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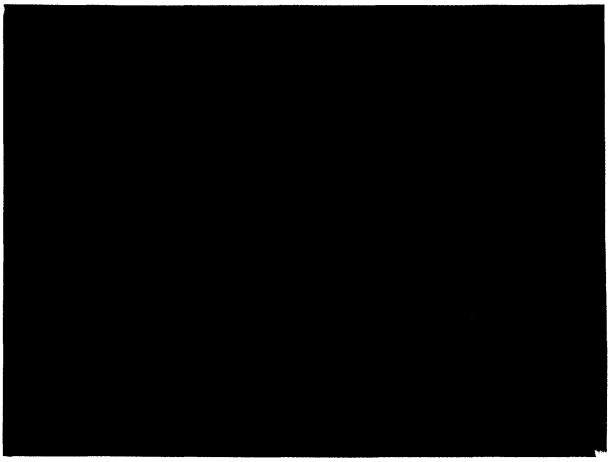
SILVICULTURAL SYSTEMS FOR BROADLEAVED WOODLAND IN BRITAIN

by

S.N. Pryor* and P.S. Savill

1986

OXFORD FORESTRY INSTITUTE
Department of Plant Sciences
UNIVERSITY OF OXFORD



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ISBN 0 85074 093 2
ISSN 0269-5790

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ACKNOWLEDGEMENTS

This research was carried out over the period 1982 to 1984, at the Oxford Forestry Institute. It was funded by the Natural Environment Research Council, to whom we are grateful.

We would like to acknowledge all the help and co-operation that we had from the woodland owners and managers that we contacted in the course of this research. It was a pleasure to learn from their enthusiastic dedication to good forestry management.

SUMMARY

Conventional clear-felling and replanting is increasingly being recognised as inappropriate for those broadleaved woodlands which have a high value for landscape, amenity and for nature conservation. This prompted an investigation into 'non-plantation', 'uneven-aged' and 'irregular' silvicultural systems, which are, or could be, used in Britain.

A new classification of such systems is proposed, with an initial division into coppice and high forest systems. The latter is then subdivided into 'clear-fell', 'shelterwood', and 'selection' systems. 'Group' and 'strip' variants of each of these three can then be identified. All systems can use planting, natural regeneration or a combination.

For each system the following is presented: i) a description based on European use, ii) an account of British examples, iii) discussion of techniques, iv) analysis of profitability, v) evaluation of benefits for landscape, amenity and conservation.

No really convincing examples of selection and shelterwood systems could be found in Britain, but some efficient group shelterwood and group selection systems exist. The failure of natural regeneration should be tackled by concentrating on prolific-seeding species such as ash and sycamore rather than oak and beech, and by more thorough preparation for good seed years - especially by cultivation and careful management of overstorey density.

Although establishment costs for shelterwood systems were lower than for clear-fell, the overall profitability for oak was similar. The Net Present Values of some 'low-input' options, such as simple coppice, were surprisingly high. Most profitable of all was an ash/sycamore shelterwood system.

For landscape and conservation, coppice, or group systems using natural regeneration, are probably the most beneficial. A uniform shelterwood system can be as undesirable as a clear-fell and replant operation if very intensively managed.

The establishment of long-term trials of the various systems is recommended, and more information is needed on the effect of degrees of canopy shading on weed and seedling growth.

1. INTRODUCTION

In the last decade or so there has been increasing interest in the broadleaved woodlands in Britain, and in particular awareness of their importance for nature conservation and the landscape. This has been accompanied by an increasing interest in woodland management regimes other than conventional clear-fell silviculture. This is a result of the disadvantages that clear-felling and planting have for woodlands of high conservation and landscape value. Clear-felling creates a sudden and dramatic change in the landscape, and breaks the continuity of woodland conditions. Planting produces crops with an artificial and uniform species composition, a restricted age distribution and an unnaturally homogenous structure.

In contrast, shelterwood and selection silvicultural systems, with their wider age distribution, provide a continuous woodland canopy. These systems also typically use natural regeneration, which results in a more natural diversity and distribution of both species and age, with the conservation of genetic variation.

However, the interest in such silvicultural systems, appears to have overtaken our knowledge and experience of them. During this century at least, uneven-aged silviculture has only been tried by a handful of British foresters. This is surprising, since many of the uneven-aged or irregular systems are so widely and successfully practised on the Continent. Apart from Troup's classic account (1952 - but essentially unchanged from the 1928 edition) comparatively little has even been written in Britain about such systems.

The following review has therefore been compiled to provide: i) a description of each system (often based on applications in Europe); ii) an account of the examples of each system seen in Britain; iii) discussion of the associated silvicultural techniques; iv) an analysis of likely profitablities: and v) an evaluation of conservation and landscape benefits. The approach has been that of a forester, rather than of an ecologist, focusing on techniques and results, rather than ecological principles. Although clear-fell and coppice systems are discussed, somewhat briefly, as much has been written elsehwere on the associated techniques and merits. Much greater emphasis has been given to selection, shelterwood and 'group' systems, since it is these which have been largely ignored in British forestry literature and practice.

Examples in Britain were located with the help of the Nature Conservancy Council and the Forestry Commission, forestry consultants, and through published accounts. A visit to north-west France and Belgium provided information about present-day applications of the systems in these countries.

Economic analyses have been kept simple, as a fuller treatment has already been published (Pryor 1982). The procedures used in preparing the economic analyses given here are briefly described in Appendix 1. The discussions of landscape and conservation values are confined to apects directly related to the silvicultural system employed. Many of the 'principles for nature conservation' listed by Peterken (1977) are independent of the silvicultural system (for example management of rides and unproductive areas, and provision of dead wood of large sizes) and these have largely been left out of the discussions. Other silvicultural aspects, such as species composition and thinning intensity, which are critical in determining conservation and landscape values, have only been mentioned where the choice of silvicultural system directly affects choice of species or thinning regime. For more detailed discussion of the inter-relationships between nature conservation and silvicultural techniques, the reader is referred to Peterken (1977, 1981) and Kirby (1984). Crowe (1978) and Helliwell (1982) provide further discussion of landscape and amenity benefits.

2. CLASSIFICATION OF SILVICULTURAL SYSTEMS

The classification of silvicultural systems, which are by nature often flexible and imprecisely defined, is not easy, and is further hampered by the existence of several, often confusing, nomenclatures in different languages. Troup's (1952) classification is clear and thorough, and he gives useful lists of the French and German terms for the various systems; but his classification of group and strip systems is somewhat confusing, and a modification is suggested below.

However, to begin with it, is useful to consider the ways in which silvicultural systems differ and could therefore be classified. Firstly, the method of regeneration involved can be coppice, planting, direct seeding or natural regeneration. Although coppice systems are clearly distinguished, most other systems can use any of the other three techniques. The method of regeneration does not therefore provide a very clear basis for a classification. Secondly, the 'even-agedness' of the stands clearly puts selection systems at one extreme, and clear-fell and coppice systems at the other. Some other systems have two age classes (two-storied high forest, and coppice with standards) and shelterwood systems have two age classes for part of the rotation. A third way in which systems differ is in the size of the 'silvicultural unit'. This ranges from the compartment in uniform, shelterwood and clear-fell systems, through the subdivisions of a compartment in strip and small coupe systems, to the groups of the group and 'irregular' systems. The place of the selection system in this hierarchy is debatable, depending on whether one considers that each felling is applied to the stand as a whole, or whether each tree is treated as an individual unit.

<u>This gives the following 'axes of variation':-</u>

i) <u>Method of regeneration:</u>

Coppice; pollard; sucker; natural seed; sown seed; planted.

ii) <u>Age distribution:</u>

Compartment even-aged; compartment containing different ages but each group even-aged; two age classes over whole compartment for a short period; two broader age classes present for long period; all age classes always present.

iii) <u>Size of treatment unit:</u>

Large compartment; small coupe; group (large to small); individual tree.

A consideration of these three 'axes' of variation suggested the following classification of silvicultural systems. Firstly a split by method of regeneration into high forest systems, and systems involving coppice (thereby following Troup, 1952). High forest systems are then distinguished essentially by their even-agedness giving clear-fell, shelterwood and selection systems. The various group systems are then considered as variants of these three basic high-forest systems. The characteristic feature determining the classification of each system is the age structure <u>within</u> each group. This gives 'group-felling', 'group shelterwood' and 'group selection' systems. A whole compartment of a group felling system may therefore be uneven-aged, but each 'individual' group will be even-aged and managed on a clear-fell system. It is hoped that this approach will overcome some of the confusion that has arisen due to the loose use of the terms 'group', 'irregular' and 'selection'.

Similarily 'strip', 'wedge' and 'edge' systems can be considered as variants of each of the three basic high forest systems. This gives 'strip-felling', 'strip-shelterwood' systems, and 'strip-selection' systems - the later being theoretically possible, but not generally practised or recognised. One can also have strip variants of group systems, such as 'strip-group-shelterwood'.

This classification only leaves 'two-storied high forest' as a difficult system to accommmodate and as it is most closely related to the shelterwood system it is classified under that system heading.

The structure of the classification is as follows:-

Coppice:	Simple coppice	
	Coppice with standards	
High Forest:	Clear-felling	- coupe-felling, group-felling, wedge and strip-felling
	Shelterwood	- group shelterwood, wedge and strip shelterwood - two-storey high forest
	Selection	- group selection, (strip selection)

In common with many classifications based on theoretical principles, some of the distinctions are somewhat arbitrary due to the continuum existing between some systems. In particular, group shelterwood systems grade into group selection systems, the distinguishing features being a only slight widening of the age distribution and lengthening of the regeneration period. Within a given stand there may, in fact, be some groups best attributed to the former, and some to the latter - and possibly even some more characteristic of a grouped felling system. For the purposes of the descriptions and discussion of these systems, it therefore seemed more sensible to discuss all group systems together under one heading, rather than under their individual 'parent-system' heading. This is particularly appropriate to the discussion of British examples, since few British practitioners distinguished between the different types of group system. The 'strip' and 'edge' variants are however, discussed under each of their parent systems, since similarities between them are less close, and they are also of only passing interest.

3. CLEAR-FELLING

This system needs no introduction or description as it is universally applied, and is likely to remain the predominant silvicultural system in forests managed primarily for wood production. Its main advantages are its simplicity and uniformity, in particular the ease of felling and extraction. The use of the clear fell system does not necessarily preclude the use of natural regeneration, but it is almost always operated with establishment by planting. The main advantages of planting arise from its artificiality, and minimum reliance on unpredictable natural events; that is, a sufficient number of plants can be ordered, for the desired year, and can then be evenly distributed across the whole area, in rows, to facilitate subsequent tending. This makes reliance on natural regeneration seem like a technique inherited from a primitive 'hunter-gatherer' technology, whereby the time of arrival, the dissemination, the genetic quality and even the species of the regneration are largely out of the control of the manager. However planting is considerably more expensive, losses are greater, especially through drought, and since stocking is usually much lower than with good natural regeneration, continental foresters at least, would say that the resultant crop will be of lower quality. Disadvantages of clear-felling itself, rather than the use of planting, largely arise from the lack of protection, leading to a rise in the water table, extremes of temperature including frost, leaching and soil acidification and rank weed growth.

The characteristics of the clear-fell system will largely depend on the size, layout and rate of the fellings. Fairbairn (1963) uses the term 'clear felling' for coupes greater than two hectares, 'group clear-felling' for coupes 1.2 - 2.0 ha, 'coupe-selection' for coupes of 0.4 - 1.2 ha, and 'group-selection' for coupes less than 0.4 ha. As all crops are single-storied, and even-aged within the coupe, I would prefer to avoid the use of 'selection', and suggest the following: clear-felling - over 2 ha; coupe-felling - 0.2-2 ha; group-felling - less than 0.2 ha (a circle of 50 m diameter). Group-felling is discussed under 'group' systems later in this paper, but strict subdivisions are artificial, and many attributes of group-fellings also relate to small coupes.

In theory, clear-felling in small coupes still gives the advantages of simplicity and uniformity, but through side shelter, it also gives some protection to soil and plants. It also facilitates the use of natural regeneration, as seed from species such as ash and sycamore can easily spread to the centre of a 0.3 ha coupe, and birch could spread across larger coupes. Bands or 'hedges' of mature trees left around fellngs act as seed bearers and provide protection, and this is commonly done by Mr C Oliver at Maiden Bradley (Somerset).

The 'small-stands forest' of Mayr, described by Kostler (1956, p. 281), falls into the 'coupe-felling' category. Groups of 0.3 - 3 ha in size are created and managed as pure, even-aged stands independently of neighbouring groups. However, each stand is regenerated by underplanting and/or shelterwood regeneration, and the bare-ground state is never reached. Kostler points out that this is largely a theoretical system, and has never been widely used, despite its simplicity.

The other major variant of the clear-felling system, is the organization of fellings into strips and wedges. A variety of such systems were developed and used in Germany in the earlier part of this century. They facilitated felling and extraction, and yet still allowed the use of natural regeneration; by careful orientation of the line of felling or strips, they also provided some protection from the sun and wind. Troup (1952) and Kostler (1956) give fuller descriptions of such systems. Some strip systems,

Table 1.

DISCOUNTED CASH FLOW : CLEAR-FELL : OAK YC6

Operation	Year	Volume	Price	Value	Disc.val.
Establishment	0			-1760	-1400
Grant	0			450	440
Thin 10cm	35	32	4	130	50
Pruning	40			-60	-20
Thin 13cm	45	40	6	240	60
Thin 18cm	55	42	11	460	90
Thin 22cm	65	42	16	670	100
Thin 26cm	75	42	18	760	80
Thin 30cm	85	42	34	1430	120
Thin 35cm	95	42	50	2100	130
Thin 40cm	110	50	70	3500	140
C/fell 53cm	125	320	85	27200	680

Annual management cost = -8
Net benefit = 34120 Net disc. revenue = 210
Net present value in perpetuity = 220
N.P.V. with 60% tax relief = 810

Table 2.

DISCOUNTED CASH FLOW : CLEAR-FELL : BEECH YC8

Operation	Year	Volume	Price	Value	Disc.val.
Establishment	0			-1770	-1410
Grant	0			450	440
Thin 8cm	30	30	2	60	20
Thin 10cm	40	55	4	220	70
Pruning	45			-60	-20
Thin 14cm	50	56	6	340	80
Thin 19cm	60	56	12	670	110
Thin 25cm	70	56	17	950	120
Thin 30cm	80	54	24	1300	120
Thin 35cm	90	51	36	1840	130
C/fell 48cm	100	390	58	22620	1180

Annual management cost = -8
Net benefit = 25820 Net disc. revenue = 590
Net present value in perpetuity = 620
N.P.V. with 60% tax relief = 1230

Table 3.

DISCOUNTED CASH FLOW : CLEAR-FELL : ASH/SYC YC8

Operation	Year	Volume	Price	Value	Disc.val.
Establishment	0			-1230	-1050
Grant	0			450	440
Thin 16cm	25	40	8	320	150
Pruning	28			-60	-30
Thin 23cm	35	55	16	880	310
Thin 31cm	45	50	31	1550	410
Thin 37cm	55	35	52	1820	360
C/fell 45cm	70	210	70	14700	1860

Annual management cost = -8
Net benefit = 17870 Net disc. revenue = 2220
Net present value in perpetuity = 2540
N.P.V. with 60% tax relief = 2960

Table 4.

DISCOUNTED CASH FLOW : CLEAR-FELL : BIRCH YC8

Operation	Year	Volume	Price	Value	Disc.val.
Establishment	0			-950	-910
Grant	0			450	440
Thin 16cm	25	40	6	240	110
Thin 23cm	35	55	10	550	200
C/fell 31cm	45	210	15	3150	830

Annual management cost = -6
Net benefit = 3170 Net disc. revenue = 520
Net present value in perpetuity = 710
N.P.V. with 60% tax relief = 1090

Table 5.

DISCOUNTED CASH FLOW : CLEAR-FELL : CORSICAN PINE YC16

Operation	Year	Volume	Price	Value	Disc.val.
Establishment	0			-1010	-810
Grant	0			230	220
Thin 17cm	25	56	7	390	190
Thin 20cm	30	56	12	670	280
Thin 24cm	35	56	14	780	280
Thin 28cm	40	56	16	900	280
Thin 32cm	45	56	18	1010	270
Thin 35cm	50	50	20	1000	230
C/fell 42cm	55	460	31	14260	2810

Annual management cost = -8
Net benefit = 17790 Net disc. revenue = 3540
Net present value in perpetuity = 4400
N.P.V. with 60% tax relief = 4840

although they eventually lead to complete felling of the stand, are often combined with obtaining shelterwood, or group, regeneration in advance of the 'felling edge'; such combined systems are described in Sections 4 and 6. There has been very little interest in strip-clear felling systems in this country, and yet they would be particularly appropriate for naturally regenerating light-demanding species. Garfitt has made several consecutive annual fellings and plantings in strips about 50 m wide at Hockeridge (Herts), which have been successful.

3.1 Profitability

Discounted cash flows are provided for oak, beech, ash/sycamore and birch in Tables 1, 2, 3 and 4 respectively, managed on conventional clear-fell systems. Ash and sycamore have similar yields and price-size curves, so Table 3 would apply reasonably well to either species or a mixture of the two. Birch (Table 4) is given as a 'low cost' and 'low-value' option, whereby some planting is assumed to be done, and the remainder of the stocking made up by mixed natural regeneration. The rotation is short and the main outlet will be turnery. It is striking that although the net benefit (undiscounted) is very low the Net Present Value (without tax relief), is greater than that for both the oak and beech options. Not surprisingly, the most profitable option is the ash/sycamore, but unfortunately the number of sites which will produce Yield Class 8 ash are limited. For comparison, a cash flow for Yield Class 16 Corsican pine is also given, and as expected, the net present value is considerably higher than those for the broadleaved species. Further analyses of clear-fell options are to be found in Pryor (1982) and Lorrain-Smith (1982).

3.2 Landscape and Conservation

The clear-fell system is widely regarded as the least desirable for both landscape and nature conservation. The lack of continuity of forest cover, and the very sudden change from mature forest to bare-ground are major disadvantages from both points of view. The use of artificial planting precludes any ecological or historical continuity with the previous crop. Weeding is usually intensive, often involving the use of herbicides; alternatively, uncontrolled weed growth may become rank and monospecific (particularly bramble and bracken), which again will impede the development of a rich woodland flora. However, all these disadvantages can be reduced, if not removed altogether, by the use of small coupe-fellings. This will lead to a mosaic distribution of age classes in the forest giving continuity and diversity which are desirable for both wildlife and landscape. This can also lead to an increase in the species diversity of subsequent crops if the increased amount of natural regeneration is accepted into the crop. Generally, the smaller the coupes/groups, the greater the benefit to conservation; however, for landscape purposes, coupes of about one hectare are probably sufficiently small.

4. UNIFORM SHELTERWOOD SYSTEM

4.1 General description

This system of management is most highly developed in the oak and beech forests of France, where over ninety percent of the stands of these species are run on a shelterwood system (Oswald, 1982). It is normally referred to as 'regeneration par coupe successives'. In Germany a variant of the system referred to as 'Hartig's darkened coupe', was very widespread in the nineteenth century (Kostler 1956) in beech forests of the north. However, its popularity has declined in much of Germany this century due to failure of the regeneration. Kostler reports that the shelterwood system has rarely been used with success in any of the oak forests in Germany.

The essential feature of the system is that even-aged crops are established, normally by natural regeneration, under a thinned overstorey, which is removed as soon as establishment is complete. Summaries of present day techniques used in France are given in Buffet (1980, 1981) and Bourgenot (1970):

1. Preparatory felling: essentially a late thinning, to encourage development of the crowns of future seed-bearers.

2. Seedling felling: once it is clear that there is going to be a good seed crop, one third to one half of the stems are removed. The understorey, and any regeneration already present is also removed. Cultivation with disc harrows is normally carried out.

3. Secondary fellings: usually 2-4 fellings, at 3-5 year intervals, with timing and intensity carefully regulated, to allow seedlings to grow, but also to prevent rank weed growth.

4. Final felling: the last secondary felling by which the remaining overstorey is removed.

The whole series of operations normally takes 5-20 years. Infrequent mast years, and frost-sensitive seedlings, both necessitate longer regeneration periods. The secondary fellings for a light demanding species must be few and rapid; in the Foret de Blois, where nearly every other year produces good mast, the whole process is often completed in five years. If mast years are more infrequent (eg. oak and beech in N.W. France) then it may take over 20 years to obtain adequate regeneration. This will then be somewhat uneven-aged, and patchily distributed; in this case the system grades into the group shelterwood system. Planting in gaps may be necessary if regeneration is incomplete.

The very dense crops of regeneration that this system typically produces (20-50 000 saplings per ha) require careful management, and the techniques currently used are discussed in detail by Lanier (1981). Weedings ('degagements') are often annual for the first ten years after seeding - the 'fournis' or 'fourres' (thicket) stage. Thereafter, in the 'perchis' (rod) stage, they are ad libitum, until about twenty years. Three to five cleanings ('nettoiements') are then necessary during the 'gaulis' (pole) stage before the crop is ready for its first commercial thinning at 30-45 years old. The 'degagements' are aimed at controlling weeds and removing all undesirable tree species. The 'nettoiements', in contrast, are largely concerned with removal of undesirable crop trees, such as wolves and forked trees, and any trees impeding the growth of promising dominants.

Troup (1952) considers one of the main advantage of this system to be its simplicity, but in areas where mast years are infrequent, obtaining a fully stocked, even-aged crop is quite a managerial problem. The damage done to the regeneration when felling the overstorey is also cited as a drawback, although this is usually less serious than expected especially if the regeneration is dense and even-aged. The system of extraction racks ('cloisonnement d'exploitation') at about 50 m spacing, and cultural racks ('cloisonnement cultural'), at 10 m spacing, assist extraction and minimise damage to regeneration. These racks are also considered essential for the proper management of the weedings and cleanings.

The shelterwood system is also used with planted stock, in areas where natural seeding is insufficient or irregular, where a change of species is required, or where seed-bearers are insufficient in number or inferior in quality - as in the conversion of coppice with standards referred to by Oswald (1982) and Auclair (1982).

Shelterwood management organised in groups is a variant of the shelterwood system. It includes both group (see Section 6) and strip systems. Kostler (1956) describes the various strip-shelterwood systems developed in Bavaria: 'the zoned shelterwood', 'the favoured edge coupe' of Wagner, and the 'wedged shelterwoods' of Eberhardt and Philipp. All these consist of shelterwood regeneration fellings carried out in a strip ahead of the advancing 'edge' of the final-felling. They are considered more suitable than uniform shelterwood systems for light-demanding species.

Examples in Britian

The shelterwood system has never been widely used in Britain, and this is closely related to the fact that both oak and beech do not readily regenerate naturally in this country. It may be that ecological factors are not entirely to blame, and that due to there being no tradition of using natural regeneration, British foresters have never gained the experience and skill needed to obtain and manage such crops. However, it seems likely that there are certain unalterable factors which make the system less easy to apply to oak and beech in Britain than on the continent. No attempt will be made here to review fully the large amount of literature on the factors affecting the regeneration of these species, as this has recently been done thoroughly by Newbold & Goldsmith (1981). Oswald (1978) also contains many valuable papers on regeneration management. The single most important difference between Britain and the continent is the lower frequency of good mast years. Jones (1952) lists good mast years for beech in the first half of this century, and makes the point that, they are not only less frequent, but also more erratic in occurence, than on the continent. There is very little that a forester can do to increase this supply of seed, apart from increasing the size and vigour of crowns of seed bearers by crown thinning (Matthews, 1963).

Apart from this difference in seed supply, there are no other obvious ecological differences between continental and British conditions. Several foresters this century have therefore attempted to emulate continental shelterwood management. Troup (1952) describes the excellent regeneration of oak that was obtained in the Forest of Dean at Blakeney Hill, resulting from an abundance of mast in 1899, coupled with fencing. Over 150 ha were established in this way, and the resulting fine stands of oak are testimony to the fact that it can be done in Britain. Brown (1953) refers to a good crop of regeneration which was obtained in Kingscote Wood, (Glos) following a thinning in 1932. However it was somewhat unevenly distributed; and the overstorey was retained for 17 years before removal, which not only suppressed the regeneration but also resulted in much extraction damage. Jones, in Troup (1952) describes the attempts by Ray Bourne to implement the shelterwood system in some Chiltern beechwoods. The eastern part of Pound

Wood at Parmoor, was the most successful area, although even now the crop appears to be somewhat uneven-aged and poorly stocked in places. Apparently Bourne retained the overstorey for over twenty years, waiting for a second good seed year to fill the gaps, but unfortunately it never came. Jones (Troup, 1952) also considers that the seedlings suffered from having to tolerate an unthinned overstorey in their first growing season. Bourne and Garfitt also attempted to utilise natural regeneration at Cirencester Park. Although their management was essentially a group system (Garfitt, 1953) (see Section 6) a few compartments (32 and 33) are fairly even-aged and were apparently established by a more uniform treatment. Garfitt obviously expected predominantly ash and sycamore regeneration initially, but hoped oak and beech would gradually increase and eventually predominate. However this has not happened, and the pole crops are almost entirely ash and sycamore, but at least they are fully-stocked. Mr Lloyd, the present manager at Cirencester, has continued to utilise the abundant ash and sycamore regeneration, but again on a 'group-shelterwood' system.

In Savernake Forest attempts have been made to naturally regenerate some of the overmature eighteenth-century beech stands. Along the Grand Avenue this has been achieved using a group system (see Section 6), but the whole of compartments 74b and 75b have received more uniform regeneration fellings over the past fifteen years. However in both cases only about half the area is stocked with desirable species. In these compartments, bramble and bracken are beginning to dominate in many of the areas which lacked adavance regeneration, making future improvements in the level of stocking unlikely.

Aldhous (1981), reviewing natural regeneration of beech in Wessex, reports 'plentiful' regeneration at Slindon (Sussex). The canopy had been light since 1950, and scarification had been carried out before two seed falls in 1970 and 1976. Unfortunately it was not possible to visit this area to assess the density of overstorey and completeness of the young crop.

By far the most impressive broadleaved natural regeneration seen in Britain are some areas of oak at Windsor. Compartments 21d (High Standing Hill) and 107 (Cranbourne Wood) both look like well-managed stands in a prime French oak forest. The regeneration is abut 5 m tall, and very dense - around 50 000 stems per hectare. Unfortunately full details of the actual treatments applied were not recorded. Garthwaite (1972) describes some of the techniques of establishment used by Mr Lindsay who was Director of Forestry when these compartments were established. Acorns were often broadcast to boost natural seed supplies, and a large rotavator was usually used to ensure this seed was buried. Seed bearers were usually retained, but the number, and length of time they were retained is not known. It may be that these particular oak crops were established with very little shelter from an overstorey. The regeneration has so far needed little tending treatment, but will certainly need a respacing/cleaning soon.

In Britain, more interest has been shown in a form of the shelterwood system whereby the new crop is established by underplanting rather than natural regeneration. In this case, the overstorey is retained primarily to sustain forest conditions, although any seed produced is usually welcomed. Fairly extensive areas of oak at Windsor were underplanted with beech following fellings in the 1940's (e.g. Compartments 104 and 106). However, this has developed into a 'two-storied high forest' as the remaining oaks have not been removed as intended. Many other smaller areas were seen where thinned overstories had been underplanted (Wakefield, Northants; Ellsbatch, Worcs.; Maiden Bradley, Somerset; Pusey, Oxon). In most cases it was clear that weed growth, particularly bramble, had been reduced by the shade. It was also clear that the overstorey had usually been retained long enough, and that the young trees were beginning to suffer from too much shade and competition.

Two-storied high forest can be considered as a form of shelterwood system. Apart from the oak over beech at Windsor, few examples were seen. Hiley (1956, 1959) tried it with conifers, and discusses its considerable merits.

4.3 Discussion

The overall feeling, having visited the various estates in Britain where a shelterwood system has been tried, was disappointment, especially when comparison was made with the oak and beech forests seen in France. However, enough stands were seen which showed promise to make it worthwhile considering the ways in which this system could be used in Britain.

Seed Supply

The most fundamental point is that this system has apparently only been tried with species which only occasionally produce adequate amounts of seed, namely, oak and beech. Surely the most obvious candidates for a shelterwood system are ash and sycamore. These species produce ample seed in most years, and the seed is also much better equipped to ensure adequate dissemination through a woodland. There could however be a slight problem with ash which is dioecious, if there are insufficient female trees, or if these are of poor form or low vigour (Matthews 1963). The seedlings of both species are shade tolerant (Okali 1966, Jones 1950, Gardner 1977), although the overstorey should not be retained for more than five years. Cirencester Park was the only place where these species had been used, and very impressive fully-stocked, even-aged crops had been established. Surely some regeneration fellings would be worth trying wherever stands of these species were being felled?

Returning to oak and beech, the fact that seed years are infrequent argues in favour of a uniform system, by which large areas can be regenerated in the occasional mast years. The ability to take full advantage of seed years as they arise does however require considerable flexibility of management. Preparatory fellings must be light if there is no understorey, otherwise weed growth may become rank before the seed has even formed. Ideally crown thinnings through the latter part of the rotation will have already produced dominants with full crowns. Local applications of fertilizer could be made (Matthews 1963) to boost the seed production of selected dominants, but again increased weed growth may result if it is not limited by shade.

Cultivation

Considering the widespread use of cultivation on the continent, before and/or after seed fall, it has been rarely used in Britain. It was striking that the two sites which had received cultivation (Slindon and Windsor) both had plentiful regeneration. A heavy disc harrow is not a specialised piece of equipment, and if stump removal is not necessary, it would be worth trying especially on soils with a mor humus. Brown (1953) also suggests trying the German practice of liming such acid soils. Newbold & Goldsmith (1981) concluded that a thin layer of leaf litter is probably desirable for the germination and growth of both oak and beech seed. However, a deep layer, especially if it dries out, is an impediment, and beech mast with its smaller food reserves is less tolerant of this than oak. Since beech litter layers are usually deeper, cultivation thus seems to be particulary appropriate to beech woods. Reade (1960), describing the beech forests at Soignes (Belgium) and Lyons (France), both of which have problems in obtaining natural regeneration, reports that rotavators and spring-tine cultivators were more favoured than disc harrows. There is also a danger of increasing the bramble problem by cutting up and spreading fragments of root and stem which can grow.

Preparation

Aldhous (1981) recommends witholding any fellings until advanced regeneration has become established, but this advice is most applicable to group systems. Jones' 'be prepared' approach (1952) seems more applicable to a uniform or compartment shelterwood treatment: once a good seed crop is predicted (usually confidently by June), then cultivation, and a seeding felling can be carried out. If bird predation of the seed is a problem, a post-seed-fall cultivation may be justified. If the forest floor is not sufficiently clean before seeding begins, due to the overstorey being too light, than a herbicide treatment of weeds, especially brambles or bracken could be considered. Watt (1923) and Jones (1952) both list plant species - non aggressive herbs and grasses - which they consider 'show that the ground is just right' for beech regeneration on the Chilterns. Reade (1960) and Becker (1969) give fuller lists of species considered in France and Belgium to indicate good conditions of soil, litter and light. A dense grass sward is particularly injurious to the establishment of beech (Chinner, 1948), and should perhaps be treated with a herbicide before cultivation.

Weeding

Once the seedlings are established, the most serious problem is usually bracken and bramble growth. Both these weeds not only compete with the seedlings for light and nutrients, but also cause mechanical damage, especially in snow. Bramble growth is checked in France (Blois and Belleme) by the use of an ordinary tractor mounted spring-tine cultivator. This is set up so that the tines do not touch the ground, but instead just pull through the vegetation. It is strikingly effective at preventing the brambles becoming dominant, and like a disc harrow would not be difficult or costly to obtain and try.

There is increasing use of herbicides in France, due to the very high cost of their intensive hand weedings. Buffet (1980, 1981) and Lanier (1981), discuss recent developments, and their suggestions of products and application times could be usefully tried in Britain.

Instability

Troup (1952) and others have warned against the use of the shelterwood system in a windy climate due to the risk of windthrow of the remaining overstorey. It was noticeable that in none of the stands visited in Britain was there any evidence of such instability of the isolated seed bearers, even though many of the beech had suffered from beech bark disease.

Overstorey

It was clear that in many cases in Britain the incompleteness of the crop arising from the initial seed fall has tempted managers to retain the overstorey too long. This has very seldom led to an improvement in the stocking, and in contrast has adversely affected the growth of existing regeneration through shading. It also means that when the overstorey is finally removed, the regeneration is too tall, and therefore suffers damage during felling and extraction, further reducing the level of stocking. A much better strategy for a shelterwood system, for such infrequently seeding species as oak or beech, would be to do all that one can to get a good crop from one particular (predicted) mast year. If this is not entirely successful, then gaps should planted, or, if desired, simply left. The overstorey should then be removed at a rate suited to the initial crop of regeneration. Waiting and hoping for a second mast-year in the near future, will usually only result in rank weed growth in unstocked areas, in which new seedlings are most unlikely to be able to establish.

Genetic Quality

The use of the shelterwood system has often been considered undesirable in Britain, due to the supposedly poor genetic quality of most of our stands of oak and beech. Certainly, the size and quality of these stands is inferior to those of continental stands, but it is far from clear that this represents genetic inferiority. Soils, climate and management regime - especially coppice with standards - are likely to be as important, if not more so, in determining size and stem form. Results from the few and incomplete progeny trials that have been carried out on broadleaves (Evans, pers. comm.; Faulkner, 1982) suggest that stem form and quality have a low heritability. In one trial, the stem form of a highly selected 'Spessart' oak provenance was considerably inferior to those from a local, random sample of seed. The seed of our British stands may therefore not be as inferior in quality as the form of the parents suggests. If natural regeneration is successful, and a dense crop results, there will be ample opportunity for the selection of fine stems. The quality of the resulting stand is likely to be just as high as that of a widely-spaced plantation, from a selected seed source, in which there is much less opportunity for selection. However, the whole subject of the genotypic/phenotypic quality of hardwoods is unresolved, and until further progeny-testing is done, no firm conclusions can be made.

Broadcasting

The success of the oak regeneration at Windsor suggests that broadcasting seed could be considered, to supplement a mediocre mast year. This is obviously wasteful of seed from a good provenance, but if seed can be locally and cheaply collected, it may be a viable proposition. Impressive crops were seen at Amboise (France) which had been established by cultivating, and then sowing acorns at 300 kg/ha. The high density of seedlings which this produced suggested that this sowing rate could be reduced considerably.

Underplanting

The examples of underplanting that were seen confirmed that it is a useful technique, especially if natural regeneration is incomplete or has failed entirely. In Britain, with our irregular seed years, underplanting should perhaps be more readily undertaken.

4.4 Profitability

Natural regeneration is often considered to be 'free', but if a complete crop is to be obtained and tended then considerable expense is involved. Ground preparation, will have to be more thorough, to allow cultivation. Weeding natural regeneration is considerably more expensive than weeding a plantation; a pre-seeding herbicide application may therefore be justified. The subsequent cleaning and early thinnings of the very dense crops can also be expensive. Finally, the revenue from the felling of the final crop may be reduced due to the greater care needed in its extraction; the spread of the revenue over 15-30 years may also be a financial disadvantage. In compensation, continental silviculturalists are convinced that natural regeneration gives a far better crop than planting, even if 6000 or more trees are planted per hectare.

Economic analysis, and discounting in particular, has never featured as much in continental forestry as it has in Britain. However, for comparison purposes, a discounted cash flow has been has been prepared for a French oak shelterwood system. Costs were obtained during a visit to Belleme, and also

Table 6.

DISCOUNTED CASH FLOW : SHELTERWOOD : OAK, FRANCE

Operation	Year	Volume	Price	Value	Disc.val.
Clear u/storey	0			-90	-90
Cultivation	0			-20	-20
Weeding yrs 1-10	5			-600	-520
Weeding yrs 11-20	15			-300	-190
Cleaning yrs 22-38	30			-220	-90
Thin 10cm	50	40	3	120	30
Thin	60	40	5	200	30
Thin	70	40	8	320	40
Thin 20cm	80	42	11	460	40
Thin	90	40	13	520	40
Thin	100	35	20	700	40
Thin 30cm	110	32	28	900	30
Thin	120	35	35	1230	40
Thin	130	32	44	1410	30
Thin	140	37	52	1920	30
Thin 40cm	150	35	62	2170	30
Thin	160	37	75	2780	20
Thin	170	36	84	3020	20
Thin	180	36	92	3310	20
Thin 50cm	190	26	100	2600	10
Thin	200	23	108	2480	10
Seed.fell'g 55cm	210	170	110	18700	40
Sec.fell'g 68cm	215	140	125	17500	30
Sec.fell'g 64cm	220	120	120	14400	20
Final fell'g 67cm	225	100	130	13000	20

Annual management cost = -10
Net benefit = 84410 Net disc. revenue = -670
Net present value in perpetuity = -670
N.P.V. with 60% tax relief = -130

Table 7.

DISCOUNTED CASH FLOW : SHELTERWOOD : OAK, BRITAIN

Operation	Year	Volume	Price	Value	Disc.val.
Ground prep.	0			-220	-220
Cultivation	0			-50	-50
Gap planting	1			-150	-150
Grant	1			450	440
Weeding yrs 1-6	3			-400	-370
Clean/respace	10			-110	-80
Thin 10cm	35	32	4	130	50
Pruning	40			-60	-20
Thin 13cm	45	40	6	240	60
Thin 18cm	55	42	11	460	90
Thin 22cm	65	42	16	670	100
Thin 26cm	75	42	18	760	80
Thin 30cm	85	42	34	1430	120
Thin 35cm	95	42	50	2100	130
Thin 40cm	110	50	70	3500	140
Seed fell'g 51cm	125	120	75	9000	220
Sec.fell'g 57cm	130	70	80	5600	120
Sec.fell'g 59cm	135	50	80	4000	70
Final fell'g 61cm	140	60	85	5100	80

Annual management cost = -10
Net benefit = 31200 Net disc. revenue = 480
Net present value in perpetuity = 500
N.P.V. with 60% tax relief = 760

Table 8.

DISCOUNTED CASH FLOW : SHELTERWOOD : ASH/SYC YCB

Operation	Year	Volume	Price	Value	Disc.val.
Ground prep.	0			-250	-250
Cultivation	0			-50	-50
Grant	1			450	440
Weeding yrs 1-5	3			-250	-230
Clean/respace	10			-120	-90
Thin 16cm	25	40	6	240	110
Pruning	28			-60	-30
Thin 23cm	35	55	14	770	270
Thin 31cm	45	50	28	1400	370
Thin 37cm	55	35	48	1680	330
Seed fell'g 42cm	65	90	62	5580	820
Sec.fell'g 48cm	70	75	75	5630	710
Final fell'g 52cm	75	70	80	5600	610

Annual management cost = -10
Net benefit = 19970 Net disc. revenue = 2730
Net present value in perpetuity = 3190
N.P.V. with 60% tax relief = 3160

from Buffet (1980). The yields are derived from the only French oak yield table available, that prepared by Parde in 1962; the prices are from Hubert (1981) and the Forestry Commission (1984). The discounted cash flow is presented in Table 6. Although the net revenue over the 210-year rotation is very large, the net discounted revenue is negative (- £670) even at the 3 percent discount rate. Many people have wondered why it is that broadleaves are often ruled out in this country, due to low profitability, whereas on the continent they are never considered 'unprofitable'. It is obvious from the analysis presented here that this is due not to a difference in yields, markets or silviculture, but simply that different economic criteria are applied.

It should be noted that the apparent unprofitability of the French shelterwood is due largely to the light thinnings giving long rotations, rather than being due to the system of regeneration used. For comparison, a tentative cash flow for oak on a shelterwood system has been prepared with conventional British thinnings, and rotation length (Table 7). It has been assumed that only about three quarters of the area is stocked by the initial crop of regeneration, and that the remaining area is planted, at a cost of £150. The full grant would be available providing that stocking is complete. The prolonged 'degagements' and 'nettoiements' used by the French are considered to be too thorough and expensive to be applied in Britain. More typical weedings, and a cleaning/respacing operation (for example Garfitt's (1963) 'Belgian System') are therefore prescribed. Such treatments are not claimed to be capable of producing such a pure and high quality crop as the French techniques, but providing some pruning is carried out, the crop is likely to be at least as good as one derived from a conventional British plantation. However, the total cost of establishment (£870) is similar to the cost in Belleme, (£910) where no planting is necessary, but approximately half that of a conventional plantation in Britain (£1760). The subsequent management and yield from the crop are assumed to be similar to those for a planted crop (Table 1). The regeneration fellings start in year 125 and the final felling is 15 years later. Prices have been slightly reduced to take into account the greater care needed in felling and extraction to prevent damage to the regeneration. Comparing the discounted revenue from these fellings (£490) with that for the clear-felling at year 125 in Table 1 (£680), shows a loss of discounted revenue of nearly £200. Furthermore, in Britain the regeneration fellings will have to be carefully timed to coincide with a good seed year. This may mean delaying the seeding fellings, and thereby extending the rotation, by up to ten years; as the discounting factor, at 3 percent, for a ten year period is 0.75, then this could result in a further appreciable loss of discounted revenue. However the fact that at least some overstorey is present during establishment, and is putting on increment, results in a slightly higher overall production for the rotation.

Comparing the net present values, in perpetuity, shows that although the French system gives a negative value, in Britain, the shelterwood system will give a better financial yield than a plantation (net present values of £500 and £220 respectively). However, if tax relief is available, there is very little to chose between the two systems. This illustrates the bias of the present fiscal incentives against 'low cost' silvicultural systems.

As discussed above, more promising species for a shelterwood system would be ash and sycamore, and a cash flow for this option is given in Table 8. Management is considered to be somewhat less intensive than for oak, resulting in a crop with an admixture of other species, and prices for thinnings have been reduced as a result. No gap planting is considered to be necessary, and weeding is less thorough and therefore cheaper, reflecting the greater abundance and vigour of the ash/sycamore regeneration. The regeneration period is ten years and the rotation length has been reduced to

65 years. Comparison of the net present values shows that the shelterwood system is more profitable than the plantation represented in Table 3 (£3190 and £2540 respectively). However, when tax relief is taken into account, the profitabilities of the two systems become more comparable.

Even if natural regeneration fails entirely then a shelterwood system may still be operated by underplanting. In this case, the loss in discounted revenue from delaying the felling, and the greater expense of felling and extraction must be balanced against the reduction in weeding costs, and the possible gain from the growth of the overstorey during establishment. There is little information on the amount by which tree and weed growth is reduced by various degrees of shading, and this has been further investigated by Pryor (1985).

The overall impression is that establishment by the shelterwood system is considerably cheaper than by planting. However, the overall effect on net present value is not as large as might be expected, and if tax relief is taken into account, there is little to choose between the two systems.

4.5 Landscape and Nature Conservation

Stands managed under a uniform shelterwood system *sensu stricto* can have many features in common with stands established by planting under a clear-fell system. They can be pure, even-aged (at least for most of the rotation), and can be uniform in structure and density over large areas. From a landscape and conservation point of view, the shelterwood system can therefore share many of the shortcomings of the clear-fell system. However, if the regeneration is less uniform the stands will be more irregular in structure and composition, and grade into the group systems. In this they will be considerably more desirable from a nature conservation point of view. However, the fact that the felling of the previous crop is spread over 10-20 years, and overlaps with the establishment of the next crop, is very significant. The felling of a mature stand is the single, most dramatic change which forest management involves. As slow rates of change are more favourable to both landscape and nature conservation, then even a slight extension of the time period in which this change occurs will assist both humans and wildlife to adapt gradually to the new environment. Having said this, it should be noted that the foresters of Fontainebleau (France), for example, frequently suffer severe criticism from the conservation lobby when they start a series of regeneration fellings.

The continuity of forest cover is also renowned to have a beneficial, 'conservative' effect on the soil (Helliwell, 1982). In a wet climate, the clear-felling of a stand eliminates interception by the canopy and leads to increased leaching and acidification of the soil. Providing the regeneration has closed canopy before the overstorey is finally removed then such soil degradation will be minimised.

The other major advantage for conservation of the shelterwood systems is the fact that natural regeneration, rather than planting, is usually employed. Peterken (1981, p. 275) lists the advantage of natural regeneration for nature conservation:-

1. It normally means that species which are locally native to that site are re-established;

2. It tends to generate mixed stands, which have a more irregular structure than plantations;

3. Natural genetic variety is maintained;

4. The natural distribution of tree species in relation to soil types is favoured.

However, if one considers a very intensively managed shelterwood stand,then it is clear that only (3) above will necessarily be true. Certainly, the French stands are strikingly artificial in their purity, uniformity and even-agedness. However, in Britain less abundant seed, and less intense management, would almost always result in more irregular and diverse stands which would be more favourable to nature conservation. From a landscape and amenity point of view, the absence of planting rows is an advantage; but there is some evidence that dense thickets are less popular as an internal landscape of a forest than a widely spaced plantation (Helliwell, 1982). Herbicide applications and cultivation could cause considerable damage to the ground flora. However highly selective herbicides, such as asulam for bracken control, will cause minimal damage. Out of season applications, and methods of application such as 'weed wipes' would allow broad-spectrum herbicides to be used with minimal damage to the woodland flora. Cultivation of the soil may cause longer-term changes, for example rise in soil pH, which would be most undersirable in a woodland of high floristic value. The value of the undistubed soil profiles found in woodlands to soil science should also not be overlooked.

Finally, considering Peterken's recommendation to follow 'traditional' systems of stand management wherever possible, the shelterwood system, having never been widely practiced in Britain, would not be highly desirable on these grounds alone. However, Parde (1980) refers to the work of Frochot (unpublished) who studied the avifauna of both coppice with standards and stands in the process of regeneration. He concluded that natural regeneration and coppice of similar ages have a similar diversity and density of nesting birds. The same comparisons can be made of the landscape qualities: although shelterwood stands are not a traditional part of the British landscape, they are sufficiently like coppice with standards to be readily accepted. However when considering similarities of both landscape and conservation values, it must be remembered that the two-storey structure will only be present for a small proportion of a shelterwood rotation.

One can therefore conclude that in its most regular and intensive form, the shelterwood system is only slightly preferable to clear-felling. This is especially so if under planting rather than natural regeneration is employed. However, if, through non-uniform regeneration, stands are more irregular in structure and composition, then it becomes very desirable as a management system from both the landscape and nature conservation points of view.

5. SELECTION SYSTEM

5.1 General Description

The French term for the selection system is 'jardinage' or 'futaie jardinees'; in Germany a variety of terms including the words 'femel', 'Plenter' and 'Blender' are used. Stands managed on a selection system are, at all times, an intimate mixture of trees of all age classes. There is no concept of a rotation length, or a regeneration period, as both harvesting of produce and re-establishment take place regularly and simultaneously throughout the stand. The only silvicultural interventions are 'selective fellings' which are carried out every 5-10 years throughout the stand. These fellings are a combination of regeneration tendings, cleanings, thinnings, final crop fellings and regeneration fellings. Marking such fellings is not easy, as the needs of each of the age classes or stories must be taken into account, and trees of all sizes are removed. Gayer, one of the first proponents of the system, considered that managing a selection forest necessitated such a good understanding of the ecological processes involved that he refered to such stands as 'the forester's school'.

In practice, not all age classes may be represented in any given area, although there will usually be three canopy storeys: regeneration, poles and dominants. Without careful intervention there is usually a tendency for a more even-aged structure to evolve. In poorly managed selection stands only one or two canopy layers will be present. There is also a tendency for the different age classes to become spatially separated, that is for a group structure to evolve. In an extreme case, this would result in even-aged, single-storied groups. This is particularly likely with light-demanding species, and such a group selection system is the only form of the selection system which is applicable to non-shade-tolerant species.

The length of the period, or time between successive selection fellings varies. Short periods - less than 5 years - allow better crop management, particularly of young crops, and by maintaining more complete canopy, give better wind firmness and protection of the soil. However, longer periods result in larger volumes of timber being removed at each visit, making them more economical. Long periods also improve the success of regeneration of light demanders, due to the greater opening-up of the canopy.

It should be stressed that there is a great difference between such selective fellings, and 'exploitative' fellings (French: 'furetage'). The former concentrate on improving the quality of the stand (eugenic), whereas the latter, by continually removing the largest and best stems, result in impoverishment of the stand (dysgenic).

By far the best known, and most impressive applications of the selection system are the mixed silver fir forests of central Europe. Reade (1960) describes the 'plenter' forests of Schwarzenegg in the Swiss Alps, and Paterson (1958), the mixed forests of the French Massif Central and Belgian Ardennes; Roisin (1981) gives a more recent account of the use of the system in Belgium. Throughout Europe applications of the selection system are largely confined to mountainous regions, especially in the Alps and the Jura, where protection of soil, and snow firmness, are of great importance. Balsiger, quoted by Kostler (1956), stated that "there are no selection forests without the silver fir". This species is extremely shade tolerant, and can recover very well from the long periods (30-40 years) of suppression to which regeneration in selecion forests is liable to suffer. Other species typically found are beech and Norway spruce. The Ardennes forest described by Paterson (1958) is beech with oak, but this is intermediate between a selection and a group selection system, as regeneration is encouraged by shelterwood-type fellings in groups. Troup (1952) describes a similar adaptaton in the Alps to allow light demanding larches to be maintained in the mixture.

5.2 Examples in Britain

There are no extensive examples of the application of the selection system in Britain. In addition the examples we do have tend towards irregularity, and merge with the group systems. None of our species, and certainly no broadleaves, can match the shade tolerance of silver fir, and this makes a true multi-storied selection stand difficult to achieve.

Paterson (1958) gives a detailed account of two selection stands: Weasenham Estate, Norfolk, owned by Major Coke, and Rossie Priory, Dundee, owned by Lord Kinnaird. The stand at Weasenham is 20 ha of mixed conifers (Douglas fir, Scots pine, larches, *Thuja*, *Tsuga*, *Abies* spp.) with a few broadleaved trees. Establishment was initially by underplanting, but is increasingly by natural regeneration, with some large gaps deliberately created to encourage the regeneration of larches, the most valuable species. Selective fellings are made on a 3-5 year period; Paterson gives the basal area just before such a felling as 32 m /ha, and 26 m ha just afterwards. Rossie Priory is of greater relevance to this study as it is a broadleaved stand. The main species is sycamore, although the regeneration is of both ash and sycamore, and the older trees include beech, oak, ash and wych elm. Sycamore regeneration occurs beneath existing mature trees, but ash is confined to open gaps which have specifically been created (0.05-0.1 ha); these are subsequently expanded. Some weeding of the ash regeneration is needed, especially in the larger gaps.

The Chiltern beechwoods are often cited as an example of a selection forest. However, Jones (1952) gives historical and silvicultural evidence which shows that exploitative fellings, rather than true selection fellings have dominated these woods for the last few centuries. The Chilterns Plan (Anon., 1970) advocates widespread use of the selection system, but with much greater regard to regeneration than previously given. Many of the beechwoods are now nominally managed on a selection system, but to my knowledge, there are very few sizeable woods in which such management has been actively implemented over a long enough period, to produce a convincing example of selection forest. Bourne (1951) gives details of the attempt to convert several woods at Parmoor, Bucks, into selection stands. Regeneration of ash was sufficient; but oak and beech were lacking. The experiment was abandoned in the 1950's, and examination of the areas now shows that the smaller size classes are lacking, as might be expected given the lack of felling in the last 25 years.

There is one exception to the lack of systematically managed selection stands on the Chilterns, and that is the estate of Mr Reade, at Checkendon, Bucks. He describes it as an irregular selection forest and it is probably intermediate between a selection and a group selection system. Many areas (e.g. The covert and compartment 5) are fairly conventional even-aged conifer plantations, although he is trying to diversify the age distribution by under-planting. However, there are several areas of beech (e.g. compartments 2 and 3) which are developing the multi-storied structure of a selection forest, through a combination of under planting and natural regeneration. Despite the fairly dense overstorey there is ample natural regeneration. He is following continental methods in allowing such regeneration to remain suppressed for twenty years or more. It has therefore developed the characteristic flat-topped form, but he claims it will respond once the overstorey is thinned. The period between selection fellings is variable, usually between six and twelve years. In other areas, a group structure becomes more apparent (e.g. compartment 10), as groups of 0.2-0.6 ha are very heavily thinned, and planted, usually with beech and grand fir. He uses grand fir as a substitute for European silver fir, which he has tried but abandoned due to Adelges damage.

Garfitt, who was involved with the Parmoor experiment mentioned above, also estabished an irregular selection system at Pusey Wood, Oxon. Following the felling of all large trees during the war, he underplanted the remaining sparse overstorey with beech, Thuja and other species. He also encouraged and developed groups of sycamore and ash regeneration. The result now is an intimate mixture of a wide variety of species, with some areas predominantly even-aged, and others with a very attractive multi-storied structure, reminiscent of Alpine selection stands.

Hiley (1967, p. 301-2) describes an experimental plot (0.4 ha) at Dartington, Devon, which he converted to a selection system. A plantation of four species of conifer (Norway spruce, Sitka spruce, Douglas fir and European larch), with ages ranging from 22-46 years, was heavily thinned,to 370 stems/ha, and underplanted with sweet chestnut, larch and Douglas fir. Hiley was particularly pleased with the good growth shown by the isolated overstorey trees, and there was very little wind damage. Unfortunately it was not possible to visit this stand, and it is not known if the original management objectives have been maintained.

A further example of a selection system being applied to conifers is John McHardy's management of 300 ha at Longleat, Wilts. The system has partly arisen as a side-product of the very heavy crown thinnings applied to all the 20-30 year old larch and Douglas fir plantations. These thinnings have allowed fairly plentiful natural regeneration of these species to develop. This is respaced with a clearing saw when 1.5 m - 2 m in height. Apart from applications of asulox to control bracken every few years, this is the only tending that is done. He aims to establish, and respace, a new crop of regeneration every decade, although fellings/thinnings of the overstorey are generally every five years. Stocking at present is remarkably light, and there is some sacrifice of volume production; however, as more age/size classes become established, canopy should become more complete, and weed growth reduced. The low stocking compared with continental selection stands means that high pruning is necessary on final crop trees, but diameter increment is outstandingly high, and the expected 'age of exploitation' is 40-50 years.

An interesting attempt to manage the light-demanding ash on a selection system has been made by Peter Garthwaite at Wakefield, Northants. Most of the wood was mixed ash, oak, lime and sycamore coppice (30-50 years old), with some oak and ash standards. A heavy thinning/felling has been carried out in compartment 1 (14 ha) reducing the basal area to 19 m^2/ha. The remaining trees, predominantly ash, are fairly uneven in size (20-45 cm dbh), and he is hoping that the soil disturbance caused by timber extraction will favour the establishment of natural regeneration. Fellings will then be made evey 5-8 years, to favour any regeneration that appears and a multi-storied structure will evolve. A mixture of species is desired, but predominantly ash and oak, and if necessary oak will be underplanted in individual tree shelters. If necessary clear gaps will be made, and a group system adopted. Providing the stocking is maintained at a sufficiently low level - probably less than at present - this could be a successful system; it will eventually be applied to the remaining 150 ha of this SSSI. However, as so often with a selection system, there is a tendency to remove the best stems, leaving an impoverished stand, and a danger of not obtaining sufficient stems in the 5-20 cm dbh size class.

5.3 Discussion

"Perhaps no subject in forestry has been more hotly or obstinately debated than the merits of the selection system" (Troup 1952). It was outlawed in Prussia and Baden in the 18th and 19th centuries, and yet has been extolled by many authors, including Kostler (1956), as the ideal, to which all other silvicultural systems are inferior.

One of the most long-standing debates is over the claim that total production is greater in selection systems, due to more efficient utilisation of incident light, and other resources, by the multi-storied canopy. The maintenance of continuous cover means that the periods of low current annual increment at the very beginning of the rotation of an even-aged stand are largely avoided. Assman (1961), Johnston (1978) and Helliwell (1982), review the conflicting evidence for higher productivity of mixed age and mixed-species stands, but no clear conclusions are possible. There have been no replicated trials, and one is tempted to agree with Troup (1952): "the difficulties of demonstrating whether this expectation is realized or not, are probably insuperable".

Size Assortment

Troup dismisses the debate on volume production by making the point that differences in value are likely to be more important, and there has been considerable discussion on this aspect as well. It is usually accepted that a much higher proportion of the total volume production of a selection forest is in large sizes, and hence high value, compared with a normal forest of even-aged stands. Bourne (1951) produces data to confirm this, suggesting that in even-aged stands, mature trees contain 50 per cent of the total volume production, whereas in selecton forests they contain 67 per cent. However, more careful studies and comparisons would need to be made to confirm these claims.

Timber Quality

There has also been disagreement over the quality of the timber produced by selection stands. The period of suppression which most young trees experience in a selection stand will certainly result in a small juvenile core, of comparatively high density wood. The selective fellings carried out in selection systems have much in common with heavy crown thinnings, and result in well-developed crowns on mature trees. This will result in high and even rates of diameter increment in the latter years of a tree's life. It will also result in heavier branching, although, as Troup suggests, such knottiness is usually confined to the low-value upper part of the stem anyway. Badoux (reported by Assmann, 1961) studied a spruce/silver fir selection forest and found that the crowns tended to be longer and broader than those of similar sized trees in even-aged stands, and the trees also had a lower height/diameter ratio, that is greater taper.

In conclusion, one could perhaps say that selecton stands are likely to have a slightly higher total productivity; that the proportion of small sized timber produced is probably lower; and that timber quality will certainly be adequate, although in sparsely stocked stands, high pruning may be necessary.

Protection

There is no doubt that the selection system is 'protective' in several senses. The continuity of forest cover gives maximum protection to the soil from leaching and erosion. It also provides protection for frost sensitive species such as beech, allowing it to regenerate even in frost hollows. The lack of sharp edges to the canopy, and the taper of the trees gives increased wind and snow firmness. In a wider context, the continuity of forest cover helps prevent landslides and avalanches and ensures constant water catchment properties. It is these attributes that have led to the predominance of selection systems in mountainous regions. Although in Britain climates and terrain are not so extreme, most of these attributes will be valued, at least in the long-term.

Shade Tolerance

The application of the selection systems in Britain has been considered difficult firstly because we cannot use silver fir, and secondly because lower summer light intensities tend to reduce the number of photosynthetically active canopy layers. Application of the system to broadleaved species in Britain is made more difficult due to the lower shade tolerance of these species. Fellings will need to be heavier, or more frequent, to prevent the suppression of natural regeneration, as broadleaved species will seldom recover. If the structure is to be multi-layered, the canopy must be sparse, as at Longleat; otherwise it should tend to a group system, as at Rossie Priory, with a mosaic of single-storied groups. In both cases the greater photo-tropism of broadleaves, when compared with conifers, could be a problem, and the use of species such as cherry and lime, with a more monopodial growth habit is advised. In the case of a sparse, multi-layered canopy, high-pruning of broadleaves is likely to be essential to obtain high quality butts. A careful balance will have to be reached between maintaining a high enough stocking to suppress weed growth, and maintaining too high a stocking, which will suppress any regeneration that does appear. A further point with regard to shade tolerance, is that tolerance of low light levels is usually greater if other growth factors are not near their limiting values. The stocking of a selection stand of broadleaves could therefore be somewhat higher on a fertile site than on a poor one. The selection system has the advantage that seed from all seed years, however irregular or partial, can be used, and this has made many, including Jones (1952), consider that it might be preferable in Britain to a shelterwood system.

Felling and Extraction

A regular system of extraction racks considerably aids management and reduce damage to regeneration during extraction. Both Weasenham and Pusey woods had such a system of racks, in the latter case at 20 m intervals. Damage is likely to be greater than in a shelterwood, or group system where the regeneration is all young and bends rather than breaks. However, there was little evidence of damage at Pusey where numerous fellings had been carried out, and as Hiley (1967) says: "it has been demonstrated again and again that, with competent woodmen, this damage is much less than expected".

'Methôde du Contole'

It is essential for the success of a selection system that adequate, but not excessive, numbers of trees of various ages and sizes are selected and retained. The 'methode du controle' was developed and used in France, Belgium and Switzerland to assist the managers in achieving this, and to predict yields. The system is fully described in English by Paterson (1958) and Reade (1957). Essentially it involves periodic ennumeration (i.e. measurement of dbh of all stems every 10 years or so); total growing stock, and growth since the last ennumeration can then be calculated using local volume tables; and the diameter and volume distribution can be compared with previously estimated 'ideal' distributions. Bloomer & Galloway (1952), Reade & Paterson (op. cit.) have all recommended its application to British stands.

Reade has been managing his Ipsden estate according to the system for the last 30 years, with an increase of growing stock being his main management objective. However, Spencer (1967) reports that even by the early 1960's the system had fallen into disrepair in Switzerland, due mainly to the excessively high labour costs, and also the outdated and inaccurate methods of volume and yield predicton. The main benefit of applying the system is probably that it ensures that the manager visits every compartment, and sees every tree, at least once a decade. The spatial variability, especially in stands tending to a group structure, is so great that informal assessments of stocking are likely to be far more use than averages for the whole stand, compartment or forest. Much more benefit could be obtained by the manager dividing the stands into identifiable units, visiting and assessing the stocking in each one, and taking action accordingly.

Application

Having seen several applications of a selection system, it appears that despite it being most suitable to conifers, it could be applied to broadleaved stands. Although in many ways it is the simplest system to comprehend, it is probably the most difficult to apply. It is particularly prone to even-agedness and impoverishment, through insufficient and excessive felling respectively. It is notable that no stands were seen which could be described as 'text book' examples of the system in operation, despite many good intentions. The system would seem to be particularly appropriate to small woods, of high landscape value, where intensive management is possible.

5.4 Profitability

The selection system differs from the other systems considered so far, in that the costs and revenues are constant from one year to the next. Once established, a selection system is thus ideal for an owner who does not have money to invest, and who is on a low tax rate or ineligible for tax relief. No estimates of costs or returns were available from the few selection type stands seen in this country. For illustrative purposes, one could assume that annual management cost was high, £20, and that planting/regeneration-tending cost £100/ha per year. Assuming that the sustainable yield was $5m^3$/year which has a standing value of £55 per cubic metre, then annual revenue would be £275/ha. This gives a net annual revenue of £155, which, when capitilised at 3 per cent gives £5200. This assumes the selection stand is already fully established, and this value is therefore not comparable to the net present values obtained for other systems. Conversion of an even-aged, mature stand to a selection system will involve some financial sacrifice, especially if a high discount rate is used. This is because the felling of some timber will have to be delayed until well past its financial maturity. Timber revenues are likely to be lower in a selection system due to the need for directional felling, the wide dispersion of saleable trees, and the increased care needed in extraction.

5.5 Landscape and Nature Conservation

In terms of continuity and lack of sudden change, selection forests are the ideal, but as Jones (1945) points out, this is not necessarily natural. Peterken (1981) says, selection forests are "quite unnatural, the product of sustained, skilled and highly regulated forestry". Within the landscape, the canopy of a selection stand is textured and yet uniform, which makes it very desirable. From within, the abundance of mature trees, with isolated well developed crowns, standing above younger trees makes it very attractive; however, to some people it is too uniform and monotonous. The lack of diversity, and of cyclic changes of light and dark phases are also possible disadvantages for nature conservation. However, the multi-storied structure is highly desirable for breeding birds, and within any stand there will be small scale spatial variations in shading and hence flora and shrub layer communities. The intimate mixing of old and young trees, and the continuous woodland conditions, would be ideal for sustaining a diverse epiphytic flora.

6. GROUP SYSTEMS

6.1 Description of Systems and Continental Applications

As discussed in the introduction (Section 1), there is a certain amount of confusion regarding the nomenclature and definitions of the different 'group' systems. The method used here is to consider all groups systems as variants of the other silvicultural systems; that is, application of these systems to only small areas, rather than to whole stands. This gives 'group-felling, 'group shelterwood' and 'group selection' systems.

'Group-felling' involves felling all the trees in a group prior to restocking. The crop within each group will always be even-aged, but the stand as whole will contain groups of a wide range of ages, and possibly of all ages. The individual groups may be pure, or mixed in species composition, and may be established by natural regeneration, or planting or a combination. The system is particularly appropriate to species which are strongly light-demanding since the only protection given to the trees is from side-shelter. Roisin (1959) and Penistan (1960) describe the use of this system in Belgium to 'transform' pure spruce plantations to stands with a wider range of age-classes and species. Groups of about 0.1 ha are felled and replanted with predominantly beech, Douglas fir and larches. Natural regeneration of other species is also accepted. Helliwell (1982) reports that the Netherlands Forest Service has recently initiated a similar programme of stand diversification by group fellings.

Group shelterwood systems involve the retention of an overstorey for a short period to provide shelter for the new crop being established in the group, which is approximately even-aged. 'Gayer's femelschlag', or the 'Bavarian Femelschlag', (which Troup (1952) calls the 'group system') is a version of this system. The main difference from the uniform shelterwood system, apart from the smallness of the areas worked, is the fact that if advanced or existing regeneration is present, it is used as the focus of a regeneration felling. (In a strict uniform shelterwood existing regeneration would be removed with the understorey). These groups are gradually enlarged, by carrying out regeneration fellings (seeding, secondary and final fellings successively) around the edges of the groups until eventually the groups meet and merge. The regeneration period is generally longer (15-40 years) than with the uniform system, and the resulting crop is therefore somewhat more uneven-aged.

However, by mid-rotation the stand appears even-aged and is single storied until the end of the rotation; this makes the term 'femelschlag' ('selection coupes') somewhat inappropriate. The system was perhaps surprisingly, not widely adopted outside Bavaria, and even there it is now seldom used. Instead it was developed into various other 'combined' systems. In the femel-shelterwood system, also referred to by Kostler (1956) as 'the old Palatinate' system, before groups are located a light seeding felling is applied to the whole compartment, as in the uniform system. Once seedlings have appeared, groups are then located, opened-up and expanded as described above. This initial seeding felling can be useful to increase the amount of regeneration, if there is insufficient existing regeneration on which to base groups. The most widely-used developments of the group shelterwood system have been various 'strip and group' systems. Kostler (1956) describes three such systems: 'the edge-femel-coupe', the 'Bavarian combined method', and 'Kubelta's femel-strip'. They are all very similar: groups are established and developed in a strip or belt through a stand; when the groups are well developed the remaining overstorey is felled; meanwhile groups have been established in a strip ahead of the felled belt, and the process is repeated and the felling 'edge' advances. They are thus a combination of shelterwood groups to start the establishment of regeneration, and strip fellings to complete the regeneration and remove the overstorey. Such systems have been more widely used that the simple shelterwood groups because both extraction and management is more straightforward, and the stands are supposedly less prone to windblow. Such systems have been widely used in the past in central Europe, especially Austria and Bavaria. Shade bearing species particularly beech, silver fir, and Norway spruce have been predominant.

'Group Selection' is a term that has been widly used and loosely applied to any irregular or group system. Here it will be used to refer only to systems in which a stand is sub-divided into groups each of which is for a large part of its life, uneven-aged and has more than one storey.

The prime examples of this system are the 'Baden femelschlag' and the 'Swiss femelschlag'. These are very similar, and Troup (1952) refers to them together under 'irregular shelterwood' systems. Kostler (1956), somewhat enigmatically, classifies the Baden femelschag under shelterwood systems, and the Swiss femelschag under 'combined systems'. Some of the 'transformation' operations described by Penistan (1960), to improve Belgian broadleaved woodland, could also be described as 'group selection' systems.

The Swiss femelschlag has been fully described by Jeffrey (1956) and also by Reade (1960). It is not rigidly defined, and great importance is attached to the flexibility given to the manager, who typically has an intimate knowledge of his forests. The system, in practice, closely resembles the selection system, as there is usually no fixed rotation length, or regeneration period. However, a group selection stand will differ from a selection forest in that a time comes when all remaining old trees must be removed merely because they are old, whereas in selection working no such time ever arrives (Troup 1952). Thus there is still a shelterwood notion: an older crop providing protection for a younger crop which is replacing it, although both crops have a broad age range and the period of shelter is often over 50 years. It also differs from the selection forest in that more emphasis is placed on obtaining and developing regeneraton in groups, rather than uniformly through the stand.

The individual groups will certainly not differ as much in structure and average age as in the group-felling system, but the group structure will definately be noticeable during the period of regeneration. In contrast to the group celar-fell system, the range of ages within a group is likely to be as wide as the range within the whole stand. However Reade (1960) points out that once the average age is over fifty years group selection stands generally appear to be fairly even-aged.

Both the Baden and Swiss systems are characterised by intensive 'education' of the young crops, whether planted or naturally regenerated, through 'tending', 'cleaning' and 'selective thinnings' - which are all 'cost' operations. Troup (1952) suggests that the Baden system only differs from the Swiss system in the greater importance attributed to 'light increment thinnings' and the maintenance of well-balanced crowns to give wind-firmness; regeneration then comes somewhat incidentally to these operations. Whereas with the Swiss system, more emphasis is laid on regeneration fellings, which also have the secondary effect of enhanced increment on the remaining seed bearers. In practice both systems are thus very similar.

6.2 Applications in Britain

Group systems have been used more frequently in Britain than either the shelterwood or selection systems, but there are still very few examples of whole estates or woods being run according to the system. Also, in contrast to the continent, there are very few clearly defined systems which have been developed and implemented. The few managers who have tried goup systems have generally been very opportunistic and flexible, not adhering to any formalised plan. It is therefore more difficult to classify the examples that exist, as distinctions between the categories have been blurred.

Group-felling has more examples than any of the other variants, partly because it is simplest to manage. Mr Ted Garfitt, whose mentor was Ray Bourne, has been the most vigorous advocate and implementer of group systems in Britain since the war, and he has recently published a succinct account of 'the group selection system' (Garfitt, 1984). In fact this is very much a 'group-felling' system, as defined above, with clear felling of even-aged groups. He has applied this system to several estates with which he has been involved: Hockeridge, Herts; Guiting, Glos; Thonock, Norfolk; Cirencester, Glos; Parmoor, Bucks; and Pusey, Oxon. Several of these were visited, and although none of them was very similar to his written account, there were parts of each that were clearly functioning group systems. At Cirencester many of the groups were uneven-aged (see below) but other areas which were lacking any usable stems after the war, were clear-felled (Garfitt 1953), and replanted in groups. In many cases the planting has been supplemented, or even overun by ash and sycamore regeneration, and fine pole crops have resulted. At Pusey, Thonock and Hockeridge group size was larger (up to one 1.5 ha) thereby making 'coupe-felling' rather than 'group-felling', systems. At Guiting 20 m x 20 m groups were cut in the hazel coppice, and replanted; hazel 'hedges' were left between adjacent groups, providing at least some protection and acting as a visual barrier.

On Harris's estates in Worcestershire a decision has been taken only to make small (less than 2 ha) fellings, on heavy clay soils, in an attempt to reduce the rise in water table that has proved a problem with larger clearances. At Chaddesley, (Worcs) an attempt is being made to regenerate an oak wood with a group system; two half hectare groups have so far been felled, in 1980. One has been planted with oak, some of which have become established. The other has been left to naturally regenerate, but as bracken has become dominant, this now looks unlikely to be successful.

The most extensive and organised group-felling system being practiced in Britain is the 'Bradford plan'. This was developed by the late Lord Badford and his head forester Phil Hutt, and implemented at Tavistock; the system is described by Hutt and Watkins (1971) and Bradford (1981). Each stand is divided geometrically, into square 'units' (18m x 18 m); each of these units is further divided into nine square 'plots' (6m x 6m). Each plot is intended to contain one final crop tree, and is initially planted with nine seedlings. The small size of these plots means that only shade-bearing species can be used, entirely conifers at present apart from Nothofagus spp. As each plot is even-aged, this system is essentially a 'clear-fell' group system, but as plots within a unit are felled and planted at six year intervals, then each unit will eventually contain plots of all ages. If the uneven-aged units, rather than the even-aged plots, are considered as the basic group, then the system could be considered as a group selection system.

Group shelterwood systems applied in Britain tend to merge with group selection systems. Management is more informal than on the continent, and the seeding fellings and definite regeneration periods, which are characteristic of group shelterwood systems, are unusual in Britain.

However, the regeneration and management regime described by Joslin (1982) for the 1200 ha of broadleaves in the Forest of Dean could certainly be described as a group shelterwood system. Seeding fellings, removing 60 per cent of the volume are made to create and enhance groups; these are followed five to seven years later by secondary felling(s); the timing of the final felling depends on amenity and other considerations. Joslin states that after eleven years of applying this system, twelve percent of the area has been successfully regenerated, and 48 percent partially stocked with advanced groups. Certainly many impressive crops can now be seen, which have been established by this low-cost regime. However, in many areas the density of saplings of final crop trees is still rather sparse, with birch and coppice shoots predominating. Hopefully, within this low-grade matrix are sufficient seedlings to make a final crop. The use of the coppice regrowth as a nurse to such seedling requires careful timing of cleanings/respacings, if the seedlings are not to be overtopped.

A moderately successful group shelterwood system has been initiated in Shelf Held Coppice, Wyre Forest, by John Thompson of the NCC. A compartment of 50-60 year old sessile oak coppice was heavily thinned encouraging crown development and seed production. There is now an abundance of oak seedlings (approximately 10 per square metre). Seventeen groups, each of about 30 m diameter (0.07 ha) were fellind in 1985. These groups will gradually be expanded by further fellings over the next twenty five years. If this technique is successful, it will be applied to much of the 1300 ha of similar old coppice in Wyre.

A similar programme of shelterwood preparatory/seeding felling, followed by group fellings has just been started in Great Breach Wood, Somerset, a fine mature oak-ash wood. The intention here will be to sustain the mixture, probably with oak regenerating under ash, and ash under oak.

Garfitt (1953) describes a form of group shelterwood management applied at Cirencester in areas where the overstorey had gone completely: the remaining hazel coppice was thinned out in groups to release the ash and sycamore seedlings which had appeared beneath it. Where the hazel coppice was subsequently completely removed and controlled these crops have succeeded, but elsewhere the hazel has remained dominant. Successful application of a group shelterwood system has been continued Cirencester, under Mr Lloyd's management. Moss's Copse demonstrates well many of the different stages in the system. Groups of regeneration are typically 0.05 to 0.1 ha in size, and the range of ages within each group less than ten years. The aim is to spread the felling of the beech overstorey over twenty to thirty years, by which stage all the groups will have merged. By far the most abundant seedlings are ash and sycamore, but through the selection applied in three cleanings in the first fifteen years, then the proportion of beech, oak and cherry is considerably increased. Ash and sycamore are, in effect, used as a matrix or nurse for the final crop species which are less abundant.

The size of the groups can be critical: Brown (1953) reports that at Queen Wood, on the Chilterns, 40m diameter groups were felled, following the good seed fall of 1922. Adeqaute regeneration was obtained around group perimeters, but the groups were too large, so that beech mast could not reach the centres.

Group selection systems are somewhat more frequent in Britain than group shelterwood systems. This is partly because long or indefinite regeneration periods have had to be adopted due to poor initial regeneration. Aldhous (1981), having visited many beechwoods in southern England, concluded that the only successful method by which to obtain natural regeneration was that of "securing advance regeneration and felling only where it is well established". This is very much the attitude applied by Mr John Workman in his group selection system at Ebworth, Glos which is the most impressive example of such management in this country. Where there is a gap in the canopy, sycamore and ash regeneration may come initially, but he will usually wait for beech to appear before doing any fellings. Occasionally beech regeneration will appear when the overstorey is not mature (100 years), in which case he will thin to favour this, and may eventually fell the overstorey before it is fully mature to ensure that the advance regeneration does not suffer. It typically takes around 30 years to regenerate a stand, and towards the end of this period he may underplant with beech to fill in between the groups of regeneration. Although no weeding is ever done, the regeneration is rigorously cleaned once the overstorey has gone, and secondary species are only retained to nurse the beech. Groups are generally less than a third of a hectare in size.

Moderate success has been obtained at Savernake, Wilts., using the group selection system to regenerate the 1750 beech Grand Avenue (eg. Compartment 18).

6.3 Discussion

Size of Groups

The size of the groups is a critical characteristic of any group system, but is particularly important for group clear-fell systems. Large groups are easier to manage, and are essential for light-demanding species. However, with larger groups, there is less protection of the soil from both rain and sun; the weed growth is more vigorous; the canopy is more uneven, thereby increasing the risk of windthrow; and natural regeneration of large-seeded species may not spread to the centre of the group. Both the Bradford system and most femmelschlag systems have groups under 0.1 ha, but they are all applied to shade-bearing species. The most useful size range is probably 0.1 - 0.5 ha, larger groups being needed in taller and more uneven-aged stands. Many people, including Brown (1953), have commented on the 'pudding-shaped profile' frequently found in groups, with taller regeneration in the centre of the group. Garfitt (1966) further discusses this observation, suggesting that in a larger group one would actually find least growth in the centre and on the margins of the groups, and most growth in ring-shaped area between these two. In this area there would be considerable benefit from the side shelter, and yet not too much competition and shading from the surrounding trees. Further investigation on the effect of shading and competition on the growth of both trees and weeds is necessary before an optimum size for groups can be recommended.

Shape

Shape and orientation of the groups can have a considerable effect on the variation of micro-climate within the group. Considerable emphasis is laid on this in central Europe (Kostler 1956, Jeffrey 1956, Roisin 1959). Fairbairn (1963) following up Andersons work on groups, made a thorough study of wind, insolation, incident rain and temperature at different points within groups. On the basis of this he makes recommendations for the distribution of planted species within the group. However, any system applied in Britain is unlikely to be so finely tuned. General recommendations might be that 1) north-south orientation of an elliptical or rectangular group provides a good compromise between wind and sun, and 2) that light demanders should be near the north edge and frost tender species near the south.

Distribution

The layout of the groups is vital in facilitating management of the stands, and also assisting extraction of timber without damage to younger crops. The extraction racks which run between pairs of 'units' in the Bradford system (i.e. every 36 m) simplify both management and extraction. The loss of productive area is minimal as canopy soon closes above such narrow racks. In fact, for light-demanding broadleaves a similar grid layout would be ideal, but without the 'units' being subdivided into plots i.e. each group being 20m x 20 m, with racks every 40 m. No such rigid layout would be considered on the continent, but extraction there is facilitated by the principle of 'limits of transport'. Wherever possible, the first groups to be regenerated are those located furthest from the nearest road, thereby mimising the amount of timber that has to be extracted through a young crop. Damage to new crops by felling will be least in group-felling systems, and most in group selection stands. However, as Mr Workman, Lord Bradford and many others testify, the damage to regeneration less than 3 m tall is minimal, providing directional felling is employed.

Protection

Fencing costs for small groups are inordinately high, and this has always been considered as a major disadvantage of the group system. Firstly, it must be stressed that fencing needs vary: at Pixton, Devon group plantings were severely damaged by deer, whereas in the Forest of Dean, Joslin (1982) maintains that light grazing by sheep is a considerable aid to the establishment by natural reneration. Secondly with individual tree protection, the cost of protection is entirely determined by the number of trees protected, rather than by the length of the perimeter of the group. Thirdly, it is frequently found that natural regeneration suffers little damage from deer when compared with planted trees, especially carefully weeded widely-spaced plantations. Respacing natural regeneration while it is still at a vunerable stage is also often followed by severe fraying of the selected stems.

6.4 Profitability

The lack of uniformity in any of the group systems is bound to increase the management costs; if they were raised from £8 to £15 per year, this would reduce net present values in perpetuity by about £500. The profitability of a group-felling system will however differ in several other ways from that of the parent clear-fell system. Most importantly, the division of the forest into a number of different age classes will give a more uniform distribution of costs and revenue through time. If there were as many groups as there were years in the rotation, and every group was a different age, then there would be an annual income equal to the net (discounted) revenue for a whole rotation of that crop. Using the oak cash flow given in Table 1 as an example, the annual income (i.e. net discounted revenue for a rotation) would be £210. The capitalised value, in perpetuity, for the whole forest would then be £7000 per hectare (=£210/0.03). This, like the value obtained for the selection-system is not comparable with net present values for clear-fell systems, as it assumes that a steady state, comparable to normal forest, has already been reaached. The conversion of an even-aged stand or forest to an 'all-ages' group system will always involve some loss of income which will be more significant if discounting is carried out. This is because the diversification of age is bound to result in some areas being retained long after this point. Discounted cash flows for such a conversion to a group system become complicated, and examples are given in Pryor (1982, p. 81-89).

The subdivision of stands into groups of flexible size may also preclude the use of tax relief, as such areas cannot be separately assessed under schedules B and D, and changes of ownership will also be difficult to achieve. Other, more technical, factors will also affect costs and revenues. A regular 'supply' of young trees, in the annual planting/regeneration areas, is ideal for sustaining high deer and rabbit populations. If groups can be estaablished, so that there are six to twelve age classes, with all groups in each class being the same age, then management will be simple and cheaper, pest populations somewhat lower, and timber prices should be higher as larger parcels can be made up by combining produce from all the groups in a class.

The group shelterwood system will have a very similar cash flow to that of a shelterwood system (see Tables 6-8). However the regeneration period be longer and the management expenses during this period greater. The group selection system will be little different from the selection system, providing the whole forest is divided up into several different age classes, so that their regeneration periods overlap. Over the forest as a whole this will result in similar annual revenue and costs as given for the selection forest. If this does not occur, there will be more clearly difined phases of felling, regeneration, tending and thinning.

6.5 Landscape and Nature Conservation

From the point of view of the landscape within a forest, and also the contribution of the forest to the landscape in which it is situated, the group systems are probably the most desirable of all silvicultural system. The greater the diversity of stand structure within the forest, the greater its amenity value; the group-felling system is therefore probably the most desirable. From outside the forest, the overall continuity of mature forest cover is maintained as an apparently permanent feature in a landscape. Aesthetics are, however, partly personal taste, and it must be said that some people find the uneven-aged, irregular structure, and especially the thickets of natural regeneration "uninteresting, untidy and unattractive" (Reade 1965).

Nature conservation is also favoured by the two attributes of continuity of forest cover and diversity of structure and species. Jones (1945) has pointed out that 'virgin' temperate forest is most likely to be a mosaic of fairly even-aged, single-storied groups. Of all the silvicultural systems, the group shelterwood and group selection are therefore the closest imitation of the structure of a natural stand. Such systems are therefore increasingly being recommended for ancient and semi-natural woodlands in Britain (Peterken 1981, Kirby 1984). Choice of species is obviously important, and the Bradford system is of considerably lower value than for example Workman's sytem at Ebworth. As an illustration of the desirability of this system for nature conservation, the Ebworth estate, having been managed as a productive economic estate for two generations, was suddenly declared a National Nature Reserve in 1975 - and the recommended management, for maximum conservation of wildlife, was virtually unchanged from the previous management system.

The group system has never been a traditional management regime in this country. It may, therefore be regarded as less desirable than a reinstatement of coppice with standards. It should perhaps be noted that a group-felling system would however give a similar mosaic structure as that produced by the cants of coupes of a coppice system, which is so valued for nature conservation.

7. COPPICE AND COPPICE WITH STANDARDS

These systems are too well known to need describing and the reader is referred to Troup (1952), Rackham (1980), Peterken (1981) and Evans (1984) for general accounts of the systems and associated techniques. Despite the fact that the Forestry Commission census (1983) classified 12 000 ha of woodland as coppice with standards and 26 000 ha as a coppice, actively worked examples are comparatively rare. Exceptions include Bradfield Woods (Suffolk), Ham Street Woods (Kent), Pepper Wood (Worcs) and Monks Wood (Hunts). Sweet chestnut coppice is rather different, and there are large areas in south-east England which have been continuously worked.

In the recent revival of interest in coppicing, due to rising firewood prices and interest in conservation, there are some aspects of traditional coppice management that seem to have been overlooked. In many cases very little attention is now paid to the age structure of the standards, whereas in the past the recruitment of a sufficient number of maidens was considered very important (Troup 1952, Stewart 1982). Troup considers 10-20 'tellers' (10-20 year old maidens) were needed for each mature standard desired. The freeing of any young seedling and saplings, in the second to fourth year after coppicing is vital if enough are to survive. Secondly, Troup (1952) states: "it is not generally recognized that the thinning of coppice is an important operation". The function of such thinning is similar to that of thinning any other crop: to remove stems of undesirable form or species, and to improve the diameter growth of the remaining stems. Troup (*op. cit*) reports the results of such coppice thinning experiments in France, and Harris (1956) describes similar thinning treatments and the resultant stimulation of diameter and height growth. It is suggested that one such thinning at 6-10 years after coppicing, could be justified to increase the dimensions of the final crop, and thereby increase its value.

One further problem encountered in recent coppice working is that deer populations (muntjac and roe) are considerably higher than earlier in this century. In many cases coppice regrowth has been almost entirely prevented by deer browsing. In areas with slightly lower populations browsing is confined to the more palatable species: ash, lime and field maple. The less palatable hazel often increases at the expence of these species, resulting in a coppice, which is not only less productive than previous species, but is also of very much lower conservation value: the very tree species that the coppicing was intended to preserve are lost.

7.1 Yield and Profitability

Considering the large areas that were managed on coppice and coppice with standards systems, there is surprisingly little information on the yields obtained. Jeffers *et al*. (1956) measured six plots of hazel coppice, and predicted standing volumes of 20-40m^3/ha at age 20 or mean annual increments of 1-2 m^3/ha. Begley and Coates (1961) describe a preliminary study which suggested that yields for simple coppice of sycamore, ash, lime, birch, oak and alder were all similar, with mean annual increments of 3-5 to 4.5 m^3/ha (20-30 year cycle). Begley (1955) suggested the mean annual increment of sweet chestnut coppice, on a 15-20 year cycle, is normally in the range 3-7 m^3/ha, although yields obtained in France are apparently somewhat higher: 5.5 - 11.5 m^3/ha (de Champs 1972). The growth of the standards has similarly been little studied, except for oak, where Jobling & Pearce's (1977) free growth model will be reasonably applicable. However, the effect of standards on the growth of the underwood has not been studied; Troup suggests that if there are more than 100 standards per hectare, of all ages, then coppice yields will begin to drop significantly.

A discounted cash flow for oak standards over hazel coppice is given in Table 9. This assumes that the mixed hazel coppice stools are alreaady present, and that approximately 120 standards are planted, in individual shelters. These are subsequently freed, and then reduced to about 60 per hectare and managed according to the free growth regime. Coppice is cut on a 20 year cycle, giving a mixture of thatching spars, bean poles and firewood (£3/m^3 or £60-120/ha). Mean annual increment is assumed to be 2 m^3/ha initially, falling to 1 m^3/ha by the end of the rotation due to the increasing competition from the standards. This gives an net present value of only £540 per hectare, or £720 if tax relief can be obtained. Oak is in many ways an unsuitable standard, and trees with more apical dominance, a lighter canopy and a lower tendency to produce epicormic shoots would really be more suitable. Ash, lime or cherry would be appropriate, and Stewart (1980) makes the interesting suggestion of conifers, such as larch. Hazel is also the least desirable coppice species for modern markets (firewood, turnery, pulpwood), due to its low rate of growth, and small diameter. Species such as sycamore and lime, both of which show some shade tolerance, would be more appropriate. A second cash flow is therefore given in Table 10, intended to represent ash or cherry standards, over sycamore or lime coppice. The coppice cycle in this case is 25 years, and mean annual increments are initially 4 m^3/ha, falling to under two by the end of the rotation. Otherwise, the management and establishment costs and techniques are similar. The financial yield is considerably greater, £1380 with tax relief, and this increase compared with the oak/hazel is due mainly to the greater revenue from the coppice. An alternative management regime giving uneven-aged oak standards over hazel coppice is given in Pryor (1982).

The profitiability of simple coppice can be estimated more simply. It is assumed again that the stools are already present, but that £150 is spent after each felling in making-good any gaps by planting. A coppice cycle of 25 years, and mean annual increment of 4 m^3/ha would give 100 m^3/ha at each felling, which at £6/m^3 yields £600 per hectare every 25 years. This gives an net present value in perpetuity of approximately £460, which is reduced to £300 once an annual management cost of £5/ha is taken into account. A sweet chestnut coppice cut on a similar cycle would probably give net present value in perpetuity of about £850/ha. Considering the lack of capital expenditure needed, in both cases such management will be an attractive proposition to many owners.

The promotion of coppice to high forest, by 'storing-up' or 'balivage intensif' is an alternative management system for most species of coppice. The French have a major programme of conversion (Hubert 1978, Lanier 1978, Auclair 1982) but in Britain conversion has been effected predominantly through neglect. Cash flows presented in Pryor (1982) suggest that thinning and promotion of oak coppice to high forest is likely to be more profitable than coppicing.

7.2 Landscape and Nature Conservation

Coppice, and coppice with standards are now regarded to be the most desirable silvicultural treatment from the point of view of nature conservation. Firstly the alternation of light and dark phases, on a short cycle (7-30 years, rather than 50-150 for even-aged high forest) encourages a rich woodland flora. The dense thicket stage (at 3-10 years) is a good habitat for a wide variety of woodland birds, including nightingales. Coppice stools are often very old and derived directly from primary woodland; they thus reflect, to some extent, the species composition and genetic diversity of such primary woodland. The fact that only small parts of a given wood are cut annually ('cants') results in a mosaic or group structure, which gives good habitat diversity within a single wood. When standards are present,

Table 9.

DISCOUNTED CASH FLOW : COPPICE + STANDARDS : OAK / HAZEL

Operation	Year	Volume	Price	Value	Disc.val.
Plant stnds	0			-180	-180
Weeding yrs 0-4	2			-60	-60
Free stnds	10			-60	-40
Cut coppice	20	40	3	120	70
Prune stnds	30			-60	-20
Cut coppice	40	30	3	90	30
Prune stnds	50			-60	-10
Cut coppice	60	25	3	80	10
Cut coppice	80	20	3	60	10
Fell stnds 55cm	80	140	70	9800	920

Annual management cost = -8
Net benefit = 9090 Net disc. revenue = 490
Net present value in perpetuity = 540
N.P.V. with 60% tax relief = 720

Table 10.

DISCOUNTED CASH FLOW : COPPICE + STANDARDS : ASH / SYC

Operation	Year	Volume	Price	Value	Disc.val.
Plant stnds	0			-180	-180
Weeding yrs 0-4	2			-60	-60
Free stnds	10			-60	-40
Cut coppice	25	100	6	600	290
Prune stnds	30			-60	-20
Cut coppice	50	75	6	450	100
Cut coppice	75	45	4	180	20
Fell stnds 50cm	75	145	75	10880	1190

Annual management cost = -8
Net benefit = 11150 Net disc. revenue = 1060
Net present value in perpetuity = 1190
N.P.V. with 60% tax relief = 1380

they not only provide a second layer of canopy but also provide continuity of woodland conditions, particularly if they are uneven-aged.

However, it should be noted that many of these features are not essential attributes of the coppice system. Planted areas of a single species (which much of our sessile oak and hazel coppice is), is certainly not an ideal habitat for conservation especially if felled in large coupes. Similarly from a landscape point of view, a mosaic of small coppice cants is very attractive, but large areas of even-aged coppice thickets are very plain. Without the continuity of standards coppice can be even more undesirable in the landscape then the unpopular clear-fell system, as the bare-ground condition is repeated much more frequently than with a high forest rotation.

It is likely that coppicing can cause long-term soil degradation. Not only are large quantities of nutrient rich bark being removed, but also the bare-ground state, with accompanied leaching and acidification, occurs much more regularly than with high forest systems. Evans (personal communication) found much of the sessile oak coppice of south-west England to have reduced soil phosphate levels, which is probably due to a combination of nutrient removal (tan-barking) and leaching. Standards would reduce the leaching, but not the removal in bark.

Finally, Peterken (1981, p. 284-5) and Rackham (1980) both make strong cases for the retention of coppice and coppice with standards on the grounds that it is the traditional management for many of our woodlands.

8. CONCLUSIONS

It is not possible, nor desirable, to pick out any one system and conclude that it provides the best combination of production and conservation. Each system will be applicable to different situations and management objectives. The aim of this review has simply been to bring out some of their attributes and to suggest potential applications.

One fact, however, is clear: that Britain is very short of working examples of all silvicultural systems apart from clear-felling. This is partly due to lack of consistent management even over short periods of time. There are too many woods, such as Parmoor and Cirencester, where change of management has meant that most of the examples and experience have been, or will be, lost. The Bradford estate at Tavistock, and Workman's estate at Ebworth are pleasing exceptions, where present management has been, and will be, sustained. Trials and demonstrations of such silvicultural systems should ideally be the responsibility of 'permanent' organisations.

Woodland management, largely irrespective of the silvicultural system employed, can be thought of as grading from 'intensive' through to 'extensive' or 'irregular'. The former implies careful and expensive tending of crops to produce valuable high quality timber. The latter implies a 'lower input' approach, accepting somewhat mixed and uneven-aged stands, and producing (cheaply) rather lower quality timber. Intensive managment is more normally associated with clear-fell and uniform shelterwood systems as practised on the Continent. The extensive approach is more appropriate to selection and group systems, which need careful, but not capital intensive, management to run well. The same distinctions could be made with regard to the strategy adopted in obtaining and using natural regeneration: a manager can either invest time and money, trying to get a full stocking from any one seed year (i.e. a shelterwood system with careful preparatory thinnings, cultivations and weed control); or he can operate a group or selection system, with minimal preparation for seed, but accepting and using the steady trickle which establishes itself largely unaided. Both approaches have their merits, and as the high profitability of the 'mixed birch' clear-fell system (Table 4) showed, the intensive 'high input' approach is not always the most profitable. The low-input approach is particularly appropriate to small woodland owners, who do not have large sums to invest.

One cannot help wondering if really good crops of oak and beech natural regeneration could be obtained in Britain by simply applying more intensive management. Too often, the use of natural regeneration is synonymous with 'laissez-faire' management. It should be noted that both the grant and fiscal incentives are aimed at high-input management, and there is very little financial aid available for less intensive management. Whether stands are planted or naturally regenerated, the less regular and intensive the management of a woodland, the higher its value for nature conservation, amenity and the landscape.

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APPENDIX 1

PROCEEDURES USED IN PREPARING THE ECONOMIC ANALYSES

Only a limited number of silvicultural options have been analysed in the text. The reader is referred to Pryor (1982) and Lorrain-Smith (1982) in which a wide range of silvicultural options are analysed, relating in some cases to particular 'case-study' woodlands. In this volume, the 'most likely' levels of the various factors affecting profitability have been assumed, whereas the earlier studies include several levels of most factors, allowing sensitivity analyses to be performed. The reader is also referred to Pryor (1982) for an explanation of discounting procedures and details of methods of calculation.

A wide variety of economic parameters can be calculated and used to compare investment options, but for simplicity, in the analyses performed here, only net present values (in perpetuity) have been calculated. Net benefit (i.e. total revenue less total cost) and net discounted revenue, for a single rotation, have also been presented. A single discount rate of 3 per cent has been used. The use of discounting and in particular, choice of discount rate, has been much debated by forestry economists (Price, 1976, Doran, 1979). Suffice to say that 3 per cent is a very frequently used rate, and it is the standard rate used by the Forestry Commission. Net present values (NPV) to infinity, or in perpetuity, were used as these allowed options of widely differing rotation lengths to be compared.

Both establishment costs and timber prices were largely based on those used by the Broadleaves Policy Review Group (Forestry Commission, 1984). Cost levels were taken as slightly less than the mean of the 'low' and 'high' levels given by the Forestry Commission, and even these means were considerably higher than those recorded by Dolan and Russell (1983) for broadleaved plantings on private estates. The costs used here include labour on-costs, but not forest management costs, which are applied separately as an annual cost. They are national average figures, so that it is not possible to say if they include, for example, fencing, but only that where fencing was necessary then it will have been included in the cost figures. There is a dearth of information on the value of hardwood timber, and the only up-to-date and comprehensive information is that presented by this Review Group. The 'high' price level 'good outurn' figures were used to construct price size curves from which prices for each thinning/felling were determined. Costs and prices for the French shelterwood cash flow were obtained from the Foret de Beleme directly; Buffet (1980) and Lanier (1982) also contained useful information on costs, and Hubert (1982) and Forestry Commission (1984) give timber prices for French oak. Additional information on costs and prices was gleaned from the various estates visited. Yields were largely derived from Forestry Commission models (Edwards & Christie, 1981); other sources are cited in the text.

Planting grants available from the Forestry Commission's Forestry Grant Scheme were included in the cash flows. The rate for woods over 10 ha was taken as being the most applicable. Tax advantages are often of greater significance than grants, and as the majority of woodland is established by owners assessed under 'Schedule D', then tax relief, at sixty per cent, on establishment costs and grant, has been taken into account in calculating the final net present value presented in each cash flow.

All the analyses were carried out using the utility program DATAB written by the author. All years are numbered from the year of planting or seeding; volumes are in cubic metres. All values are in 1983 pounds per hectare. The final column 'Disc. val.' is the discounted value, at 3 per cent, of the cost or revenue shown for that year. In the first column the mean diameter of each thinning or felling is given in centimetres.

Printed by **Print** *Parchment (Oxford) Ltd., 60 Hurst Street, Oxford*
From originals supplied by Publisher