of the two species of lime overlaps in the Derbyshire dales and the Wye valley and there trees of intermediate characters also occur and are almost certainly hybrids (Pigott, 1969).

The correct name for this hybrid is Tilia x vulgaris which was originally described as a species by Hayne (1905). It is, in fact, this hybrid which is most frequently and widely planted, and distinctive clones were propagated vegetatively and imported from the Netherlands during the seventeenth century to be planted often in avenues, but also as solitary trees in parklands. One such clone is particularly characteristic of early planting and is widespread. It has tall vertical main limbs, a trunk which develops hemispherical masses of epicormic buds and in old age flanged buttresses; it has bright green leaves of moderate size, slightly glaucous beneath and profuse hanging inflorescences, each normally with seven flowers. It sets a proportion of fertile fruits.

After 1750 the popularity of limes diminished and, when they began to be planted again in the early ninetieth century, along streets, in town parks and gardens and churchyards, a much wider variety of clones, as well as the original clones, were used.

Though less frequent, T. platyphyllos has a similar history of planting. It was planted in parks in the sixteenth century and was occasionally used for avenues in the early eighteenth century as at Hatfield House and Stowe. In contrast, T. cordata, although the commonest native species, was rarely planted in parks and never as the principal species in an avenue.

In Britain, the silviculture of lime, almost always Tilia cordata, has a long history as coppice. To judge from the uniformity and purity of some surviving lime-coppices, they must have either been planted, or encouraged by propagation, though possibly from locally indigenous stock. For example, the wood at Linwood (a Saxon name) near Market Rasen in Lincolnshire, until cleared and replanted in the 1950s, consisted of parcels of pure coppice of T. cordata. The use of such coppices is poorly documented, but there are scattered references from the Middle Ages to the eighteenth century to the collection or sale of the fibrous bark, or bast, for rope-making.

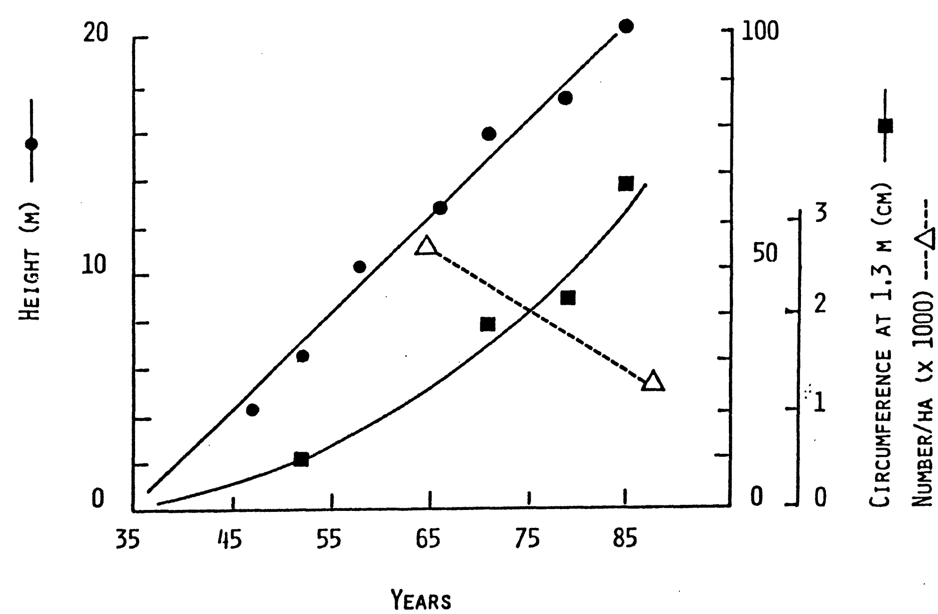

Fig. 1. Growth in height and circumference of trees of Tilia cordata on an experimental plot at Holt Down, Buriton, Hampshire. (Information from 1935 to 1977 from the Forestry Commission).

The timber of lime is light (specific gravity 0.45 g cm^{-3}), with an even grain and uniform texture. It is white when freshly cut, but darkens to pale yellow after cutting. In eastern Europe, especially the Soviet Union, the species continues to be planted and its timber used for a variety of purposes in furniture and the manufacture of small articles (Murakhtanov, 1981). Recent planting of lime in Britain is quite exceptional. The potential is shown by the experimental plot established in 1935 on Holt Down in Queen Elizabeth Forest, Petersfield. Growth in height has been almost directly proportional to age (Fig. 1) to reach 20 m at fifty years (equivalent to Yield Class 8 for oak or beech). The stems are straight and branchless to about 10 m with a mean diameter at 1.3 m of 32 cm. At least in form, if not in value, the stems of the adjacent plots of beech are of poor quality.

A striking feature of the plot is the influence of lime on both the field-layer and soil. Directly beneath the lime canopy is a dense growth of dog's mercury (Mercurialis perennis). This contrasts abruptly with the almost bare ground beneath the adjacent plots of beech. There is a no less remarkable and abrupt change in the soil which has developed from about 30 cm of brown flinty loam over chalk. Beneath lime the soil is well-aggregated and friable with numerous large earthworms. Beneath beech the soil is compact and weakly structured with occasional small pigmented earthworms. The mean pH of the upper 30 cm of the profile is 5.1 (SE = 0.29) under lime and 3.8 (SE = 0.17) under beech. The soil under lime is also richer in mineral nitrogen and phosphate.

Limes are readily propagated from basal sprouts, by grafting and by seed. It is often stated that limes usually fail to set fertile fruit in Britain, but this is not true. Surprisingly T. platyphyllos, the more southern species, sets fertile fruits in most years in Britain. Seedlings often appear in abundance and there is good regeneration in some native sites.

T. cordata produces fertile fruit regularly in southern England, but the crop varies from year to year. Seedlings are often abundant beneath trees which flower freely, but beneath overgrown coppice they occur but are sparse. It is surprising that Elwes and Henry (1913, p 1659) never found seedlings in spite of searching for them. In northern England, in contrast, most fruit is sterile and only when July and August are exceptionally warm are small quantities of fertile fruit produced. Normally the majority of fruits contain shrivelled ovules which are apparently not fertilised. Experimental study (Pigott and Huntley, 1981) shows that the pollen tubes emerge from the pollen but require temperatures above 19°C - 20°C to grow down the style sufficiently rapidly to achieve fertilisation. In the cool summers of northern England, the tubes are often arrested in the style and fertilisation fails. In the continental climate of central Finland, early August is normally warm enough to allow fertilisation, but the rapid fall of temperature in September prevents complete development and ripening of the fruits (Pigott, 1981b).

It is remarkable that the fertile seeds of lime have no invertebrate predators; ripe fruits are reported to be taken by birds and when fallen are often neatly opened and the seeds consumed by both mice and voles. Fruit collected in early autumn and sown immediately normally germinate the following spring, but when collected late or dried after collection, only 5-10 per cent germinate in the first spring and the remainder germinate a year later. Exposure to low temperatures during the winter is essential. Fruits may be stored dry for at least two years.

Seedlings are vulnerable to damping-off. Mortality is reduced if seedlings are pricked out into a sandy compost and watered sparingly. Apical growth of the shoot ceases in the open after production of 3-5 true leaves and when it is about 10 cm tall: by then the main root may be 2-3 times as long. Much of the seed available in Britain comes from Poland and, when unshaded, gives rise to young plants with two or three main shoots. Shades with a transmission of about 50 per cent ensure a single dominant leader and greater growth in height (Fig. 2).

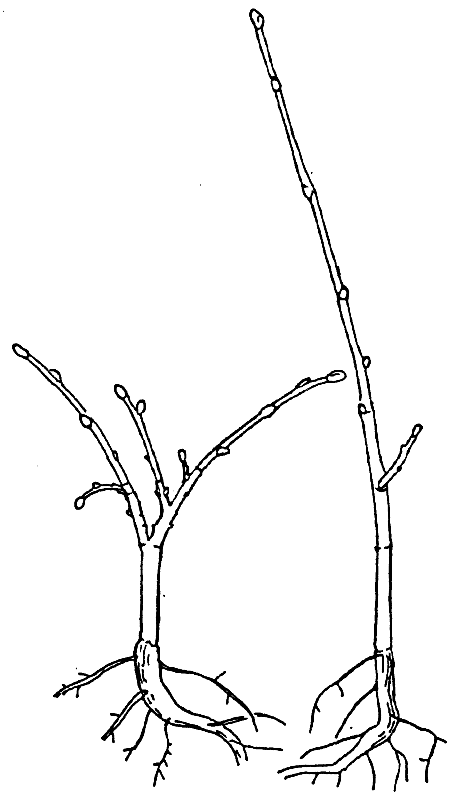

Fig. 2. Seedlings of Tilia cordata of Polish provenance at the end of their second year when grown in full sun (left) and under a screen of 50 per cent transmission (right)

Saplings planted into thinned or cleared woodland may be damaged by voles (Pigott, 1985), especially where there is a cover of bramble, and they also need protection from roe deer which show a marked preference for lime during the winter (König, 1976). Lime is not normally damaged by grey squirrels, either when young or at the pole stage. The seedlings tend to grow slowly for the first few years, but respond well if grown in tree shelters. Top shade or dense planting is required to ensure suppression of laterals. Saplings are shade-tolerant and will maintain vertical growth under a canopy of 10 per cent transmission, but in deeper shade growth of the leader becomes horizontal.

Natural regeneration of T. cordata does occur in a few sites scattered through England, and depends on high densities of seedlings which, in turn, depend on a significant proportion of parent trees in the canopy. The rarity of regeneration is because when lime is abundant it is almost always old coppice, which not only produces relatively little fertile fruit, but also casts deep shade.

Lime survives in spite of its poor regeneration from seed because of its great longevity. Old trees show a remarkable tenacity for life and are more or less indestructible; as old stems collapse, new sprouts arise to take their place and essentially trees coppice themselves. Trees which fall over often retain part of their root-system and sprout not only from the base, but from wherever the stems are resting on the ground. In the Lake District trees have fallen across narrow raviness and rooted on the opposite slope, and some have formed clumps on both sides arranged in a zig-zag pattern. Although single stems rarely show more than 250-300 annual rings, there is evidence from the diameter of stools, from the size of clonal groups and from the extent of exposure of roots by the retreat of slopes that some individuals are almost certainly over 1000 years old. The combination of great longevity and poor regeneration from seed means that the natural distribution of T. cordata dates back to prehistoric and early historic time. Indeed, in the north of England, where regeneration from seed no longer seems to occur, such trees may actually be living survivors from earlier warmer episodes in the postglacial period.

Since about 1960 the planting of small-leaved lime has been strongly recommended for amenity, as a replacement for elms and even to replace T. x vulgaris in avenues. It is a very handsome tree and it has many qualities which make it an attractive proposition. It is deeply rooted and, as Evelyn (1706) states "it stoutly resists a storm". It appears to be more resistant to heart-rot caused by Ganoderma australe (= G. adspersum) than T. x vulgaris and in general it remains free from disease. When grown in gardens and streets it may become infested with aphids (Eucallipterus tiliae), but possibly not so severly as do some clones of T. x vulgaris.

To be correct historically it is not the lime to use when replanting avenues of the seventeenth and eighteenth centuries. Most forms of T. cordata have broad rounded crowns and for this reason are not well-suited to the traditional form of lime-walk or avenue. There is probably potential for selection of leader-dominant genotypes with narrow crowns. Such forms occur in some populations and their seedlings are strongly leader-dominant. The cultivars 'Swedish Upright' and 'Greenspire' are selections for these characteristics.

The disadvantage of planting Tilia cordata into woodlands is that it obscures and confuses the uniquely intricate pattern of distribution which was established in prehistoric and early historic times. The presence of this species in a wood carries an important message about the history of that wood, and the detailed distribution within a wood is no less informative. Haphazard planting can only result in a loss of that information.

REFERENCES

Elwes, H.J. and Henry, A. 1913. The Trees of Great Britain and Ireland, 5. Edinburgh.

Evelyn, J. 1706. Silva, or a discourse of forest-trees and the propagation of timber. London.

Hayne, F.G. 1905. Getreue Darstellung und Beschreibung der in der Arzneykunde gebräulichen Gewachse. Berlin.

König, E. 1976. Wildschadenprobleme bei der Waldverjüngung. Schweizerische Zeitschrift für Forstwesen, 127, 40-57.

Murakhtanov, E.S. 1981. Lipa Bibliotechka "Drevesnie porodi", Moscow.

Pigott, C.D. 1969. The status of Tilia cordata and T. platyphyllos on the Derbyshire limestone. Journal of Ecology, 57, 491-504.

Pigott, C.D. 1981a. The status, ecology and conservation of Tilia platyphyllos in Britain. In Synge, H. The biological aspects of rare plant conservation, Wiley.

Pigott, C.D. 1981b. Nature of seed sterility and natural regeneration of Tilia cordata near its northern limit in Finland. Annales Botanici Societatis Zoologicae-Botanicae Fennicae, 18, 255-263.

Pigott, C.D. 1985. Selective damage to tree-seedlings by bank voles (Clethrionomys glareolus). Oecologia (Berlin), 67, 367-371.

Pigott, C.D. and Huntley, J.P. 1978. Factors controlling the distribution of Tilia cordata at the northern limits of its geographical range. 1. Distribution in north-west England. New Phytologist, 81, 429-441.

Pigott, C.D. and Huntley, J.P. 1981. Factors controlling the distribution of Tilia cordata at the northern limit of its geographical range. 3. Nature and causes of seed sterility. New Phytologist, 87, 817-839.

THE DEVELOPMENT OF A TRANSFORMATION TO IRREGULAR FOREST: 35 YEARS EXPERIENCE AT THE GLENTRESS TRIAL AREA.

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INTRODUCTION

Irregularly structured forest differs from regular forest or plantations by having all size classes represented in each management unit (eg compartment). In Europe the management of irregular forest developed (Matthews, 1986) in a restricted area in stands composed of a few indigenous species, on relatively base-rich freely-drained mineral soils, and which had generally started life under regular managment. Professor M L Anderson instituted several trials of irregular working in Scotland in the 1950's and the Glentress trial area was established in 1952. Situated near Peebles, about 25 miles south of Edinburgh, the 120 ha of Forestry Commission stands are currently about halfway through a planned 60-year transformation period. The aim of this paper is to describe and discuss experience in their management to date.

SITE CONDITIONS AND FOREST HISTORY

Glentress Forest is located on steep rounded hills which are typical of the Tweed valley. The underlying Ordovician sediments give rise to generally well-drained soils, grading from colluvial acid brown earths on the lower slopes to podzolised peaty iron-pan soils at the top of the hill, an altitudinal range from 240-560 m. (Heavy glacial till occurs on the lowest slopes and valley floors which are just outside the trial area.) The general aspect of the local ridge-valley system is south west, giving site aspects ranging from 100 to 300 degrees, and the area is moderately exposed (Windthrow Hazard Class II-IV) with exposure being accentuated by wind funnelling up the valleys. Annual precipitation varies between 1000 and 1500 mm, with snow falling on about 60 days and lying for about 20 days a year. The mean annual temperature is 7.2 °C, and ground frosts occur, on average, on 100 nights a year. The ground vegetation on the lower colluvial slopes is of a grass-herb type with ferns (*Holcus*/*Dryopteris*) and *Deschampsia caespitosa* in small mid-slope flush areas. On the higher slopes grass-heath conditions (*D. flexuosa*/*Vaccinium myrtillus*) prevail with *Calluna* increasingly important towards the top and in openings. Early plantings included European larch on Caresman Hill (1878), a shelterbelt of Scots pine and European larch on the exposed Smithfield ridge and patches of Douglas fir and Sitka spruce in the valley of the Glentress burn (1903). After acquisition by the Forestry Commission in 1920 the main species planted were Douglas fir on the lowest ground with Japanese and European larches on the middle slopes. Scots and Corsican pines were planted on the upper slopes, but were extensively beaten-up or replaced with Norway and Sitka spruce in the 1940's.

MANAGEMENT OF THE TRIAL AREA

Initial approach

Professor Anderson believed that an irregularly structured forest, in which mixed species stands predominated, would provide and maintain ecological conditions for sustained yield with some protection from wind and other damaging agencies. He envisaged this as particularly important on higher elevations. With the Forestry Commission's agreement he initiated the transformation of the existing pole stage stands with the following objectives:-

i to create mixed stands of irregular structure "best adapted to site conditions" in order to maintain and improve soil fertility;

ii to maximise value production by achieving the highest possible volume increment and timber quality;

iii to determine the optimum growing stock composition, avoiding the use of clear felling, for the provision of a sustained yield;

iv to obtain experience in the management of irregular stands;

v to improve access within the forest to ensure satisfactory harvesting.

As the existing stands were about 30 years old a 60-year transformation period reduced the potential loss of increment and required the regeneration of about 2 ha annually. The Gurnaud-Biolley Check Method was introduced, the 120 ha area being divided into six approximately equal areas or blocks (Fig 1) which were then worked on a 6-year cycle, with all operations, including 100 per cent enumeration, carried out in the year of treatment. Initial increment studies suggested an average Current Annual Increment of 2 per cent and a Time of Passage, (ie the average time for a tree to pass through a 5 cm diameter class) of 12 years, hence the choice of a 6-year operational cycle.

Edinburgh University (Department of Forestry and Natural Resources) was responsible for the enumerations, location of regeneration fellings and choice of species to be planted, while the Forestry Commission carried out the harvesting, establishment and maintence work involved. This division of labour still pertains and the current 'block of the year' (Forest Year 1988) is Block A at the start of the sixth operational cycle.

Originally it was intended to concentrate species selection on Norway spruce, European silver fir and beech with some additional broadleaved species. The selection was based on central European montane irregular forests where the shade tolerant species form an important component. However the silver fir was difficult to obtain and it was supplemented by grand fir, noble fir and western hemlock. The broadleaved component included small plantings of sessile oak, ash, sycamore, grey and black alder, rowan and whitebeams. At higher elevations Sitka spruce, hybrid larch and lodgepole pine were used.

The structure initially aimed for was group selection and to this end a somewhat cautious start was made by uniformly distributing the fellings, throughout the yearly block in small areas of 0.01 - 0.02 ha each. These usually had two species planted in them, the shade tolerant one at the southern end. Planting was at 0.9 m spacing with the deliberate intention to avoid weeding and beating-up.

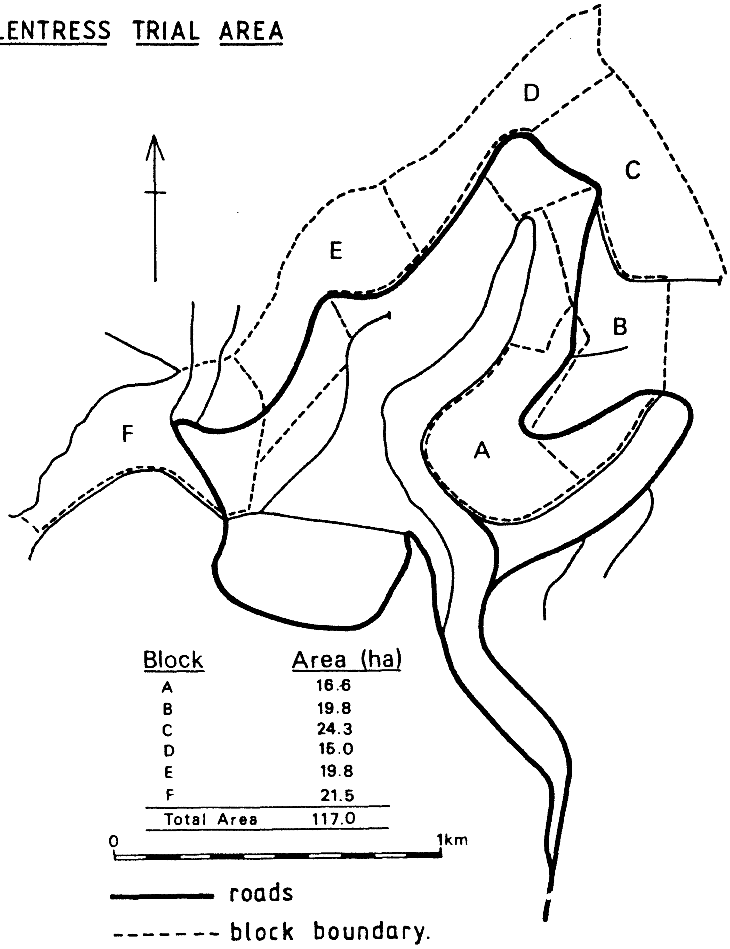

Fig. 1. Glentress trial area - Blocks A to F

Developmental changes

As time has progressed a number of changes have been introduced:

i complete enumerations were discontinued after two complete cycles because the stands were still far from achieving an irregular structure (Table 1) and the information obtained did not justify the effort involved. Now that after 35 years an irregular structure is developing, an annual 10 per cent sample enumeration is being introduced so that increment and yield can be assessed by the 'check' method with a practical work input.

ii group size was increased by the second cycle for a number of reasons: firstly, shading of the groups by the original crop trees was bound to increase during the transformation period - the stands planted in 1926, Blocks A and B for example, were in the pole stage at the time of the first regeneration fellings but are now much larger; secondly, the heavy browsing of shade-tolerant beech and European silver fir has meant greater reliance on relatively light-demanding species; thirdly, the transition from horse to tractor or cable crane extraction has increased the relative cost penalty of small scale working. The present practice is to make groups roughly circular with an effective diameter at least twice the height of the tallest adjacent stand trees, giving group sizes of approximately 0.1 - 0.2 ha at higher and lower elevations respectively.

TABLE 1: Stem diameter distributions (Block A) in 1952 and 1980.

dbh class (cm)	stem number (%) 1952	1980
10	10	12
15	45	17
20	31	25
25	11	26
30	3	11
35		5
40		3
45		1

iii choice of species has been reconsidered continuously in the light of performance over the last 35 years: the planting of beech and European silver fir was discontinued early because of sheep and deer browsing. Although sheep are now excluded and roe deer under control, these species would still require individual tree protection to ensure growth above browse levels. Sitka spruce is, of course, resistant to browsing and arguably the most productive species for much of the trial area, though equalled on the lower slopes by Douglas fir which, however, is highly susceptible to browsing. Noble fir appears to be the least attractive of the silver firs to deer. Although slow to start, it produces excellent form on the exposed upper slopes; western hemlock has suffered from both browsing and snow damage but displays vigorous growth and is acceptable in small quantities. Norway spruce also suffered from browsing but often has better form than Sitka. Appropriate provenances which are only slightly less productive than Sitka are still desirable to maintain diversity. The deciduous habit of (hybrid) larch earns it a limited place, and the broadleaved species are now considered to be sufficiently well established to ensure a broadleaf element from natural regeneration without further planting. Sycamore, birch and Sorbus species are now appearing spontaneously.

In view of the continuing, though reduced, problem of browsing and the desire to maintain productivity at higher elevations the overall species composition currently aimed for is 50 per cent Sitka spruce, 40 per cent other conifers and 10 per cent broadleaves by area.

Two additional points are worth noting. Firstly, natural regeneration of all the conifer species present (predominantly Sitka spruce) has occurred in recent group fellings (Blocks E and F) and appears sufficient to form an acceptable crop: this will be discussed later. Secondly, the original spacing of 0.9 m has been changed in recent years to the current norm, of about 2.0 m.

iv recreation, conservation and education have been added to the list of major objectives. Waymarked footpaths and an orienteering course exist in the trial area. There is a generally accepted view that an irregular structure enhances both wildlife value and visitor enjoyment due to the increased structural diversity. Additional permanent extraction tracks may increase the potential for recreational use and enable visitors to appreciate the nature of management which is being carried out.

v there are a large number of possible research and teaching projects afforded by the trial area, some of which are outlined in the next section. The wide range of planted species allowed a study of browse preferences (Thomson, 1966) while later, the territorial behaviour of roe deer was studied (Loudon 1979). Current studies include an assessment of operational and managerial costs (Nicole Shrimpton) and a comparison of the 'check' method with conventional techniques of yield control and production forecasting (John Blyth).

DISCUSSION

The principles of irregular forest management have been summarised by Biolley as follows:

i sustention - a continuity of stands well adapted to site conditions and maintaining constant regeneration;

ii production - maximum standing volume and yield of quality timber, obtained by full site utilisation and the maintenance of an 'ideal' growing stock.

These principles raise a number of silvicultural, organisational and financial questions, some of which have already been alluded to.

Silvicultural considerations

The response of tree crowns and roots to their atmospheric and soil environments is the basis for stand growth and yield. Malcolm and Taylor (1979) discussed the likely effect of canopy structure on five fundamental process - radiation, gas exchange and momentum within the canopy, interception of rainfall and snow, leaf area and productivity relations, litter decomposition and nutrient cycling. They considered that irregular canopies may trap about 10 per cent more radiation than dense, single-stratum canopies but that lower canopy strata (eg group plantings) receive reduced radiation of lower phytosynthetic capacity. Compared with even-aged (regular) stands, mixing of the canopy atmosphere is likely to be greater in irregular stands but lower stocking levels of large trees are necessary to achieve stability; interception of precipitation may be greater because increased turbulence would give rise to evaporation while snow is likely to be less damaging, and the breakdown of organic matter on the soil surface is likely to proceed faster because of higher radiation at the forest floor. Total stand leaf area and hence productivity is mostly site-determined and differences in leaf area distribution may not be important. In summary, any differences in productivity between regular and irregular stands are likely to be small, and although shade-tolerant species are adapted to benefit from early shade and the protection provided by an irregular structure, the latter is not essential for their successful establishment and management.

The mosaic of small, even-aged group stands envisaged at Glentress, with a predominance of shade intolerant species, will involve considerable shading of edge trees and hence reduced growth. This can clearly be seen in a height profile taken across a group and, indeed, some of the original very small groups have been shaded out. This edge effect is particularly evident during the transformation period when the crop surrounding a group felling is all of the same height. When the mosaic structure is complete shading will be less severe but the possibility of planting relative shade-bearers in the more shaded part of each group should be considered. In a comparison of early height growth rates in group plantings, Harrison (1986) found these to be greater than in adjacent regular stands of similar age and species but the difference was not significant.

Other aspects of the edge effect implicit in small group working include heavy and/or asymmetrical branching, the need to control browsing animals (whose habitat is enhanced), the opportunity to utilise natural regeneration, and stability.

Asymmetrical branching is particularly noticeable in group edge trees of Norway spruce, accompanied by poor stem form, but this is likely to be less of a problem in younger groups where spacings are 1.8 - 2.0 m, compared with the 0.9 m of early plantings, and will also be proportionately less for larger group sizes. Asymmetric branching can also develop in the released trees surrounding a newly cut gap, and larch in particular can close a 10 m wide gap. Salutary evidence of preferential grazing pressure is provided by European silver fir and beech still less than 50 cm tall after 30 years! The fact that they are still alive is noteworthy but, more important, they are still capable of developing normally if the grazing pressure is reduced. Western hemlock, grand fir and noble fir appear to be the next most preferred species by the roe deer, in that order. Beech is clearly preferred amongst broadleaves while sycamore is relatively untouched and appears able to recover from bark stripping.

Natural regeneration has been prolific in most group fellings in Blocks E and F during the last two growing seasons and in Cpt 1216 (Block E) over the past 10 years. The latter area was an old Scots pine/European larch shelterbelt cleared in 1968, with group plantings in 1962, 1968 and 1976. The western hemlock and Norway spruce planted in 1976 have been largely overtaken by natural regeneration (mean height 2 m) mainly from the adjacent P53 Sitka spruce, but including Scots pine, larch, Douglas fir, silver firs, and broadleaves. A sample area was respaced in 1987 with a brushcutter from approximately 5000 to 2500 stems per hectare, releasing species other than Sitka spruce where possible. A financial analysis shows that in this relatively easy example respacing of natural regeneration with a 5-10 year delay in establishment is a viable option (Table 2). The group felling system simplifies the adoption of an opportunistic approach to utilising natural regeneration, in that each small area is considered separately anyway. The development of both natural and planted regeneration in groups compared with conventional coupes needs further study.

Stability of edge trees has not been a problem at Glentress, probably because of the generally deep and well-drained mineral soils. Group felling, however, cannot be advocated readily for stands on gleys and organic soils because of their inherent instability.

Organisational considerations

These relate to operational management, in particular harvesting and yield control, but first there are two general points to make. Since the trial area represents only about 1 per cent of the forest estate in the Lothian and Tweed Forest District and because changes in working methods as well as stand structure are inevitable during a long transformation period it is not surprising that some aspects of operational management have been neglected.

TABLE 2: A financial comparison of respaced natural regeneration and planting.

Year	Direct Costs £(87) ha^{-1} Planting		Respacing	
0	plants & labour	235	delayed revenue	141 (251)
1	beat-up	35		
2	weed	45		
10			respace	100 (100)
DE_0 (at 5%)		309		202 (312)

<u>Assumptions</u> SS YC 16 DR_0 = £650

5 year delay DR_0 = £509 penalty = £141

(10 year delay DR_0 = £399 penalty = £251)

Maintenance of small group plantings requires more intensive supervision to ensure that timely weeding is carried out, for example, and the densely planted groups have been largely ignored during thinning operations (except for some removal of Christmas trees!). Lack of familiarity with group locations is not a problem for the territorial forester who manages all, or a significant part, of his woods on an irregular system (as, for example, in some parts of Germany) but at Glentress this has led to the failure of some groups, especially those located out of sight of the roads. Indeed, a conscious effort is needed to avoid the tendency to miss out stands situated mid-way between roads in locating groups for felling. When transformation is complete and an appropriate network of permanent extraction routes established (see below) this problem may be eased. Meanwhile, posts labelled with the Block letter and group number are being used to identify individual groups and, in conjunction with a map showing the groups for each year, to aid location and supervision.

Secondly, the carrying out of all forest operations within the 'block of the year' may be difficult to arrange and evaluate for just 1 per cent of the forest estate. In practice the whole trial area has been thinned, for example, to fit in with Forestry Commission thinning plans for any one year, and only group felling and planting have been done on a 'block of the year' basis. The 'block of the year' approach would attract a smaller organisational (and hence financial) penalty - perhaps none - if the trial area were 1200 hectares in extent.

Harvesting timber from a mosaic of small group fellings requires a permanent network of extraction routes to provide access to all parts of an irregular forest and to minimise extraction damage to other trees (which should also reduce damage to the site itself). This is not difficult to organise on gentle, well-drained terrain but poses problems on slopes too steep for easy working with wheeled tractors. Maximum gradients in the trial area are about

50 per cent and the proposed regeneration fellings in Block A included mid-slope groups which would have been difficult to harvest without a cable crane. The plans in the current cycle were altered to allocate half the total felling area to a bulldozed forwarder track, at no more than 10 per cent grade, linking the existing upper and lower roads. A study of production foregone because of a more intensive extraction route network compared with conventional even-aged stands needs to be undertaken; on gentle terrain this might be minimal.

Yield control by the 'methode du controle' or check method was considered essential by Professor Anderson and the first two working cycles included 100 per cent enumeration. Stem diameter was measured by caliper, the point of measurement being scribed on the tree, and recorded in 5 cm diameter classes from class 0 (15 cm) to class 10 (65 cm). Enumerations were discontinued because of the obvious lack of 'normality', with the intention of starting them again when meaningful yield control could result from the data. An attempt at 100 per cent measurement during the 5th cycle proved impracticable and a 10 per cent sample enumeration is currently being implemented in the 6th cycle, using 6 m wide strip transects. These permanent transects are being located at random within each block, running up-and-down the slope, and all measurable trees are paint-marked at breast height. With a group size of 0.1 to 0.2 ha the possibility exists of adapting even-aged stand models to take account of 'the edge factor' and implementing yield control by conventional methods. A comparison of these two approaches is one aspect of current research.

Financial considerations

Conventional economic theory suggests that small-scale working should increase unit costs. Records of work carried out in the trial area over the past 7 years show that, on average, establishment and maintenance (weeding) costs are 10 and 50 per cent higher than the local norm, while harvesting costs (group felling of mature stands) are not significantly different. Some additional operations (and therefore costs) can be incurred by small group working. One notable example at Glentress has been dealing with heavy brash in confined spaces, particularly Sitka spruce brash which can make restocking impossible in the year of felling. Group sizes greater than 0.1 ha have been found large enough to pile and burn the brash, or alternatively to push it to the end of the group (which may also act as a temporary deterrent to roe deer). The extra cost of such additional brash treatment has averaged £1 m^{-3}. Pruning of edge trees to improve timber quality could be another example of potential increased costs.

The expected increase in supervision, management and protection costs is difficult to evalutate from a relatively small trial area during a transformation period. For instance, demarcation of the group fellings in the 'block of the year' (totalling 2 ha) has typically taken 2 man days in recent years but an experienced forester who was used to the system could probably do the same job in half the time. At this stage it is probably more rewarding to consider experience in continental Europe where irregular forest working has been practiced for some time (see Shrimpton in this volume).

Finally, non-timber benefits deserve a mention. It is generally agreed that irregular working enhances the recreational and amenity value of a forest. The increased structural diversity is pleasing, as well as providing a richer habitat for wildlife. A group size of about 0.1 ha means that areas of daylight (young groups) are always visible, making the forest less threatening to the predominantly urban visitor.

CONCLUSIONS

Irregular forest, worked on a group felling system, is a viable alternative to the conventional clearfell system on well drained mineral soils, especially in areas of high amenity value and recreational pressure. Experience at the Glentress trial area suggests that an acceptable balance between the benefits of structural diversity and the extra costs of more intensive management can be found with a group size of between 0.1 and 0.2 ha. Irregular forests provide ample opportunity for research into the ecological and management implications of small group working, but a full evaluation of many aspects is not possible until transformation is complete and the forest staff have become accustomed to working the system. For a transformation to be successful, tenacity of purpose and a clear idea of the structure aimed for is required. This can probably best be achieved in a limited area of forest within one ownership or management unit. It is worth noting that even in the most advanced transformations to irregular forest the oldest trees have their origins in regular stands.

At Glentress the transformation has been conducted against a background of shifting attitudes to forest production and its economics. There have been many technological developments in the last 35 years ranging from a far better understanding of the environmental relations of various species and their cultural needs to the increased mechanization of harvesting. If an irregular structure is to be managed satisfactorily the changing scientific, economic and social milieu must be accepted and the methods of working adapted within the overall objectives. Whatever the arguments, it is likely that the physical environment and public pressure will impose greater irregularity on British forests and that experience gained in trial areas such as Glentress will be of considerable value in the future.

ACKNOWLEDGEMENTS

The continued interest and help of the many Forestry Commission staff involved in working the Glentress trial area is gratefully acknowledged as is the assistance of several generations of students and the staff of the University.

REFERENCES

Harrison, A. 1986. An assessment of growth in a group selection forest. Unpublished Honours dissertation, Department of Forestry and Natural Resources, University of Edinburgh.

Loudon, A.S.I. 1979. Social behaviour and habitat in roe deer (Capreolus capreolus). Unpublished Ph.D. thesis. University of Edinburgh.

Malcolm, D.C. and TAYLOR, C.J. 1979. The place of irregular forestry in North Britain. IFGB Discussion Meeting Paper, March 30, 1979 Edinburgh.

Matthews, J.D. 1986. The history and status of uneven-aged forestry in Europe and Britain. Proceedings Discussion meeting on Uneven-aged Silviculture, Pershore, October 29, 1986.

Thomson, B.R. 1966. A roe deer browsing and grazing assessment. Unpublished Honours Dissertation, University of Edinburgh.

MODELLING THE COSTS OF UNEVEN-AGED FOREST MANAGEMENT

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INTRODUCTION

The objective of this study is to quantify the costs involved in converting from even-aged to uneven-aged forest management, by developing a computer model to simulate the time taken for various forest operations under each system. The same model will then be used to quantify the costs of managing an uneven-aged forest. Comparisons are based on a fixed size forest block which is divided into different group sizes to represent a continuum from clear felling to single-tree selection. The model can then be used to compare the effects of various management strategies - such as harvesting method and machine type - on yearly or periodic incomes and costs. Eventually the aim is to produce an interactive program which could be used to investigate the financial implications of changing to uneven-aged management.

THE MODEL

The model is in the form of a Fortran program which uses two-dimensional arrays to represent the forest block. The size of the block has been set at 16 ha and it is divided into four different group sizes - 1.00 ha, 0.25 ha, 0.11 ha and 0.0625 ha (see Fig. 1).

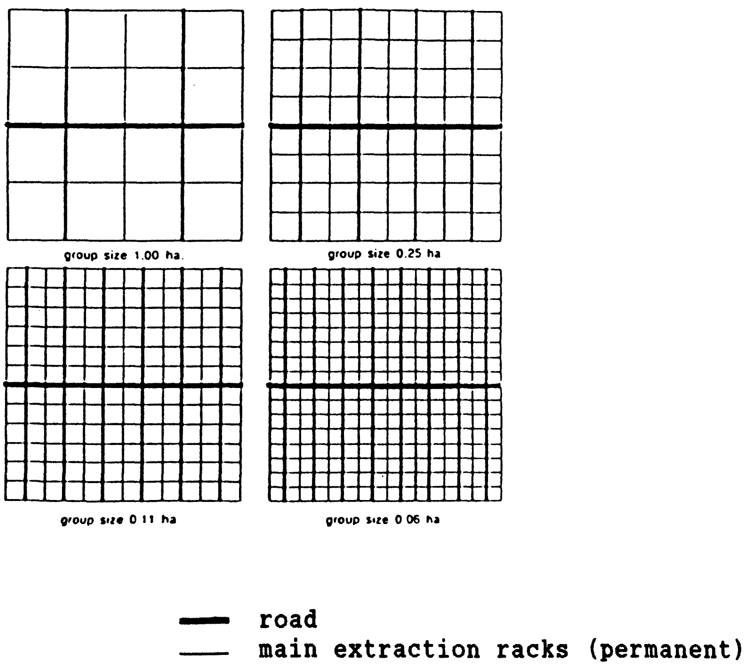

Fig. 1. Diagram showing division of a 16 ha block into 4 group sizes

Each cell in the matrix represents a group of trees which will be thinned, harvested, and regenerated. This computing approach was chosen so that distance calculations could be made simply. Data stored in this matrix form have implicit coordinates because location information is not specified for each element, but is implicit in the method of storage. Therefore, distance calculations can be made using the row number, column number, and cell size (MacDougall, 1976). In this way, extraction distances and movement distances for workers can be calculated for each group size.

All the operations are carried out in one year, and repeated at five-yearly intervals, the assumption being that there are four other 16 ha blocks being worked by the same methods, but in the other four years of the five year cycle. A five year cycle was chosen in order to make the best use of the Forestry Commission's Yield Tables.

The data used to calculate the timing of an operation comes mainly from Forestry Commission Standard Time Tables, and other studies from the Work Study Branch of the Forestry Commission. In the case of extraction, for example, the speed of machines under various conditions (loaded/unloaded, on road or rack) has been determined experimentally. Combined with extraction distances on road and rack, calculated in the program, total machine movement time can be found. The Work Study data are supplemented by information collected from managers of uneven-aged forests, records from the Edinburgh University experimental area at Glentress, work study experiments from other countries, and work study experiments set up at Glentress.

The groups that will be harvested in a single felling period are assigned randomly, but with the constraint that adjacent groups will not be felled in consecutive felling periods. This constraint was introduced to reflect the policy generally followed at Glentress, in order to maximize the irregular appearance of the forest. Fig. 2 shows some of the options available within the program.

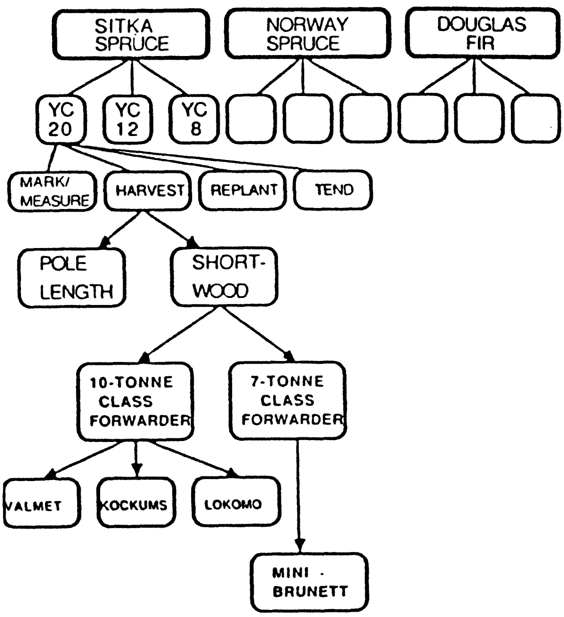

Fig. 2. Diagram showing a selection of Program Options

DISCUSSION

Felling and Extraction

Although the management principles behind selection systems and group clear felling systems are quite different, the costs of harvesting are independent of them, and dependent on the size, density, and dispersion of the individual felling areas. Also, differences in costs can be attributed to two distinct causes; group size and degree of fragmentation of the forest block. Felling costs, for example, are related to the absolute size of the felling area and differences in costs between group sizes would be constant, even if the forest block size were increased or decreased. On the other hand, cost differentials for machine movement occur as fragmentation increases and this is not directly related to the absolute group size. In this case cost differences between, for example, 1.00 ha groups and 0.06 ha groups, would not be the same if these groups were part of a 32 ha block (transformed over the same period) rather than a 16 ha block.

Felling

Increased felling costs are incurred in terms of movement of workers between felling sites and may be incurred in the extra time needed for directional felling to avoid regeneration, or in payments to compensate for the extra care needed when working small areas. Secondly, slight cost increases may occur with extra snedding time needed for coarsely branched trees on the edges of groups. Finally, there may be increases in supervision time.

In the Bradford Plan system at Tavistock 10 per cent is added to the Standard Time Tables for felling (Timmis, pers. comm.), and in the Bavarian State forests, wages for felling are increased in irregular systems by extra payments based on tree volume. In both cases, trees are being felled on extremely small areas so it is reasonable to assume that 10 per cent is the maximum increase likely to be encountered during felling. At the other end of the scale, there would be no increase in costs up to a point where trees could no longer be felled into the group or onto a rack. This point is determined by tree height and diameter of the felling area. Between these two points (0 per cent and 10 per cent) are a range of values for increased costs. By constructing curves based on tree height and group diameter, the costs increase for fellings at any point during the transformation period can be found.

Fig. 3 shows felling times for six periods on a block of yield class 8 Sitka spruce. The increase in time for the smallest group, averaged throughout the conversion period, is approximately 3 per cent. The increases are slightly higher (c. 4 per cent) on higher yield class sites, because the trees are taller.

Forwarder Extraction

Differences in machine movement times between large groups and small groups tend to be greatest on low yield class sites, because the smaller groups do not contain full loads of a single product on a rack. Hence, so more time is taken moving to other racks to make up a full load. Fig. 4 shows machine movement time during felling and thinning for Sitka spruce yield class 8, over a forty-year transformation period.

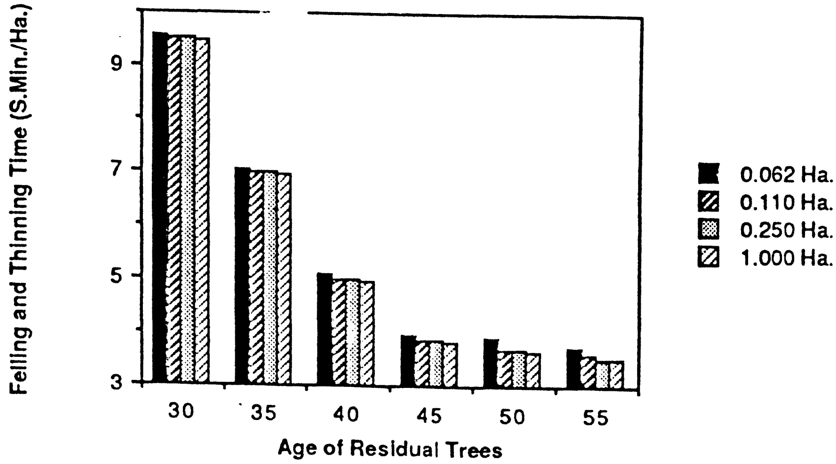

Fig. 3. Felling and Thinning Time (YC 8)

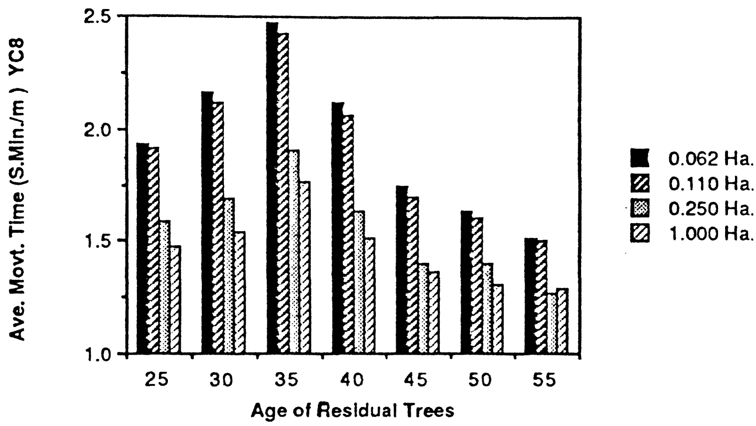

Fig. 4. Movement Time for 10-tonne Forwarder

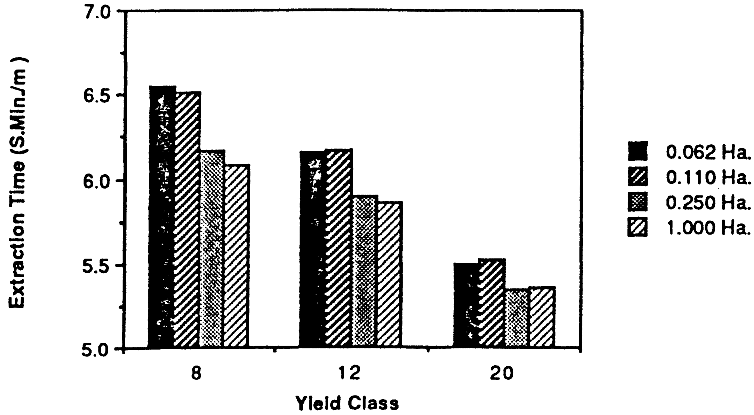

Fig. 5. Total Extraction Time for 10-tonne Forwarder

The increased movement time in YC 8 Sitka spruce averages approximately 30 per cent for the 0.0625 ha groups, 28 per cent in 0.11 ha groups and 6 per cent in 0.25 ha groups. Although the increase in 0.0625 ha groups appears substantial, it represents an increase of only about 7 per cent for the total extraction time (6 per cent in 0.11 ha groups and 1 per cent in 0. 23 ha), because movement time only makes up a small proportion of total time. The bulk of the forwarding time is in 'terminal time' (loading and unloading). Increases in movement time for yield class 12 sites are approximately 20 per cent in the smallest groups (20 per cent in 0.11 ha groups and 2 per cent in 0.25 ha groups), with only a 5 per cent increase in total extraction time in the 0.0625 ha groups (5 per cent in both the larger group sizes). Felling small areas does not necessarily lead to increased costs. On higher yield class sites where full loads of a single product can be extracted from a single rack, the network of extraction racks improves accessibility and may lead to slightly reduced costs. Fig. 5 shows average extraction times for the four group sizes, on three yield class sites.

In no case are overall harvesting costs increased significantly when changing from a 1.00 ha group to a 0.25 ha group. However, these values are based on only a few runs of the model and the statistical significance of the differences has not yet been calculated.

REFERENCE

MacDougall, E. Bruce. 1976. Computer Programming for Spatial Problems. Edward Arnold, London.

IRREGULAR SYSTEMS OF SILVICULTURE FOR BROADLEAVES AND MIXED CROPS: DO THEY WORK IN AN ENGLISH CONTEXT?

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INTRODUCTION

My involvement with broadleaved forest and its regeneration goes back a very long way. When I was reading for my forestry degree in Oxford I spent a month in beech woods on the Hampden Estate in the Chilterns, accumulating data under the aegis of the late Ray Bourne for the old Continental and Indian type of working plan that was then obligatory. There were a few patches of larch but the rest of the woodland was pure beech. By the time all the data we had accumulated had been worked up into a coherent plan I felt I knew the beech woods pretty well. Bourne had made a practice of conducting the students' working plan tour on a different estate in the Chilterns every year so that his knowledge of these woodlands was extremely deep. This was increased even further by the fact that he actually managed a number of the estate woodlands himself. On the tour and in management lectures much of his wisdom rubbed of on us. And during subsequent Continental tours we were given a deep insight by him into the application of the classic selection system in the forests of Couvet and Boveresse in the Swiss Jura.

Later I spent five years managing virgin tropical rain forest in Malaya. I was in charge of two thousand square miles of it when the Japanese landed in the north. Much of our work was concerned with initiating and ensuring the survival of groups of naturally occuring regeneration of the more valuable species.

GROUP SELECTION SYSTEM

When I took over management of the Bathurst Estate woods at Cirencester after the war I found a group system of planting and natural regeneration to be the most promising means of restoring them to a productive state, in the shortest possible time and at minimum cost. The 50,000 cubic metres of prime beech and larch timber that had been felled to provide vital supplies of timber for wartime purposes had been sold at very low controlled prices, and the whole of the proceeds had been absorbed by taxation on the death of the old Earl. I had 600 ha of felled-over woodland to deal with, a third of it clear-felled and the rest with all trees over 20 cm dbh removed. Fortunately the topwood and brush been cleared and there was a mass of 'bristle-stage' ash and sycamore regeneration, widely spread throughout the woods and also a little beech locally.

By conserving the best of the remaining standing trees where they formed groups, thinning-out advanced regeneration where it occurred (also in groups since these generally represented the space exposed to light by the felling of one heavily-crowned tree), and planting between the groups where the bristles were absent, an irregular system was already developing. The old Earl, who inherited early and lived to a great age, had been opposed to the felling of any trees during his lifetime. Such felling as had been necessary had to be distributed very widely and confined to relatively small patches. In consequence there were, in some areas, patches of younger trees, mainly larch, planted after such fellings. Fortunately these were still too young to attract the interest of the army units engaged in harvesting the big timber. We thus had an additional size-class to add to the groups of bristle-stage regeneration: new planting, sapling regeneration, and groups of older ash, oak, and sycamore that had escaped the axe on account of their size. Later I was able to persuade Lord Bathurst to allow large group-felling in sensitive areas of unfelled woodland near the town and to fill them with natural regeneration of ash, sycamore, and beech.

These developments aroused considerable interest and we were visited annually over a period of years by a party from the Oxford Department of Forestry. It will be understood that I was in actual charge of the woods myself, at first in the capacity of working forester with a gang of some half-dozen woodmen and a group of ex-servicemen trainees; later as forest manager and then as consultant. By the end of four five-year dedication plans when I handed over to a new manager I was very heavily involved in the system and had, for some years, been devising variants on other estates.

One of the latter was Houghton, an estate neighbouring the Sandringham property. When the study tour of the Institute of Chartered Foresters was visiting Sandringham from its Norwich base some years ago I was able to persuade the party to take a quick look at a sample of the irregular group system developing at Houghton. The stage of first thinnings in the under- and inter-planted mixed crop of beech, ash, sycamore, larch, Scots pine, and Thuja had just taken place. The summer aspect was almost that of a continental selection forest, with fine large clean butts of oak, ash and larch looming up through the mass of young trees. The next felling stage was then due. The young crop having reached a marketable size for selling as stakes, groups were to be harvested and the crowns of selected old trees felled into the patches so opened up. Their immediate re-stocking by natural regeneration or planting would produce the next stage in the development of true irregularity.

A further example on a Lincolnshire estate is provided by a mature ash wood on very fertile soil, already beginning to decay. It is very important to the owner, standing as it does on the boundary of the park and forming part of the screen against a main road. In this case blank areas created by earlier windfalls were increased by the felling of a minimum number of trees to create suitable sized groups for planting. In doing this care was taken to ensure that the planting would not close off the extraction routes for the remaining timber trees. The young plantings have now been thinned and the trees marked for the next felling. These have been designed in roughly wedge-shaped groups, allowing space for the crowns to fall and the trees to be removed without damaging the young crops already established.

Elsewhere on this same estate, group-felling and planting have taken place in important amenity belts near the big house, using in one case pure beech with a surround of Thuja to make use of the shaded space below the crowns of the neighbouring very large beech trees; and in other cases a mixture of ash, beech, and sycamore conforming with the structure of the rest of the wood.

An 80 ha oak wood on another estate in Lincolnshire provided an opportunity to develop a rather different variant of the same general idea. It was observed that nearly all the oaks felled from time to time in this wood were shaken and the owner decided that it must be cleared and replanted with something more valuable. I was asked to produce a plan for this to be achieved within thirty years. The wood was an important one from the shooting, shelter, amenity, and conservation angles. It was also on level ground, quite isolated with no protection from neighbouring woods. The system we used was to divide the whole into 1.2 ha rectangles, with their long axes north to south, and to fell and replant with groups of broadleaves in a confer matrix. The felling areas were so distributed over the wood so that each area of newly-planted trees would have protection on all sides (except of course those that abutted on the perimeter where one side was unavoidably exposed). That is to say, we did not return to fell the block adjacent to new planting until the latter was itself able to provide shelter to the land to be exposed by the felling. The 1.2 ha blocks averaged 90 m wide by 160 m long, the long axis being south to north to allow maximum insolation. Observation of the growth pattern of the planted trees showed that the proximity of standing trees on all sides produced a stimulation of growth near the standing trees, progressively decreasing towards the centre (see Garfitt, 1966).

This system may be considered to be a group system taken to its limit in that the 'groups' were in fact rectangles and that they were much larger in area than is usual. But the wood was developing an irregular structure; there was protection and stimulation of growth for the young crops raised in shelter; there was enhanced value for shooting by the production of nesting-cover, warm thickets, and open shooting stands. The wood as a whole would remain in a permanent state as a unit and would never have to be clear-felled, with all the benefits to amenity and habitat for wildlife that this would provide.

SELECTION SYSTEM

In my remarks so far I have been concentrating on the group selection system in which I have a special interest and have shown how a number of examples have been or are working.

We have heard in earlier papers about other uneven-aged silvicultural systems in use in Britain. The only other one of which I have practical experience is the true selection system. This depends on the use of shade-bearers and the only useful broadleaved shade bearer in England is the beech. Without the European silver fir, which is an essential ingredient in the classical continental selection forests, the operation of the system is a difficult one. My only real experience of it was on the Parmoor Estate in the Chilterns where Ray Bourne had established a version of it with control by regular enumerations on the lines of the Swiss Check Method. There I continued his system of fostering regeneration which I believe is also employed by John Workman in his Cotswold beechwoods; that is, of observing where beech seedlings are appearing and gradually felling back from these away from the sun, allowing side-light to penetrate below the canopy and so to provide the very critical conditions essential for successful establishment of new beech seedlings.

This is probably the only reliable practical method of establishing regeneration in beech selection forest where cultivation of the soil is not feasible, and it tends inevitably towards the production of groups. Ray Bourne spent many years as an academic on the problems of establishing natural regeneration of beech in the Chilterns and produced a detailed chart to show the conditions necessary for its success (Fig 1).

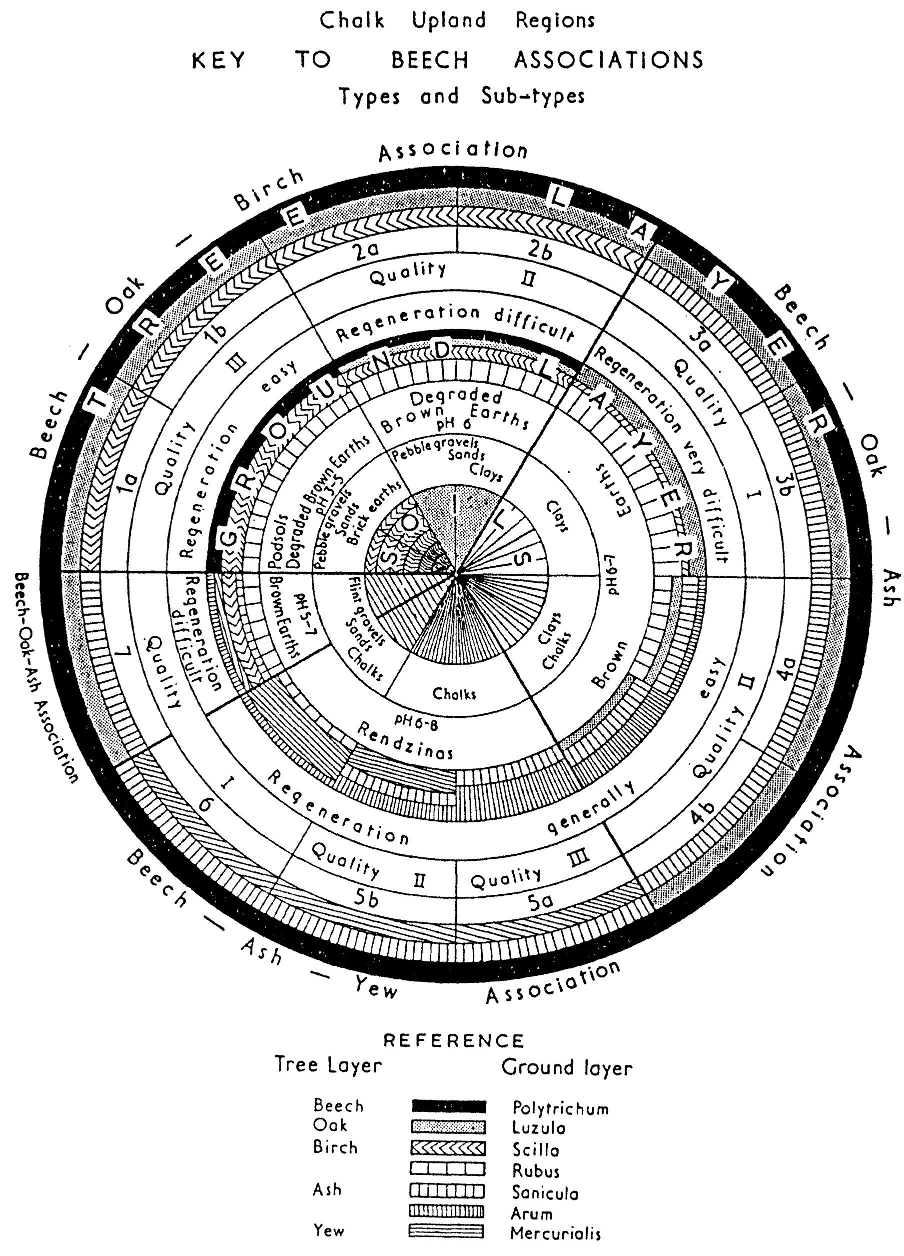

Fig 1. Key to beech associations, types and sub-types. (Reproduced from McNeil (1961) with permission from the Editor of Forestry).

The fact that I have not mentioned other examples of successful selection working with beech must not be taken to mean that I am not aware of their existence; it means that I have no detailed personal knowledge of them. Among these should be mentioned Mr Michael Reade's beech woods at Checkendon where he has, I believe, operated the Swiss Check System for many years with considerable success. I have deliberately omitted consideration of the Bradford System since this is concerned more with shade-bearing conifers that with broadleaves.

CONCLUSION

I have given some examples of irregular forestry working satisfactorily and it may be asked under what conditions this can be achieved, or what are the factors limiting its success.

The essentials are, first of all, continuity of management. I well remember Dr Colyear Dawkins saying to me on a visit to see what we were doing in the Bathurst woods, "What about the 'bus factor'?" It is vital that the same system is continued and applied. This means that the owner must understand the system and be whole-hearted in its application and his intention that his woods shall never be clear-felled. The second essential is a proper application of the tax strategy. I remember being highly impressed when visiting the late Mr Rennie Hoare's woods at Stourhead and being told that every minute group of regeneration and planting was mapped and allocated to the appropriate tax schedule, and agreed with the Inland Revenue. The third essential is the control of rabbits, squirrels, and deer. On a small scale groups can be surrounded by wire-netting on a temporary basis, the netting being tied to trees round the edge of the group and lifted when the plants are out of danger. On the large scale, as in the case of the 1.2 ha blocks, the cost of fencing was charged to schedule D in the normal way. And now that tree-shelters are so widely used, selected individuals in regeneration groups as well as plants can be given full protection.

I should end, perhaps, with a caveat. Farmers are now being encouraged to make clearings in their woods and to replant. This may well be attractive to today's farmers who see short-term profits from their timber and from planting grants - but this is not irregular forestry as we understand it. It is not a system unless the future development of the wood is provided for. Today's farmer no longer confidently expects that his son will farm his land. He may well take the profit and be thankful for it with little thought for the distant future during what are likely to be difficult times for the agricultural industry. But forest management calls for more than cutting holes in woods and replanting them. This is not to be dignified by the term 'Irregular Forestry' any more than taking out the best trees in a beechwood is to be referred to as 'The Selection System'.

REFERENCES

Garfitt, J.E. 1966. Edge-effect. Forestry 39, 189-190.

McNeil, W.M. 1961. A key to beech associations on chalk uplands in England, devised by Ray Bourne. Forestry 34, 116-118.

WEEDING AND CLEANING OF BROADLEAVED HIGH FOREST

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This translation of Les dégagements et nettoiements en futaie feuillue (Revue Forestière Française, 1981, 33 (special number), 19-40) is published by kind permission of Professor Lanier and the Revue Forestière Française.

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TRANSLATOR'S NOTE AND ACKNOWLEDGEMENTS

There are no consistently exact equivalents in English for the French words dégagement, nettoiement or cloisonnement. For convenience, dégagement is here translated as weeding because it includes control of herbaceous vegetation. In the context of natural regeneration dégagement also means control of unwanted trees and shrubs at the young stages (seedlings and coppice regrowth); an operation hardly known in British forestry since control of these woody weeds normally takes place later during cleaning, at the thicket stage. French nettoiements are more detailed and thorough cleanings than usually undertaken here in plantations, and are made repeatedly over a long period in the life of the stand before the first thinning. Cloisonnement literally means partitioning, ie of the stand into blocks; the process of cloisonnement is best translated as racking or putting in racks and the cloisonnements themselves as racks. "Lignes de silviculture" and "filets" have also been translated as racks, here exclusively narrow racks for access for silvicultural treatments. In general I have tried to use terms consistently after Ford-Robertson (1983) and Métro (1975).

I am grateful to the Forestry Institute for the facilities to make this translation, to Claire Gurney for typing a difficult manuscript, to Professor L Lanier, Dr P S Savill and J Everard for encouragement and help, and particularly to Carol Dewberry of Trinity College, Oxford for help with the translation and the correspondence.

INTRODUCTION

Although silvicultural operations in the life of a stand form a continuum it is useful, if artificial, to separate a phase of weeding and cleaning. This phase is part of the long period of tending operations involving investment to form the future stand, as compared with the fellings which improve the stand while taking a harvest. The forester concerned with economics will always find this phase too long and costly but the true professional takes pride in its indispensability and as a guarantee of the future. Both will be keen to carry out these operations with the least expense, hence the resort to modern methods: chemicals, systems of racks, and mechanization.

These obligations and constraints, often contradictory, lead to the following plan for this article.

1. Weeding, primarily of natural regeneration: the need; the aim; the way carried out according to circumstances; and the current improvements in the light of relevant conditions, especially economic.

2. Cleaning, equally as necessary as weeding: a similar plan with the addition of the results of experiments done in particular cases which develop methods that should lead to considerable improvements.

WEEDING

All the experts agree on the absolute necessity of management of young stands. Upon it depends the whole future of the stand. To be convinced that weeding is essential it is only necessary to have seen the disappearance of groups of seedlings, however well stocked, as a result of either frosts or rising of the water table (against which weeding can do little), or as a result of competition or damage by pests and diseases, or a combination of several of these disasters.

The objective is therefore clear: to protect the desired tree species from these dangers which threaten them. It is concerned with the removal of the sources of damage, the diseased, damaged or weakened trees, and with the formation of a balanced mixture of the desired species. To achieve this, treatment is needed from the very beginning, above all with light-demanding species, and where the young regeneration is not sufficiently stocked, or is rich in advance regeneration or threatened by vigorous weed trees and shrubs.

In fact, in all the early years when the seedlings grow thickly (the famous brosse of oak, or the Buchensalat of German beechwoods) there seems to be no danger in delay. The young seedlings do not hinder each other much. However, the needs are already contradictory: light must be let in but not excessively, the fatal effects of frost must be avoided by maintaining an irregular canopy which breaks up the cold layers and limits nocturnal radiation from the seedlings themselves; but it is necessary to remove the seed trees which compete for water and soil nutrients and bring caterpillars which browse the seedlings having defoliated the adult trees (as has now been proved in the case of oak); it is necessary to avoid raising the water table, mildew (Microsphaera alphitoides Griff. & Maubl.), damping off of the seedlings, rodents, slugs, and so on. All this explains why the success of the regeneration is very often uncertain even if it appears assured from the beginning.

Still, supposing that it has succeeded. Once formed the groups of seedlings rapidly become complete, enlarging and joining; the stems fill out and branch. Competition then rapidly becomes damaging even for the best trees. To this competition within the species (often thought to be favourable if it is not excessive, the best stems tending to grow towards the light) is added between-species competition of weed trees and shrubs, most often owing to light-demanding species which benefit from their usually higher speed of growth. If in addition there is, on a fertile soil, an invasion and sometimes complete cover of rampant brambles or climbers, or equally on more acid soil sometimes total submergence under bracken or graminaceous plants such as Carex brizoides L., the fate of the regeneration is seen to be closely linked to the vigour, timeliness and quality of the weeding.

Timeliness is vital: weeding therefore must begin from the first secondary felling, in the context of the uniform shelterwood system. In the case of clear felling followed by sowing or planting, weeding must start from the earliest years, and be repeated two or three times. It should be continued for as long as necessary.

The ultimate aim is to obtain a large number of vigorous, healthy trees, in the midst of a well-assorted growth of varied woody species (of which the desired species forms the great majority), spaced out enough so as not to get too much in each other's way. A good working figure is about four per sq m (after the first treatments, ie when the thicket is about 2 m tall). At the time of the later treatments this number can decrease from 40,000 to 20,000 stems per ha, for species such as beech or sessile oak, without worrying too much about within-species competition at young ages; and from 30,000 or 40,000 to 10,000 (one per sq m) for the more exacting species from the point of view of within-species competition: pedunculate oak, ash, high quality broadleaves, or on poorer soil. [High quality broadleaves include gean (<u>Prunus avium</u> L.), wild service tree (<u>Sorbus torminalis</u> (L.) Crantz) and true service tree (<u>Sorbus domestica</u> L.).]

So, how should these weedings be carried out? The operations for thinning out the regeneration are based on the following principles (Schädelin 1937; Leibundgut 1966, 1976; Silvy-Leligois 1964; Mayer 1977).

1. If the regeneration of oak or beech is dense (a sea of seedlings) is it necessary to intervene or not? Yes, for the presence of individuals showing early signs of poor form can most often be spotted from the earliest stages and during all the weedings. They will be destined for removal at the same time as the majority of weed trees and shrubs and, above all, of the advance regeneration of these species which is unwanted and ultimately dangerous. Also at this stage the control of bramble and large herbaceous plants (purple moor-grass, sedges, ferns) is necessary. On this last point there is little to be done in the middle of areas of regeneration.

2. If on the other hand the regeneration is of low density, irregular, even sometimes with wanted trees isolated amongst weed trees and shrubs, it will be necessary to go through more often and clear around these isolated trees, making for them a well, as it were, with a rim of woody growth frequently cut back to mid-height.

The operation is a tricky one and is usefully accompanied by the conservation of high quality accessory species. This is the time to favour any root suckers of gean, any vigorously growing ash, any wild service trees located in the middle of a group of poor beech, which can be profitably rediscovered and favoured at later stages.

In their treatises on silviculture Cochet (1959) and Perrin (1954) dealt with these problems and arrived at similar guidelines, varied slightly according to the details of the stands.

The thicket stage is the most difficult because of the impenetrability of the stands which makes it hard and tedious to carry out the operations at the height of summer, with the trees in full leaf. At this stage it is necessary to know how to work out the need for each removal, as a function of the local density of the main desired species, of the relative speed of growth of the different species present, and of the ability to produce coppice shoots of more or less rapid growth. With two valuable species growing side by side the treatment is against the one which could become invasive, but without eliminating it. In the case of sessile oak woods, the accompanying beech therefore will be considered less dangerous than hornbeam which in turn is less dangerous than lime, hazel, alder, sycamore or Norway maple. On the other hand, the willows which do not coppice very strongly will not be troublesome at the beginning, if not too numerous, because of their light canopy. (More caution is needed with aspen which suckers vigorously.) In the common intimate mixture of oak and beech, cutting back to soil level has even been recommended sometimes; this allows the strongly coppicing oak to dominate the beech which coppices poorly or not at all. This technique, which does not work with hornbeam, unfortunately necessitates a second operation in the following year to single the best shoots of oak from the groups of shoots formed. If this is done too late there is inevitable damage to the oak stand (Lafouge, personal communication).

In the case of an intimate oak/hornbeam mixture, one of the most unfavourable at the start, the only solution is to root out the hornbeam with a mattock. (This is dreadfully expensive once the hornbeam is established: the most recent cost given by those in charge of Montargis, where the problem is particularly acute, is 3,000 fr. per ha for this single operation.) This is why there is every reason for controlling the hornbeam before regenerating the stand, if possible, ie suppressing all the hornbeams before the seeding felling.

The tools used for these operations are always billhooks, long-handled billhooks and secateurs. Numerous attempts at mechanization with pneumatic secateurs are being adopted with difficulty, in so far as it is the qualities, above all, of observation, experience and stamina which are actually reflected in the quality of work done.

Progress in this difficult area is advancing essentially on two fronts: on the one hand the organization of work from racks with the possibility of limiting the area worked, and on the other experiments on methods of chemical weeding.

The contribution of racks

What strikes those who wander around the high quality oak regeneration of Bercé, Bellême, Blois or Tronçais at the sapling-thicket stage is the extraordinary density, purity and ..... impenetrability of the stands. It is easy to imagine how a worker with a billhook could lose himself in the stand. For a long time, therefore, a general system of working has been adopted, varying with the region, but commonly a network dividing the huge compartments into units of limited area (for example half a ha with the classical network of 100 x 50 m). This system is the origin of the system of racks, which is fortunately tending to spread.

Once the principle was established there was much discussion on the best distances between racks, when to put in the racks in the life of the stand, the methods of carrying this out and the routine of maintenance. This obviously arises from the variety of circumstances. The issues are summarized in a booklet (CERAFER (now known as CEMAGREF) 1971) which clearly defined two sorts of racks:

(i) access racks, a network to facilitate work in the young stands; and,
(ii) extraction racks, designed for the harvest of produce.

There are numerous arguments in favour of racks. Without doubt the best ones arise from the improvement in the organization and quality of work which they allow: provision for supervision of the work; access to the very heart of thickets.

The disadvantages are minimal. The loss of area is negligible especially considered in the long term. Even the wide racks (sometimes 2 m) made by machine every 10 m close rapidly and the convenience of access and maintenance largely compensates for the loss of area involved (20%). Amongst the counter-arguments is the temptation to cut costs excessively. Thus various ways of limiting the area worked along the racks have been considered, before involving the trees that will become the future stand: first, only working on 2 m or 2.5 m (the length of a long-handled billhook held at arm's length) on both sides, or sometimes on only one side, and even only on small patches more and more reduced in size.

An important and logical idea about racks is that the treatments, which are better done when concentrated, should lead to finding the future elite trees exclusively in the areas treated from the start. Hence the distances between lines of treatment should correspond to the average distance in the future between the maturing trees (see the diagrams suggested by Venet 1978).

These days more caution is exercised in estimating for how long the effects of a weeding will last. In the case of high quality oak where the system is necessary, however costly, there are two extreme choices of either carrying out the weeding in full on tens of hectares without racks, an option to be rejected; or treating patches of about 25 sq m where a tree will be specially favoured. A reasonable middle way, on ground which is not very uneven and giving an excellent experimental result, can be as follows. This method is applicable with slight variations to the numerous different circumstances found in even-aged high forest. (It goes without saying that other methods are possible according to the availability of labour, machinery, etc.)

1. From the stage of the first secondary felling, extraction racks are made at 100 m intervals, towards which timber is moved from the stump and along which further extraction takes place. In most cases topping (removing the crown) takes place after felling and the lop and top must be cut up with the minimum delay, immediately if the crown crushes a patch of regeneration. (With high value produce, topping is done before felling to avoid any risk of damage to the bole.) These racks serve as an outline system for the compartment when it comes to be regenerated as a whole. Other layouts are possible, in particular more frequent extraction racks (every 50 m) when a very high standing volume increases the risks of harvesting for the regeneration.

2. Just before the first weeding, racks at 50 m interval are made perpendicular to the extraction racks, forming a grid of half-ha units.

3. Parallel with these last racks further, narrow, access racks are cut allowing access to the middle of the bushiest thickets (Fig. 1). There is every advantage in establishing this fine network as early as possible, when marking it out with stakes is simple and light machines can be used (small motorized ground clearance machines).

4. The tending can then be carried out along both sides of these racks, intensively on a band 2 m wide, ie the length of a long-handled billhook at arm's length, and, less intensively but still some, in the interband (Fig. 2).

Once this system is established on the ground the fundamental problem is to obtain the maximum value from the effort involved: the ultimate aim is to give the best possible form to the stand.

Venet (1978) recommends proceeding in two stages.

1. A first treatment in full, in order to obtain a maximum of valuable species over the whole area of the compartment. Early cutting of the racks makes organization of the work easier and enables it to be done more readily.

2. On a second occasion, in very dense thickets of seedlings passing into thickets of saplings, a treatment in full becomes excessively expensive for a single operation (up to 6-10 man-days per ha), a prohibitive cost except in very special cases.

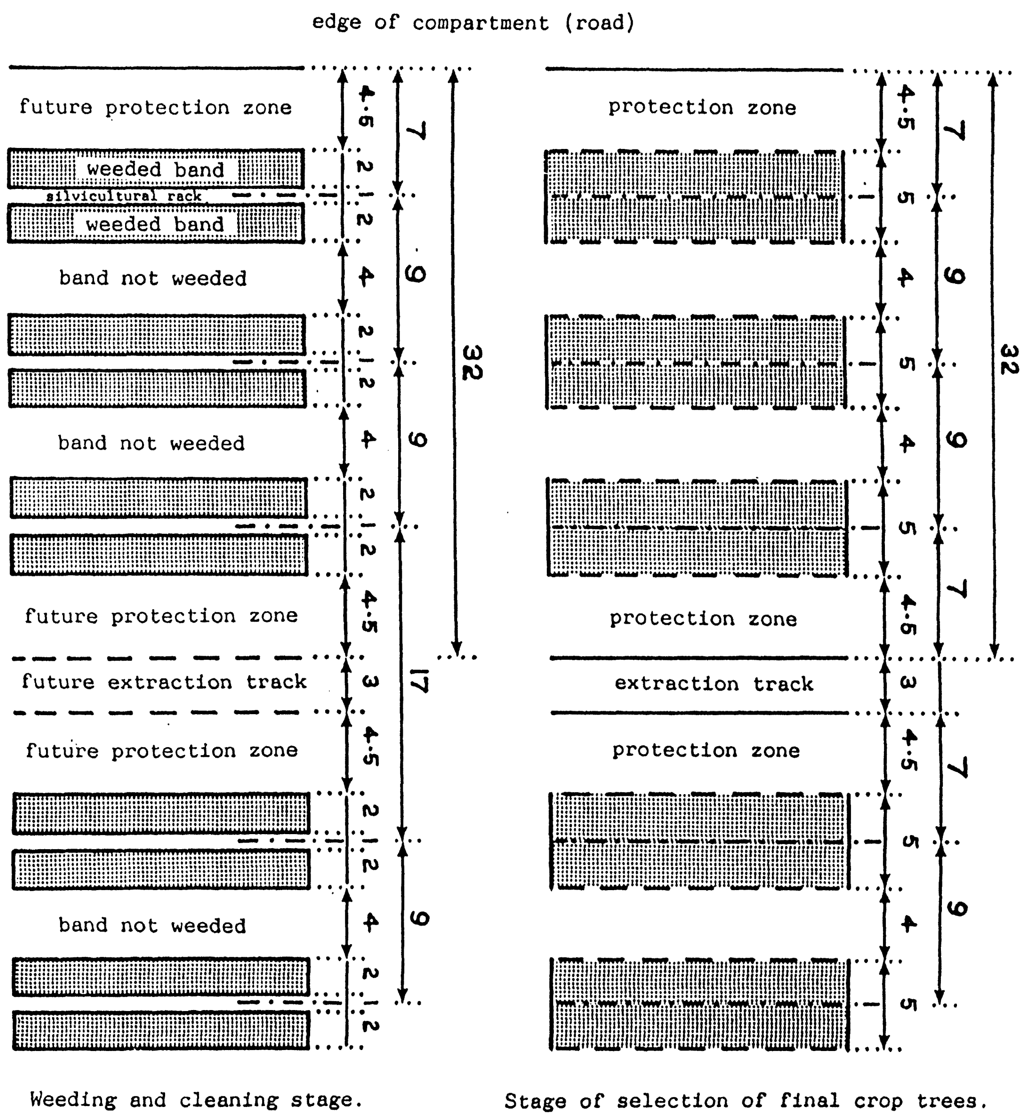

Fig. 1. An example of a system of racks (beech, 9 m interval). Dimensions are in metres.

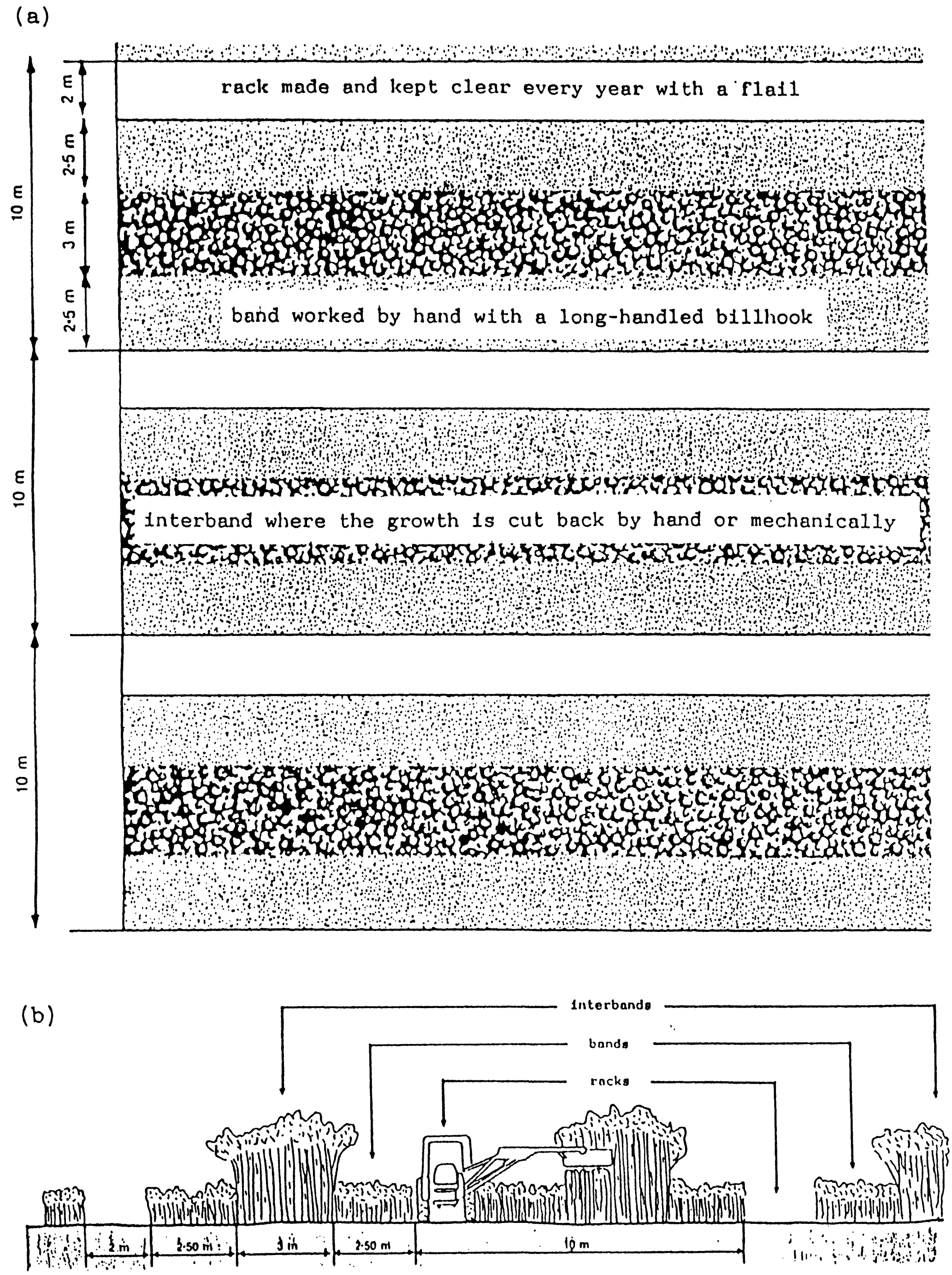

Fig. 2. (a) An example of the system of work in a compartment with linear regeneration.
(b) Side-view of natural regeneration with mechanized weeding.

Racks around one metre wide need hardly any maintenance at this stage. In the case of oak with strips between racks 11-12 m wide and weeded bands 2.5 m wide on both sides of the rack only 42% of the net area (extraction racks excluded) is treated (see Figs. 6 and 7 in Appendix 2).

The basic idea is that each treatment improves the results of the previous one and prepares for the subsequent treatment. The last weedings deal with the climbers, weed trees and coppice shoots which are sometimes vigorous and grow into the dominant storey and which simply require cutting back half-way up. Some care is taken of the understorey of auxiliary species (hornbeam, beech, sycamore, Norway maple), and the suckers of gean and good stems of associated species are favoured (ash with pedunculate oak; sycamore, Norway maple, wild service tree with beech; whitebeams, true service tree, lime with sessile oak). In all, they prepare the future pole-stage stand of mixed species put forward for later treatments.

The best weedings are therefore early, often, usually light and always carefully selective; they produce a thicket of saplings which will grow into the low-pole stage containing a majority of good, vigorous and healthy stems full of promise.

Chemical weeding

Introduction

It might be thought that there is enough experience with chemical weeding of herbaceous vegetation amongst conifers for it to be extended to broadleaves. Unfortunately, at the moment there are few possibilities for selective chemical weeding in broadleaves. M Frochot (Centre National de Recherches Forestières, Laboratoire sur le Désherbage) has kindly summarized the possibilities below. [Current British practice is given by Sale, Tabbush & Lane (1986).]

Control of herbaceous vegetation

With wide spectrum herbicides.

(i) Atrazine (4,000-6,000 g/ha active ingredient (a.i.)) usable as granules at the end of winter, or as a complete spray before bud-break of the trees. Ash and poplar are not, or scarcely, resistant.
(ii) Dichlobenil, and chlorthiamid (4,500-6,000 g/ha), as well as the mixture dalapon + dichlobenil, applied as granules at the end of winter, but only for seedlings or plants established for at least a year.

With herbicides active mainly against graminaceous plants.

(i) Propyzamide (1,500-2,500 g/ha) as a complete spray in the course of winter.
(ii) Dalapon (8,000-10,000 g/ha) at the end of winter just before bud-break.

Bramble

If brambles entirely cover the seedlings, glyphosate (1,440-2,160 g/ha) sprayed after the fall of the tree leaves but as long as the bramble stays green is effective for at least three years. The herbicide 2,4,5-T (700-1,000 g/ha + oil) is rarely effective for more than one season and has been shown to be dangerous sometimes on young regeneration, even after leaf fall. If the seedlings are taller than the brambles and liable to receive large doses of the spray then fosamine ammonium (3,360-4,800 g/ha) is less risky in terms of phytotoxicity than glyphosate in the same conditions (after leaf fall of the seedlings). This is also effective for three seasons.

Bracken

Bracken can be partly controlled by annual applications of chlorthiamid or of dichlobenil (6,000 g/ha, only on plants established for at least a year). A lasting treatment (three growing seasons) is obtained with asulam (3,000-5,000 g/ha) applied on green, well-expanded fronds (June to August). The treatment is relatively selective and does not affect broadleaves which are not actively growing. In addition, the screen formed by the bracken avoids excessive exposure of the plants or seedlings to the herbicide.

Woody weeds

At the moment there are no ways of using complete sprays of selective herbicides to control woody weeds among broadleaves. In certain special cases it can be worth killing individual trees, or brushing over the stools after felling (2,4,5-T, 15-30% in fuel oil or oil), this being done at the sapling-thicket to low-pole stages. As a general rule, a rational chemical control of woody weeds in the silviculture of broadleaves must be considered <u>before</u> regeneration, by spraying on to the foliage of shrubs or coppice shoots in August and September (glyphosate, 2,160-3,240 g/ha; fosamine ammonium, 3,360-4,800 g/ha; 2,4,5-T, 2,000-3,500 g/ha; triclopyr, 1,000-2,000(?) g/ha; aminotriazole + ammonium thiocyanate, 9,100 g/ha total active ingredient). Such a preparation avoids several years of weeding and limits treatment to the herbaceous vegetation alone.

Conclusion

To sum up: these methods are still dangerous in so far as, on the one hand, accidents with the desired species are to be feared (they are catastrophic when they occur), and on the other what becomes of the products of decomposition of the active ingredients is still poorly known. Apart from the important cases of bracken and bramble, where the methods are well worked out, caution is to be recommended in the use of herbicides.

In the end the fundamental question which remains is knowing the optimum moment and forms of the progressive change from negative treatments (the chief point of weeding) to more positive treatments, preferentially favouring groups of trees showing the best promise (Schütz 1979; Schütz & Badoux 1979).

CLEANINGS

Indeed the time gradually comes when the purely negative operations carried out during the whole of the long period of weeding (up to the age of 15-20 years and heights of 3-5 m for species with slow initial growth) can be replaced by positive action, in favour of the best individuals of the best species for the site. A large part of the forester's experience is exercised in the recognition of trees having good genetic qualities, at the awkward age of the pole-stage, when the stems of the final crop trees are still shapeless; often sinuous; and covered with lateral branches, evidence of belated self-pruning. This awkward age, corresponding to adolescence, is the most important for the future form of the stand. It is in fact the age of maximum growth in height for most species.

The objective is clear and perfectly defined by Köstler (1952). This is without doubt the most complete attempt to draw together the knowledge of this fundamental phase in the life of stands which runs from the last weeding at the stage of the thicket of saplings to the last cleaning when the pole-stage stand formed is ready for its first commercial thinning. It concerns the operations (in the surgical sense) which act to encourage the best growth of the best, instead of allowing nature to take its course which favours the strongest. The law of survival of the strongest is transformed into the law of the survival of the best, for technological purposes; all the while safeguarding the maintenance or improvement of optimal ecological conditions by judicious treatment of mixtures. Those who write in German (Köstler 1952; Mayer 1977; Leibundgut 1966) have adopted the explicit term dickung to distinguish this period in the life of an even-aged stand, characterized by the struggle of individuals to eliminate each other.

Following on from the exact, punctilious analyses of Köstler (1952; Fig. 3), Wagenknecht & Henkel (1962) and Leibundgut (1966) the basis of a rational treatment of a stand at this stage has been established (Fig. 4). The set of operations is defined on an exclusively cultural basis, founded on an analysis and exact inventory of the stand (number of stems, species composition, qualities, etc.), from which the detailed techniques to be used can be worked out with the objectives in mind. Schädelin (1937) dwelt at length on weeding and cleaning and emphasized their costs, but above all their fundamental rôle for the whole future life of the stand. The basic concern is reflected in his conclusion: "When considerations of a biological nature are ranged against economic motives the latter (and not the former) must give way". This implies that weeding and cleaning must certainly not be neglected on the grounds of cost, nor because of the pleading of hunters for game from unkempt stands, nor even because of the foresters in charge who complain of the cost, the scarcity and the incompetence of labour. Schädelin even advocates that the forest officers follow these operations very closely and practise them so as to assess both their value and the difficulties. Schädelin was right. Is it not possible, however, while entirely recognizing the excellence of these principles, to make some savings, in particular benefitting from the results of recent experiments?

First, the system of racks set up at the weeding stage will form a valuable aid for organizing the cleaning. They will no longer even have to be maintained at this stage, at least the access racks above which the pole-stage stand has closed. Better still, the extraction racks will facilitate the extraction of poles removed. If necessary the main system, established, for example, at 50 m intervals, can be doubled by a system at 25 m which distance corresponds to about twice the height of a stand at the stage of cleaning.

The cleaning operations are based on the following principles.

1. The number of stems of probable good future form is often high, mainly in the dominant and co-dominant storey. Cleaning is therefore a positive way of benefitting these probable future final crop trees; it must be given priority.

2. Wolf trees which have survived the last weeding (advance regeneration of the main species or individuals showing certain genetic unfitnesses) must be ruthlessly removed at this stage. It is always too late afterwards.

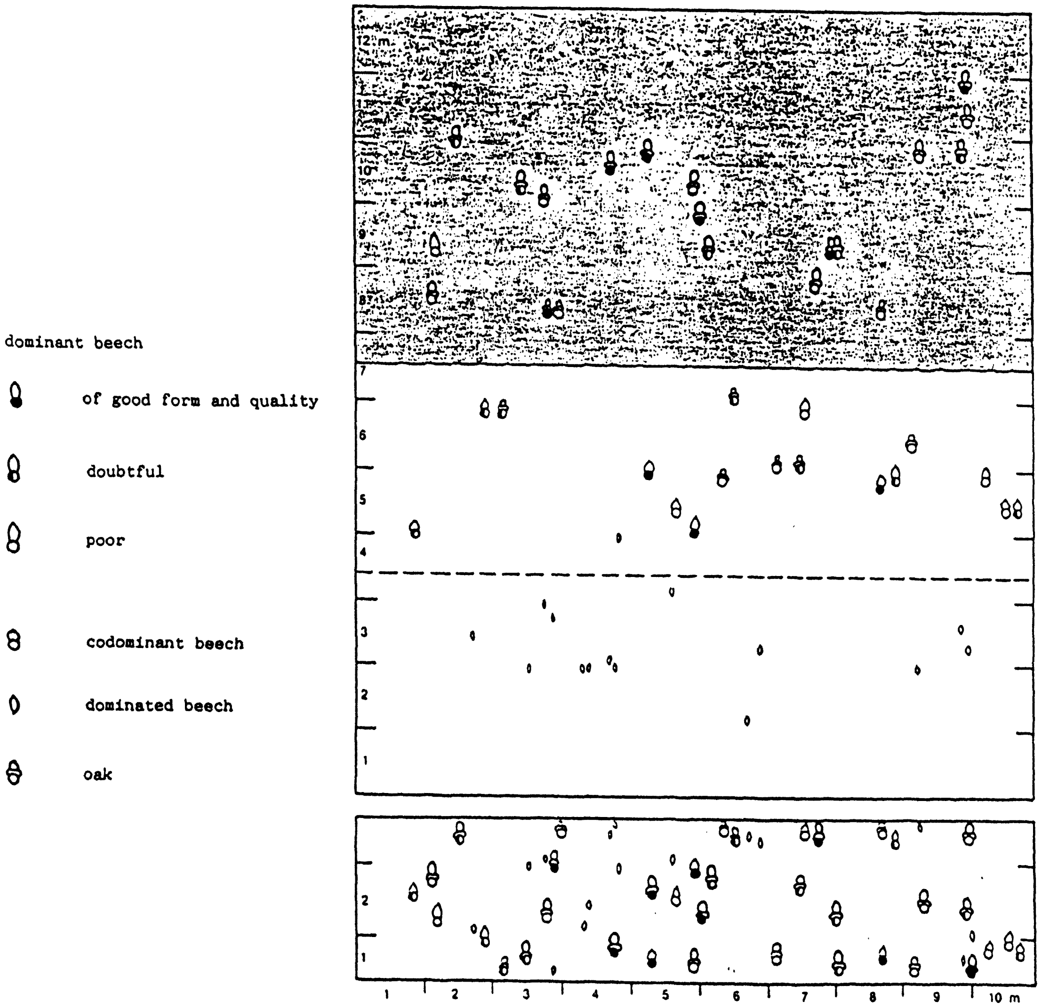

Fig. 3. An example of the analysis of a pole-stage stand by the method of Köstler (1952). Side-view showing three storeys (above) and plan (below) of an oak/beech stand dominated by oak, comprising to the ha 8,700 oak (2,600 high quality) and 6,800 beech (700 high quality).

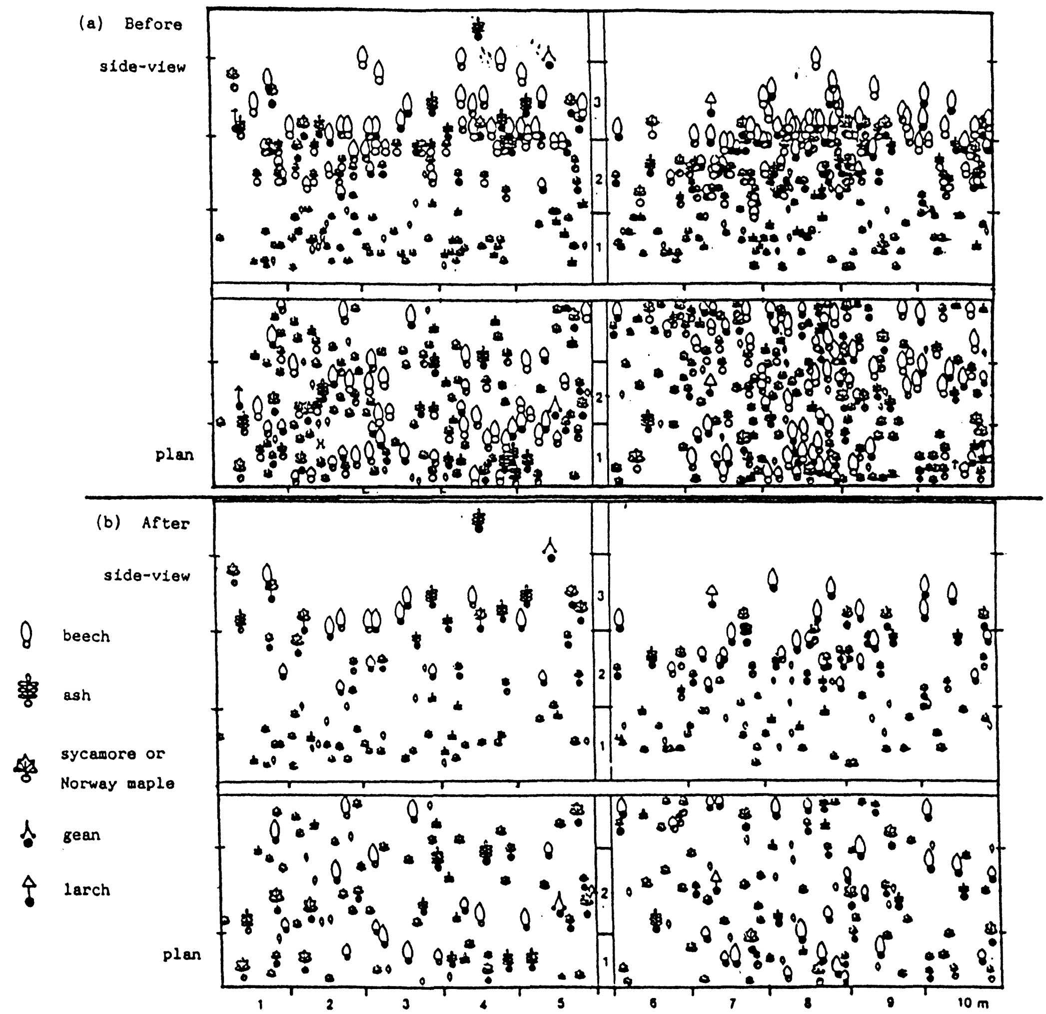

Fig. 4. An example of treatment: side-view (upper part) and plan (lower part) of a sapling-thicket.

(a) Before cleaning, 148,000 stems per ha
(b) After cleaning, 73,600 stems per ha

3. The treatment should be varied slightly where associated species occur.

Thus the cleanings will be determinedly positive in favour of species such as ash, gean, sycamore and Norway maple which are damaged easily when put under harsh competition. Leibundgut calls this operation Begünstigung (favouring). In contrast, for other species, in particular beech where improvement in form is still possible, or in oak because the future high-quality trees are still rather unclear at the age of cleaning, these cleanings will remain negative for a long time; the term Saüberung (cleaning) is used. But this involves the need for frequent, light treatments, only removing the trees of no value and the unwanted species from the dominant storey, leaving all the rest and especially all the understorey which happens to occur. Comparative studies made in the case of beech in particular have shown the correctness of these views and the slow, gradual improvement which justifies the extreme patience of the silviculturalist (Kurth 1946; Fig. 5).

Methods and tools

Cleaning treatments are made classically with chain-saws, using small manageable models. For a long time the stagnation in the market for small wood and the high costs had led to consideration of chemical methods: killing standing trees, for which the comparable costs were around one-third those of a classical cleaning. The treated stems rotted standing and gradually fell apart without disrupting the stand, which maintained its stability. The risks, both of accidents resulting from root-grafting and of invasions by insects aided (it seems) by the phytocides denounced by Röhrig (1968), had led to the development of new methods such as the ringing of trunks (stem girdling) carried out by means of a sort of chain-saw manipulated with handles (Ringel-Säge or Brady Tree-Girdler). Peine (1978) has emphasized the value of this technique. The cost is about the same as a chemical treatment, for the same effectiveness. One of the fortunate consequences of the energy crisis is that the otherwise burdensome operations of felling poles left to rot in the stand are made profitable or at any rate break even.

The stands arising from the exceptional mast of 1949 in France provided an excellent opportunity for the application of these principles. This widespread mast, often very heavy for both sessile and pedunculate oak, was much used by foresters at the time. It has provided pole-stage stands of around 30 years of age now suitable for treatment to produce some remarkable crops. The weedings have generally been carried out very well and the cleanings almost too well, seeing that many of the stands appear to be very homogeneous, of good quality, and almost pure oak. The best are those which benefit from an understorey of beech regularly lopped, but not completely suppressed (Bellême), or of hornbeam in the process of establishing itself, with difficulty (Montargis). Censuses made in the oakwoods of the Plateau of Lorraine have produced figures of 12,000-15,000 stems per ha, which is two or three times too much for a good stand at this age.

The cleanings, which merge into thinning out operations (pre-commercial thinnings), will concern the worst trees of the dominant storey, and will not touch the understorey if there is one, nor the dominated oaks in the process of disappearing (unless they rub against a good stem). They will strive to give priority to the final crop trees, or groups of them, which can be conveniently marked by painting so that care can be taken at the time of felling. In the case of very dense pole-stage oak stands and in areas with low rainfall a late thinning out, including the lesser quality dominated oaks, may turn out to be useful in removing competition for water, where it is a limiting factor (Montargis in 1976).

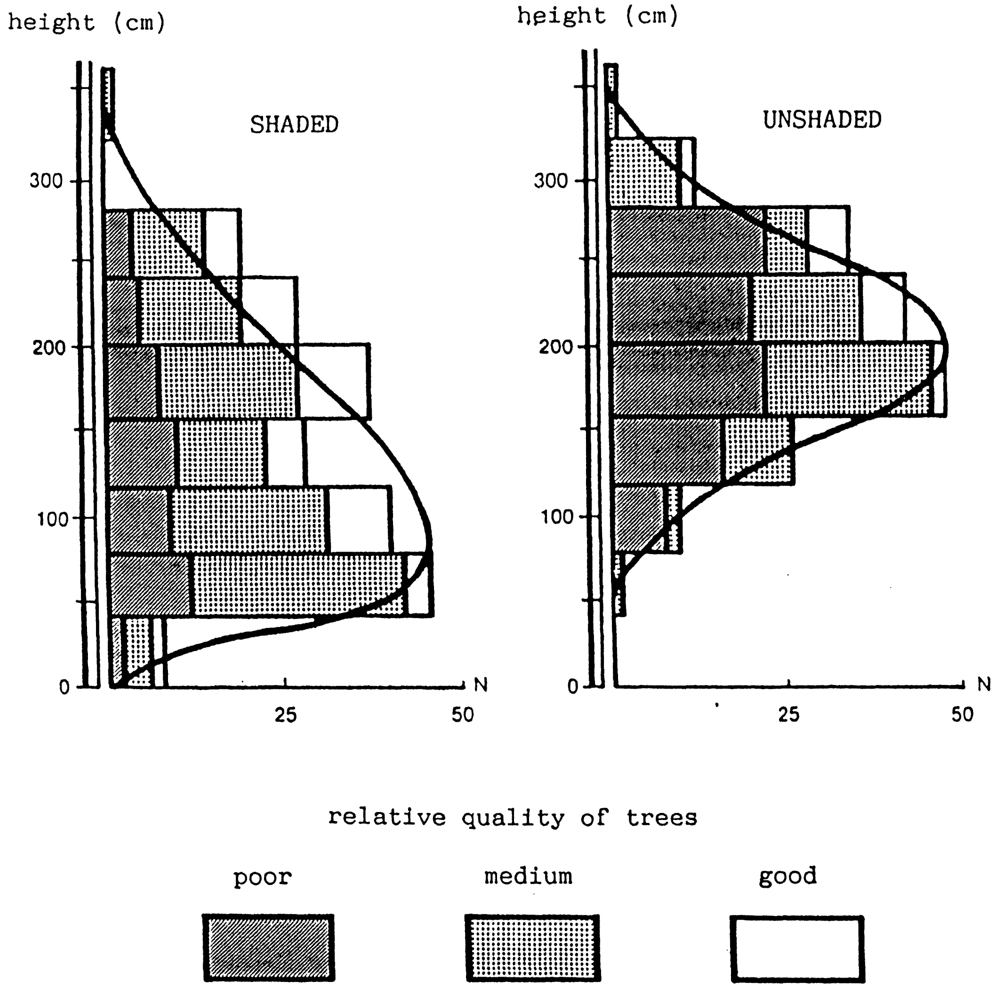

Fig. 5. An example of the development of a young beech stand in terms of individual tree quality in relation to shading (after Kurth 1946). The gradual removal of partial shade seems to be the best treatment for beech to obtain a suitable proportion of good quality stems.

A set of experiments trying to define exactly the optimal densities of high quality stems at different ages is being established. It should allow connection to the norms recently established by Pardé (1978) and by Oswald (1979) for high quality oak silviculture.

OAK AT BELLEME AS AN EXAMPLE

Before concluding, the efforts needed during this long phase in the life of stands (about one-fifth of the total) devoted to weeding and cleaning are summarized in Table 1. The timetable from the control-book of a compartment of high quality oak at Bellême is taken as an average example (extract of working plan: Régénération du chêne en forêt de Bellême, Monomakhoff, 1978, Centre O.N.F. Alençon).

Table 1. Timetable of treatments for high quality oak at Bellême. Brackets enclosing X mean possibly.

Year	Type of felling	Type of work	Manual	Mechanized or mechanizable
n-1		Marking out the extraction racks with stakes	X	
n (nominal year of seeding)	Seeding	Removal of holly	X	X
		Soil cultivation		X
		Cutting of the extraction racks by the harvesters	X	X
n+1		Maintenance of drainage ditches	X	X
n+2		Weeding of regeneration	X	
		or ground preparation in expectation	(X)	X
n+3		Weeding of regeneration	X	
n+4	First secondary	Weeding of regeneration	X	(X)
		(Ground preparation in expectation)	(X)	X
		Soil cultivation (the remainder)		X
n+5		Weeding of regeneration	X	(X)
n+6	Second secondary	Weeding of regeneration	X	(X)
		(Sowing of acorns)	X	
		Cutting of access racks	X	X
n+7		Weeding of regeneration	X	
n+8		Weeding of regeneration	X	

Year	Type of felling	Type of work	Manual	Mechanized or mechanizable
n+9	Third secondary	Weeding of regeneration	X	
		(Sowing of acorns)	(X)	
		Maintenance of ditches	X	(X)
n+10		Partial weeding of regeneration	X	
n+11		Partial weeding of regeneration	X	
n+12	Fourth secondary	Partial weeding of regeneration	X	
		(Sowing of acorns)	(X)	
		Soil cultivation (partial)		X
n+13		Partial weeding of regeneration	X	
n+14		Partial weeding of regeneration	X	
n+15	Final	Partial weeding of regeneration	X	
n+17		Partial weeding of regeneration	X	
		(Cutting of access racks)		(X)
		Maintenance of ditches	X	(X)
		The remainder of regeneration (planting)	X	
n+18		Partial weeding of regeneration, and of planting	X	
n+19		Partial weeding of regeneration, and of planting	X	
n+20		Partial weeding of regeneration, and of planting	X	
		Maintenance of racks	X	(X)
n+25		Cleaning	X	
		Maintenance of racks	X	(X)
n+31		Cleaning	X	
		Maintenance of racks	X	(X)
n+37		Cleaning	X	
		Maintenance of racks	X	(X)
n+42	First thinning			

The weeding of regeneration is carried out with long-handled billhooks. When the seedlings are not too large, the weeding can be done mechanically using a spring-tine cultivator.

The ground preparation in expectation (year n+2, possibly n+4, where n is the year of the seeding felling) is to keep the soil clean in case of an absence of mast or in the parts where there is no regeneration. Except in inaccessible places where it is manual, the spring-tine cultivator is preferred to the rotary slasher which gives a pleasing appearance at the time but in the end little reward since it encourages the proliferation of competing vegetation.

After n+10, the weedings of regeneration are made ad lib., ie in general in one part only of the compartment, wherever the young seedlings are still in danger. The thickets which emerge from the earliest regeneration no longer need annual treatments, but a treatment every two or three years without fail. Nevertheless, broadly speaking, it must be admitted that each part of a compartment being regenerated is gone through about ten times in total during the weedings between the seeding felling and the end of the weeding (n+20).

Up to 1978 access racks were cut with the rotary slasher (or with a billhook and saw) after the final felling (n+17) or at the time of the first cleaning (n+25). Experience has shown that it was worth cutting access racks for silvicultural purposes sooner, at the time of the second or even the first secondary felling (in the case of early and abundant regeneration). This was especially valuable in reducing costs because the maintenance of the racks was then easier. As the note by Monomakhoff states, that should allow better organization of the later work, and a saving of 8% of the area to weed, when an access rack of 80 cm every 10 m is cut. The difficulty in establishing the system of racks at this early stage arises from the numerous seed trees which it is necessary to go round. The solution would lie in a mixed form of racking with a portable machine for ground preparation.

The remainder of the regeneration can be filled in by sowing acorns then by planting oak (or planting beech in the gaps).

The cleanings are made at the same interval as fixed for the first thinnings (six years), possibly a little more often. (Other managers prefer to fix exact dates for cleanings, eg at age 22, 28, 34, 40 years, with a first thinning at 48 years. Setting exact dates in the management plan requires that each cleaning is carried out or that its postponement is justified).

The aims are as follows:

1. To remove beech which is too numerous or invasive. An effort is made to keep them in the dominated storey by cutting them at breast height, to try and retain a certain number. On the other hand, weed trees, and oaks badly formed, damaged, forked or from advance regeneration are removed selectively.

2. To even out the thicket of saplings.

3. To control honeysuckle, which is dangerous at this stage.

The approximate costs are shown in Table 2. In round figures the cost of obtaining natural regeneration of high quality oak in 1981 was about 20,000fr. per ha, in favourable conditions.

Table 2. Costs of treatments to secure natural regeneration of oak.

	Average cost per ha (francs)	Labour (hours)	Machines (hours)	Materials (francs)
Marking extraction racks with stakes	70	3		
Removal and burning of holly	1,400	44	4	
Soil cultivation	370		4	
Maintenance of ditches (average)	140	6		
Weeding of regeneration before the final felling (10 times)	11,500	470		
Ground preparation in expectation	1,400		16	
Weeding of regeneration and planting of remainder after the final felling (twice on average over the whole area) + access racks	2,700	112		
Miscellaneous (remainder of regeneration, notice boards, painting, etc.)	550	15		140
Cleaning (3 times)	3,300	135		
Total	21,430	785	24	140

CONCLUSIONS

It is easy to understand the great interest shown in the contributions to continuous progress in this field through:

(i) mechanization, of the operations which can be mechanized;
(ii) the establishment, from the stage of the secondary fellings, of a general system of organizing the work;
(iii) the improvement of chemical treatments so being able to save on labour (a particularly expensive item), and;
(iv) the development of clever techniques (the German clearing saw would without doubt deserve trials in the stands derived from the 1949 mast).

A new element, doubtless arising by chance but not to be ignored, is introduced by the increased value (momentary?) of small wood, through the existence of numerous licence-holders eager for firewood. It is an opportunity not to be missed, in order to make the work of cleaning profitable, while increasing the interest of people in the life of the forest and in its improvement. Careful recruitment is needed as well as exact instructions.

The weedings and cleanings form a fundamental phase in the management of stands. The rules are well known, but sometimes little applied. It is to be hoped that they can be put into practice more widely.

REFERENCES

Buffet, M. 1980. La régénération du chêne rouvre. Bulletin Technique ONF 12, 3-29.

CERAFER. 1971. Traitement des essences. Le cloisonnement. Note Technique 17.

Cochet, P. 1959. Étude et culture de la forêt. Nancy (E.N.E.F.).

Köstler, J.N. 1952. Ansprache und Pflege von Dickungen. Forstwissenschaftliche Forschungen 1.

Kurth, A. 1946. Untersuchungen über Aufbau und Qualität von Buchendickungen. Mitteilungen der Schweizerichen Anstalt für das Forstliche Versuchswesen 24: 581-658.

Leibundgut, H. 1966. Die Waldpflege. Bern (Haupt).

Leibundgut, H. 1976. Grundlagen zur Jungwaldpflege. Ergebnisse zwanzigjähriger Untersuchungen über die Vorgänge der Ausscheidung, Umsetzung und Qualitätsentwicklung in jungen Eichenbeständen. Mitteilungen der Schweizerischen Anstalt für das Forstliche Versuchswesen 52: 311-371.

Mayer, H. 1977. Waldbau auf soziologisch-ökologischer Grundlage. Stuttgart (Fischer).

Oswald, H. 1979. Die Durchforstung der Werteichenbestande in Frankreich. In: Begründung und Pflege von Wertlichenbeständen, Bad. Württ. Arbeitstagung, 10-11th June 1979: 56-78.

Pardé, J. 1978. Normes de sylviculture pour les forêts de chêne rouvre. Revue Forestière Française 30: 11-17.

Peine, J. 1978. Läuterung ohne Lärm und Chemie: eine Ringel-Säge für die Laubholzläuterung. Allgemeine Forstzeitschrift 26, 754-755.

Perrin, H. 1954. Sylviculture. II. Le Traitement des Forêts: Théorie te Pratique des Techniques Sylvicoles. (Page 29 and following.) Nancy (E.N.E.F).

Röhrig, E. 1968. Probleme der Jungbestandpflege im Laubholz. Forst- und Holzwirt 23: 409-412.

Schädelin, W. 1937. L'éclaircie. Traitement des forêts par la sélection qualitive. Neuchâtel (Attinger).

Schütz, J.Ph. 1979. Le chêne est-il devenu l'enfant pauvre de notre sylviculture? Journal Forestier Suisse 130: 1047-1070.

Schütz, J.Ph. & Badoux, E. 1979. Production de jeunes peuplements de chênes en relation avec la station. Mitteilungen der Schweizerichen Anstalt für das Forstliche Versuchswesen 55: 1-176.

Silvy-Leligois, P. 1964. Cours de sylviculture. Nancy (E.N.E.F.) (Duplicated.)

Venet, J. 1978. Nécessité des interventions sélectives du sylvicateur dans les jeunes peuplements de futaie régulière. Nancy (E.N.G.R.E.F., duplicated).

Wagenknecht, E. & Henkel, W. 1962. Rationelle Dickungspflege. Radebeul & Berlin.

ADDITIONAL REFERENCES

Ford-Robertson, F.C. (editor) 1983. Terminology of Forest Science, Technology, Practice and Products. (Second printing with Addendum.) Washington D.C., U.S.A. (Society of American Foresters).

Métro, A. (editor) 1975. Terminologie Forestière. Paris (Conseil International de la Langue Française).

Sale, J.S.P., Tabbush, P.M. & Lane, P.B. 1986. The Use of Herbicides in the Forest - 1986. Edinburgh (Forestry Commission Booklet 51).

APPENDIX 1

Table 3. Details of weedings and cleanings carried out in the silviculture of high quality oak (modified from Buffet 1980).

Location	Weedings. Number and types	Cleanings. Details	Total cost of operations in 1979 (including beating-up, soil cultivation and connected work) (fr. per ha)
ALENÇON (Bellême)	Ten; up to 20 years in full from access racks	Cycle of 6 years from 25 to 40 years. Beech cut back, unwanted trees, oak, honeysuckle	15,000
LE MANS (Bercé)	Nine; one per year up to 5 years, one every two years up 13 years, in full	Cycle of 5 years from 15 to 40 years. Beech cut back, unwanted trees, honeysuckle, oak	17,200-24,600
BLOIS (Blois, Boulogne, Russy, etc.)	Five to seven; up to 12 years, in full	Three cleanings from 15 to 30 years	8,300
BOURGES	Three to seven; by hand, in full	Beginning from towards 20 to 30 years according to need	Figures not available
NEVERS	Three to four; by hand, from racks every 6 m	Beginning at 30 years. Two cleanings at 10 year intervals, the second after tree selection	Figures not available
MOULINS (Tronçais)	Three to twelve; in full	Four cleanings from 18 to 36 years	9,100-19,500
DIJON-EST (Longchamp)	Six; up to 12 years. By hand from racks partly mechanized. Planting.	Starting from 25 years	15,000
CHATEAU-SALINS (Bride, St-Jean)	Five to six; from racks on 50% of area	Not yet at the stage of cleaning. Got under way in the 1949 mast on access racks made by hand	10,000

APPENDIX 2

Some details of trials of weeding of regeneration using racks and of cleaning, with estimation of the quality of the treated trees. Forêt domaniale de Champenoux.

Weeding

Compartment 56 (part). Mast in 1961.
System of racks established in 1970 with a Gravely machine (ground clearance machine). Racks 80 cm wide every 12 m.
Three hours work per ha, cutting about 800 m of racks. Manual upkeep of racks in 1973 and 1977.
Time needed: about 60 m per man-hour, amounting to about 15 hours per ha.
Weeding on a band 2.5 m wide on both sides of the racks in 1972 and 1974 (Fig. 6).
This needs 13 days per ha, amounting to about 2,000 fr. for each treatment.
In 1977 two types of weeding were done (Fig. 7):

(a) a band in full in the classical way, with long-handled billhook, billhook and small saw for the large clumps of coppice regrowth (20 days per ha, amounting to 3,000 fr.);
(b) bands of 2.5 m with an untouched interband between from where only the vigorous trees falling on the worked strip were removed (13 days per ha, amounting to 2,000 fr.).

The results are clearly better in type (a), taking into account the vigour of the coppice shoots (hazel, aspen, lime and hornbeam).

Cleaning

Compartment 56 (part). Mast in 1949.
Good uniform pole-stage stand in which weeding has been carried out classically and carefully over the whole area. Some access racks have been cut (12 m intervals). The cleanings have allowed the restoration of the number of oak stems to an average of 5,000 per ha of which about half are high quality stems.

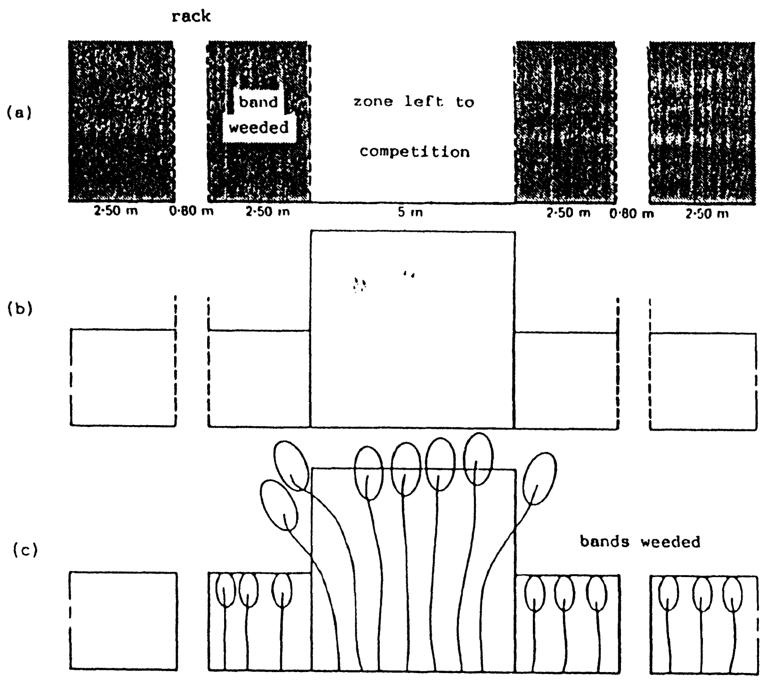

Fig. 6. Racks and weeding in 1970.

(a) Diagram of the work (plan).
(b) Immediately after weeding (side-view).
(c) A few months after weeding (side-view).

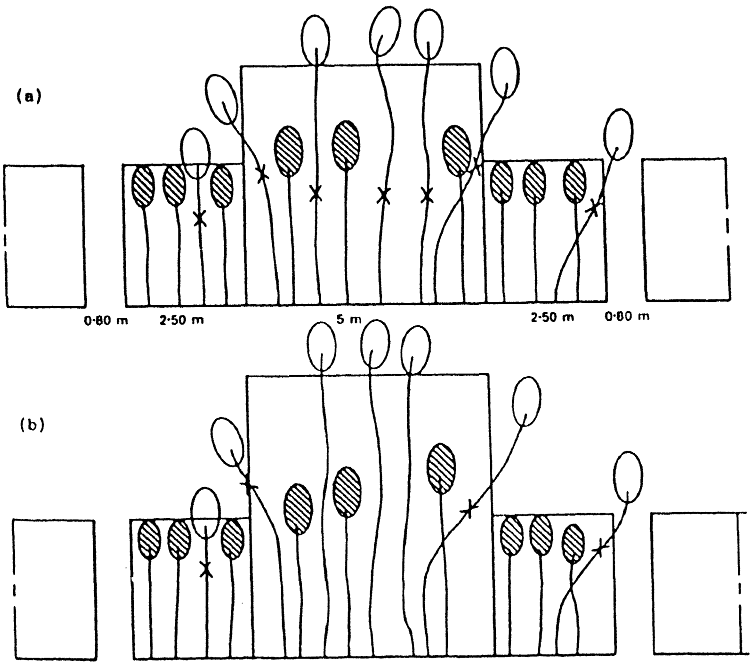

Fig. 7. Weeding carried out in 1977.

(a) A band in full in the classical way.
(b) A band of 2.5m with untouched interband.

ADVANCES IN TREE SHELTER RESEARCH AND DESIGN

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The following Table and Figures were inadvertantly omitted from Mark Potter's paper, in the Report of the Seventh meeting of the National Hardwoods' Programme for 1987 (Oxford Forestry Insitute Occasional Paper 34, pages 1-4).

TABLE 2: Growth of broadleaved transplants in coloured shelters in the first year after planting (increments adjusted for covariate).

	Colour:	Netguard	White	UV-exluded	Red	Orange	Yellow	Yellow-green	Green	Blue-green	Blue	Violet
	Transmission band (nm):	-	-	-	620+	575-600	560-610	530-570	500-540	470-520	440-490	380-470
ASH	Mean height increment (cm)	12.3 A B C D	7.7 A	8.3 A	8.8 A B	25.8 B C D	12.0 A B C	29.8 D	29.3 C D	24.9 A B C D	13.1 A B C D	23.0 A B C D
	Mean diameter increment (mm)	2.688 C D	2.789 D	2.388 C D	1.576 A B	2.977 D	2.740 D	1.439 A B	1.576 A B	0.975 A	1.551 A B	1.926 B C
BEECH	Mean height increment (cm)	6.16 A B	10.32 B	4.63 A B	6.12 A B	2.07 A	10.07 A B	6.19 A B	6.66 A B	5.40 A B	9.93 A B	8.62 A B
	Mean diameter increment (mm)	1.271 D	0.792 B C D	0.565 A B C D	0.054 A B C	−0.099 A B	1.061 C D	0.047 A B C	−0.094 A B	−0.326 A	0.098 A B C	0.423 A B C D
OAK	Mean height increment (cm)	6.9 A B C	13.4 B C D	−0.2 A B	9.8 A B C	25.4 D	−0.9 A	5.5 A B C	5.7 A B C	11.1 A B C	16.4 C D	17.1 C D
	Mean diameter increment (mm)	1.109 C D	1.349 D	0.909 B C D	1.168 C D	1.258 D	0.426 A B C	0.321 A B	0.262 A B	0.064 A	0.161 A	0.286 A B

Duncan's Multiple Range Test: In each of the six cases, treatments which do not share the same letter are significantly ($p < 0.05$) different from each other.

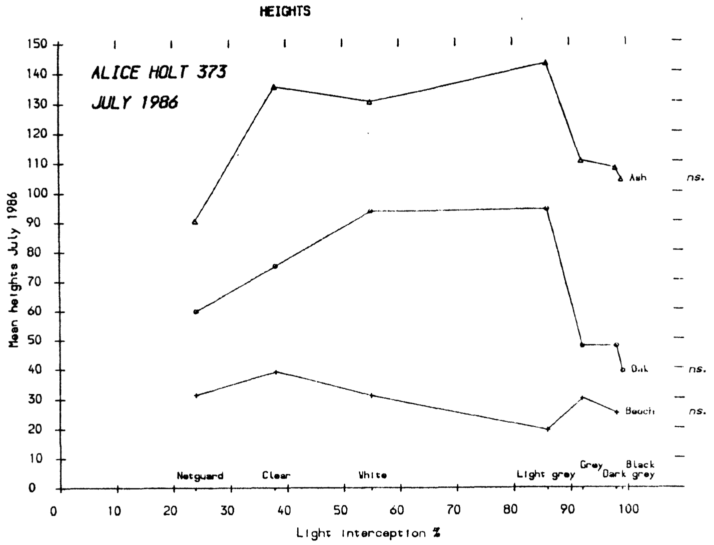

Fig. 1. Height of transplants after 1½ growing seasons in shelters of different opacities

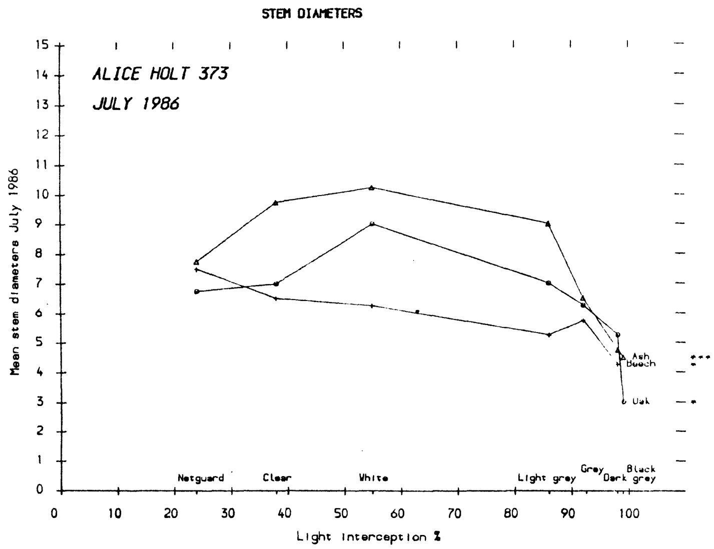

Fig. 2. Diameters of transplants after 1½ growing seasons in shelters of different opacities

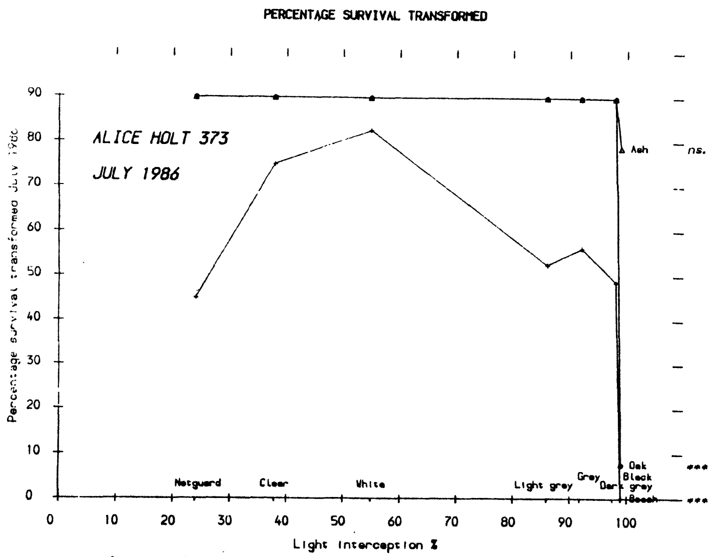

Fig.3. Survival of transplants after 1½ growing seasons in shelters of different opacities

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