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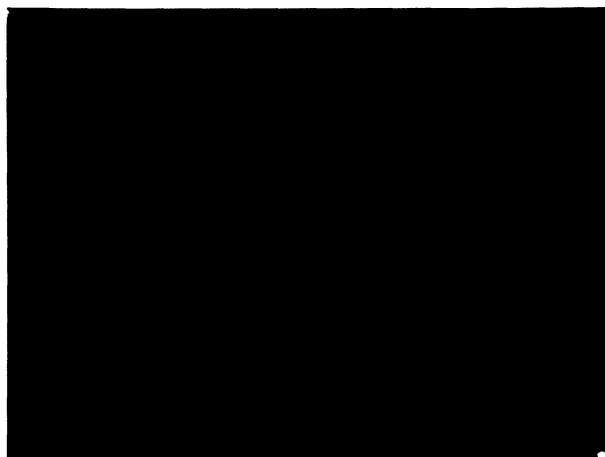
NO. 34

NATIONAL HARDWOODS PROGRAMME
REPORT OF THE SEVENTH MEETING
8 January 1987

edited by
P.S. Savill

1987

OXFORD FORESTRY INSTITUTE
Department of Plant Sciences
UNIVERSITY OF OXFORD



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ADVANCES IN TREE SHELTER RESEARCH AND DESIGN

MARK POTTER, Silviculturist, Forestry Commission

1986 has been a year of great activity in the tree shelter field, characterised mainly by a dramatic expansion in the market as shown by table 1:

Table 1: ESTIMATED USE OF TREE SHELTERS

Year	Cumulative Total
1979	80
1980	12,000
1981	112,000
1982	360,000
1983	860,000
1984	1,860,000
1985	3,400,000
1986	6,000,000

This accelerating interest can at least in part be explained by substantial improvements in shelter design as manufacturers have tackled, and possibly solved, the main problems that have become apparent in recent years. These problems concern:

1. Premature splitting of shelter material along corners. This has been tackled by improving material specifications and producing double-thickness tops.
2. Abrasion of stem at the rim of the shelter: tackled with fold-over tops and flared rims.
3. The worry that persistent wire ties might become embedded in the growing tree: tackled by the pre-placement of ties or nylon clips in the factory.

Probably the major remaining concern among tree shelter users is that of stake reliability. The strength of small dimension sawn softwood is very variable and a high proportion of breakages has sometimes occurred during erection, followed by poor reliability in subsequent years. It is clear that the minimum cross-sectional size for stakes being used on the most favourable sites should be 25 mm by 25 mm. Where the planting site is exposed, the ground stoney or hard, this specification should be increased to 35 mm by 35 mm or more. Where available, cleft chestnut can provide a durable and cost effective alternative.

The Forestry Commission has embarked on a project in conjunction with Imperial College, University of London, that will examine rates of decay in tree shelter stakes and, it is hoped, lead to recommendations on stake selection and treatment methods.

Recent research undertaken in several series of forest-based experiments has investigated in some detail the influence of the tree shelter environment on the growth of transplants. The first of these used shelters made of materials in a range of opacities such that light levels measured in the base of the shelters varied from 76 per cent down to approximately 1 per cent of the levels outside the shelters. Some of the results from one of these experiments are summarised graphically in Figs 1, 2 and 3, where it can be seen that height growth in two light-demanding species, ash and oak, continues to increase with decreasing light levels up to the treatment in which 86 per cent of light was intercepted. Rapid decline was apparent thereafter. Stem diameter begins to decline much earlier than this, suggesting a degree of etiolation when more than around 55 per cent of light is intercepted. Beech, a very shade tolerant species, shows a more or less steady reduction in terms of both growth parameters as light levels decrease.

The success of tree shelters might be better evaluated in terms of the survival of trees planted inside them. From Fig 3 it can be seen that survival in ash and oak was not affected by available light until the most extreme treatment, whereas beech declined rapidly when light interception exceeded 55 per cent.

A second series of experiments compared growth of the same species in shelters made from material in a kaleidoscopic array of colours of narrow wavelength bands distributed through the visible spectrum (see Table 2). The only significant increase in any parameter of growth compared with that of the white shelter control occurred with ash height increment in the green and yellow-green shelters; diameter increment in this species is correspondingly reduced in these treatments so it can be assumed that the extra height growth is due to etiolation.

The chlorophyll absorption spectrum peaks in the blue/violet region and again around red/orange. Between these peaks of activity there is a trough of inactivity through the various shades of green. Although interactions between biological processes may complicate the picture, it can be summarised that all species generally grew well when receiving light readily absorbed by chlorophyll; diameter increments were depressed when the plant received only green light.

The intensity of colouring used in the commercially produced tree shelters is thought to be unlikely to affect the growth of young trees and this was tested in a series of experiments that examined growth in the full range of available colours and shades. No significant differences in the growth rates of ash, oak and beech were detected in any of the experiments.

It is planned that future research will continue to examine the nature of the 'tree shelter response' and to investigate problems as they arise. One of current concern relates to the unpredictable performance of beech in shelters.

When the results with a range of over 40 species were reported (Evans and Shanks, 1985) we were confident enough about the behaviour of beech to categorise it with the best responders: that is to say height increment could be expected to be more than doubled in the first two or three years after planting. The worst results achieved in species trials were recorded at Exeter where the mean height increment of beech in shelters after three years was only 80 per cent better than that of the netguard controls.

I have, however, received an increasing number of reports of beech faring badly in shelters and there appears to be some link, though not a definite one, with wet summers and the wetter west of the country. Nonetheless, the cause may be more complex and it is interesting to note that among the conifers tested only Tsuga heterophylla and Abies procera, both very shade tolerant, have not performed well. Research in progress is investigating the effects of high humidity and aphid populations on the growth of beech in shelters, but no meaningful results have been obtained so far.

One thing I have realised from examining the results of experiments is that they often contradict statements I hear made concerning tree shelters. As with many exciting new developments tree shelters have attracted their fanatical supporters, who are apparently prepared to ascribe near-magical powers to these plastic tubes, and their detractors, who can see no place for such a 'gimmick' in British forestry. The reality of course lies somewhere between these two poles. I would therefore like to take this opportunity to tidy up what I see as a few misconceptions.

The most frequently reproduced data concerning the growth of trees in shelters are taken from the longest established experiment, planted in 1979. Graphs of height growth show the sheltered trees having a striking advantage over the controls for the first three years. However, their height increment during the 4th growing season shows a marked decline and is noticeably less than that of the control trees in the same year. This is usually explained in terms of the plant devoting its resources to crown development and diameter growth, and is often considered inevitable. A more important factor is probably the climatic damage these trees suffered during the spring of that growing season. The height growth of sheltered trees has also been arrested elsewhere when no physical damage has been incurred but this can often be explained by a combination of poor apical dominance, species not suited to site and inadequate weed control. Given suitable conditions and reasonable management, sheltered trees will maintain their advantage over conventionally protected plants.

The enhanced height growth means that stem form is very distorted in the first few years after planting and this has given rise to a number of worries concerning strength and stability. It is certainly true that many sheltered trees would not be able to support themselves if the plastic tubes were taken away within two or three years of planting. However, a reliable make of shelter will last at least 5 years, by which time almost all trees would have emerged for long enough to have acquired sufficient girth to ensure stability.

Some excavations of experiments have shown reduced root development in sheltered trees (e.g. Rendle, 1985) but this result is not universal, and has occasionally been contradicted. It is, perhaps, more important to note that even where the root/shoot ratio initially appears to be very imbalanced the proportions are seen to revert towards normal rapidly in the 2nd and 3rd growing seasons.

CONCLUSIONS

This is a paper of divergent themes rather than one focussing in on a definite end point. Nonetheless there seems to be a common thread running through the various points discussed and this perhaps can be summarised as follows:

1. Tree shelters and tree shelter designs are getting better.
2. Our understanding of the effects of tree shelters is improving.

3. The problems with shelters are being tackled and the results are encouraging.

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TREE BIOTECHNOLOGY AND THE FUTURE POTENTIAL APPLICATIONS OF CLONAL FORESTRY

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Unlike crop plants forest trees are not amenable to conventional breeding techniques. There remains considerable potential for increasing the genetic quality of forest trees. Over the last 10-15 years a number of new techniques have been developed which involve the manipulation of plant cells, tissues and organs under aseptic conditions on defined nutrient media. Known collectively as biotechnology, such techniques have been applied to the propagation and genetic manipulation of a wide range of crop species. More recently there has been considerable interest in the application of biotechnology to the improvement of forest trees.

Possibly the most direct way in which biotechnology may be applied to forestry will be in the use of micropropagation. Micropropagation is the clonal multiplication of plants under aseptic conditions in vitro, and can be considered as an extension of conventional vegetative propagation techniques. Micropropagation, however, has the advantage that it is considerably faster, and requires less space than conventional techniques (Murashige, 1974). Micropropagation might be useful in a number of different circumstances:

- a) In some cases forest tree species produce insufficient seed to satisfy the demand, or seed storage problems result in a shortage of viable seed.
- b) The demand for seed produced from seed orchards usually exceeds the supply.
- c) Micropropagation may be particularly useful if selected elite trees can be propagated.
- d) Micropropagation is essential if other new techniques are to be applied to forest trees. Any genetically superior material from somaclonal variation, somatic hybridisation or transformation experiments would need to be multiplied by micropropagation for it to be used.

Micropropagation can be considered as having three stages:

- 1. The selection of plant material, removal of suitable explants and their initiation in vitro.
- 2. The proliferation of shoots on a multiplication medium.
- 3. Transfer of the shoots to a rooting medium, and hardening of the shoots facilitating transfer to and establishment in the field.

Each stage will be considered in detail.

1. Initiation

There is an obvious need to select carefully any plant material which is to be micropropagated. In the case of multiplying seedlings, the seed should be collected from elite trees, or seed orchards. Similarly careful selection of elite trees is essential when mature trees are to be micropropagated. Care must also be taken to avoid culturing any diseased plant material. For example tests may need to be developed to detect any latent viral infections.

Whenever possible the growth conditions of the plant material to be cultured must be optimised, since the physiological status of the donor plant affects the success of subsequent in vitro manipulations. When material collected from the field is to be used, a major problem is the successful surface sterilisation of the plant material. Fungal spores can be protected from commonly used surface sterilants between the bud scales. Some bacterial infections exist within the plant tissues, and are therefore difficult to eradicate.

Depending on the micropropagation technique to be used, shoots from seedlings or mature tree would initially be established as shoot cultures, or be placed directly onto a multiplication medium.

2. Multiplication

Multiplication of plants in vitro can be brought about in a number of different ways. Perhaps the simplest and most widely used technique involves the release of apical dominance, permitting the growth of axillary shoots. Although the control of apical dominance is thought to involve a number of plant growth regulators, in many species the growth of axillary shoots is controlled by the supply of cytokinin. Shoots grown on a culture medium containing a supply of cytokinin undergo extensive branching as the axillary buds are released from apical dominance. This leads to a proliferating cluster of shoots. These shoots can be further multiplied following transfer to fresh multiplication medium. With a conservative multiplication rate of only 7 shoots on a 6 week sub-culture cycle, a theoretical clonal multiplication rate in excess of 5 million plants per year can be achieved from a single seedling.

Not all species can be propagated in this way. A number of other techniques are available. In some species adventitious shoots can be recovered. Adventitious shoots are stem and leaf structures arising from plant tissues located in sites other than the normal axillary shoot regions. Adventitious shoots can be induced in vitro by appropriate manipulation of the balance of plant growth regulators in the culture medium.

By further altering the balance of plant growth regulators in the culture medium, plant cells can be induced to grow and proliferate in a disorganised fashion, giving rise to a mass of callus tissue. Very large amounts of callus tissue can be grown on solid media, or suspended in liquid culture medium in large flasks. Small lumps of callus tissue, or clumps of cells from cell suspensions, will regenerate shoots when placed onto a shoot initiation medium permitting rapid multiplication.

It has, however, been found that the growth of cells in a disorganised callus tissue is associated with genetic changes which can result in considerable variation arising among plants propagated in this way (Bayliss, 1980). Such variation would probably be unacceptable for micropropagation purposes.

One possible way of overcoming the problem of variability among plants regenerated from callus cultures exploits the observed uniformity among plants regenerated from embryogenic cell cultures. Rather than growing in a disorganised fashion the cells proliferate as a mass of pro embryos. The pro embryonic tissue is capable of giving rise to perfectly formed somatic embryos, and ultimately normal plants. Somatic embryogenesis also eliminates the need to transfer shoots to a separate rooting medium. While somatic embryogenesis has so far only been reported for a small number of angiosperm forest trees (including poplar), it is of particular interest since techniques are being developed whereby somatic embryos can be encapsulated in a protective matrix forming an artificial seed. Such developments may, in the future, allow micropropagation to be highly mechanised substantially reducing productive costs (Redenbaugh et al. 1986).

3. Establishment

Where shoot proliferation has been used for the multiplication stage, the shoot must be transferred to a rooting medium, frequently the same culture medium as used for multiplication of the shoots, but with the omission of cytokinin, and possibly with the addition of a low level of auxin.

Tissue culture-derived plants initially have a much reduced cuticle as a consequence of the high humidity found in vitro. Plants directly transferred from tissue culture into the field would rapidly become dessicated. Micropropagation material must therefore be hardened before transfer to field conditions and this is usually accomplished in a mist or fog humidified greenhouse. Such facilities allow a high success rate in transferring and establishing micropropagated plants in the field.

A number of problems are associated with micropropagation. These can be considered to be either technical or financial.

a) Technical problems

Some of the technical problems have already been mentioned. For example initiating contamination-free cultures can be extremely difficult especially when field grown plant material is to be used. A number of bacteria can survive the initial surface sterilisation procedure, and persist often reducing the vigour of the cultures. As the cultures are routinely subdivided the bacteria may remain undetected, spreading, and may result in the ultimate loss of a batch of cultures. Bacterial contamination can however be controlled using a range of bacteriacidal antibiotics which have limited toxicity to plant cells (Young et al. 1984).

Another problem particularly associated with micropropagation of woody species is the accumulation of phenolic compounds, the oxidation products of which inhibit growth during the initiation phase. Such compounds can be leached out of newly excised explants prior to culture. Alternatively activated charcoal or P V P (polyvinyl pyrrolidone) can be incorporated into the culture medium, and prevent inhibition of growth by absorbing the phenolic compounds.

Most tree species show two distinct growth phases. The juvenile growth phase is characterised by rapid vegetative growth but no floral development. This is followed by a gradual transition to the mature growth phase characterised by less vigorous vegetative growth and floral development. Conventional vegetative propagation techniques usually employ juvenile shoots, or specifically more juvenile parts of mature trees, such as suckers, stump shoots or epicormic shoots. This is necessary because of the observed sharp decline in rooting ability in particular, and propagation success in general,

with increasing physiological age of the plant material. Similarly the success of micropropagation tends to decline with increasing physiological age of the plant material.

There are, however, a number of reports which suggest that micropropagation and other tissue culture manipulations might actually be useful in achieving rejuvenation of shoots from mature trees. Once established, shoot cultures from mature trees become increasingly easy to maintain and multiply. For example, micropropagation of black cherry (Prunus serotina) has been achieved having initiated and maintained shoot cultures, whereas conventional vegetative propagation techniques failed due to a lack of rooting response (Tricoli et al. 1986). Rejuvenation may also be achieved by regenerating shoots from callus initiated from mature tissues. In English ivy (Hedera helix) regeneration from callus tissue initiated from physiologically mature tissues gave rise to shoots which were morphologically determined to be juvenile (Banks, 1978).

The ability to rejuvenate tissues is of particular interest when considering multiplication of selected elite trees by micropropagation.

b) Financial problems

Little information is available about the relative costs of conventional propagation and micropropagation. Clearly the micropropagation production costs must be kept as low as possible. A major factor in the cost of production is the simplicity of the production techniques. Around 60-80 per cent of the total micropropagation cost is taken up by labour. Any procedure which requires a large number of individual steps must be avoided. For example, multiplying plants via a callus initiation, callus multiplication, shoot regeneration and shoot rooting protocol requires considerably more effort than a semi automated process involving the recovery of somatic embryos from embryogenic cell suspensions. Combining several steps in the micropropagation protocol also reduces the production costs. Micropropagated birch shoots do not require to be rooted before transfer to a mist humidifier in the greenhouse, enabling root initiation and hardening of the shoots to be combined and therefore simplified.

While production costs must be kept to a minimum, there is a limit to economies which can be made in this way. Another way to offset the production costs is to increase the value of shoots obtained from micropropagation. An example of this is the clonal multiplication of radiata pine (Pinus radiata) seed from seed orchards in New Zealand. The cost of micropropagated planting stock is ten times greater than similar material produced using commercially available seed. The micropropagated material is however genetically superior, giving on average a 38 per cent increase in volume production over commercially available seed controls. In addition, less planting stock is required since the growth characteristics of the clonal material are known to be more reliable than is the case for commercial seed. The increased production costs are more than compensated for by increases in yield (Smith, 1986).

Naturally occurring variation may be exploited using micropropagation to clonally multiply elite trees. Improvements in yield may also be achieved using seed from carefully selected seed orchards multiplied by micropropagation. Micropropagation will also play an essential role if other aspects of biotechnology are to be applied to forest tree species. A number of techniques are available which allow us to genetically manipulate forest tree species. Such techniques include somaclonal variation, somatic hybridisation and transformation, each of which will be briefly described.

a) Somaclonal variation

The observation that plants regenerated from disorganised callus tissue frequently vary from the plant from which the callus tissue was initiated excludes the use of callus tissue in micropropagation. Such somaclonal variation does not necessarily result in the regenerated plants being less desirable. A number of somaclonal variants have been regenerated which vary for economically significant traits, such as increases in yield, increased disease resistance and tolerance to physiological stress (Larkin and Scowcroft, 1981). Somaclonal variation is the result of genetic changes which occur while the cells are growing as a disorganised callus tissue, or may be the result of variation among the cell population of the original explant. The genetic changes vary from gross changes in ploidy, to cryptic rearrangements, and single gene mutations. Somaclonal variation is useful in introducing a new source of variation to breeding programs. In the context of forestry, it is conceivable that small genetic changes could be introduced into commercially desirable clones multiplied by micropropagation.

b) Somatic hybridisation

Plant cells can be stripped of their cell wall, and free protoplasts isolated in this way can be cultured in vitro. Protoplasts from a wide range of plant species can be induced to regenerate a cell wall, begin to divide and can ultimately give rise to normal fertile plants (Davey, 1983). Plant protoplasts can also be induced to fuse together. Heterokaryons formed by fusing protoplasts of different species may also be capable of cell wall synthesis, division and the regeneration of novel somatic hybrid plants. Potentially somatic hybridisation could be used to break down existing incompatibility barriers enabling plant breeders to introduce a much wider range of alien genes into crop plants (Pental and Cocking, 1985). Protoplast fusion also results in unique combinations of nuclear and organelle genomes. The chloroplast and mitochondrial genomes may well carry a number of economically important traits, and are known to be involved in male sterility and herbicide resistance.

Protoplast fusion can also be attempted when one of the fusion partners has been partially inactivated in such a way as to limit the extent of the transfer of genetic information from the inactivated protoplast. Thus partial hybrids may be formed in which only a few alien genes may have been introduced into the plant of interest. Such limited gene transfers will be significant where single gene characters such as herbicide resistance are being transferred from species to species.

c) Transformation

Somaclonal variation and somatic hybridisation have limits in terms of their usefulness since in both cases most of the variation obtained would be random. The plant material generated would need to be grown and screened for desirable characteristics. Transformation permits a much more direct manipulation of the genome. Transformation techniques permit single genes to be isolated and inserted into the genome of the target species. The most successful transformation system currently in use exploits the natural ability of Agrobacterium tumefaciens - a soil born bacterium - to insert functional genes from its own Ti plasmid into the chromosomes of plant cells. Combining modified Agrobacterium based Ti plasmid gene vectors with efficient tissue culture techniques has enabled plants to be recovered with express novel genes of foreign origin. In the case of forest trees, poplar has been transformed using the Ti plasmid. A gene for resistance to the herbicide glyphosate has been isolated from bacteria, inserted into the Ti plasmid and transferred to poplar. The poplar plants have a level of resistance to

glyphosate close to that which is necessary for protection against this herbicide in the field (Fillatti et al. 1987).

In the future it would seem likely that as our understanding of the organisation and expression of the genome advances, so too will our ability to genetically manipulate plant cells. Such advances, coupled with efficient micropropagation techniques will ultimately lead to significant quantitative and qualitative improvements in forest tree species.

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THE RELATIVE ECONOMICS OF DIFFERENT SILVICULTURAL SYSTEMS

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Introduction

This paper covers some of the research carried out at the Oxford Forestry Institute, as part of a project funded by the Energy Technology Division of the Atomic Energy Research Establishment. The work is concerned with the management of existing woodlands for the optimised production of fuelwood and timber under differing silvicultural regimes (Crockford, Corbyn and Savill, 1987).

The priorities and objectives of woodland management for the private owner may vary considerably. They can range from maximisation of timber production or returns on investment, to low intensity management for conservation and amenity.

The financial viability of woodland management systems is conventionally assessed by considering the return on investment at an appropriate real discount rate. A discounted monetary value expresses the current value of a future cost or revenue. Foresters use this technique because, unlike many other forms of investment, forestry has very long periods of time between the investment of capital and the generation of a return. Individual woodland and estate owners, when considering the profitability of alternative management strategies, do not usually apply discounting techniques as such, often being more concerned with the maintenance of a positive net periodic revenue from their land as a whole. But the concept of discounting, however, is often used on an intuitive basis in that immediate costs are given far greater consideration than revenues in the future.

The economic analyses were based on the methods of an earlier study carried out for the Nature Conservancy Council on the economics of silvicultural options for broadleaved woodlands (Pryor 1982). Discounting techniques are used when assessing the profitability of a long-term investment and they were used in our research to compare the profitabilities of a range of woodland management options. In order to compare the profitabilities of silvicultural systems of differing rotation lengths, Net Discounted Revenues alone are inadequate and to account for this, Land Expectation Values (LEV's) are used. Land Expectation Values convert Net Discounted Revenues onto an infinite time scale by consideration of an infinite number of rotations. The use of this technique allows comparison of the profitability of a wide range of management alternatives because they are then compared over the same period of time.

The appropriate discount rate to use has always been a subject of considerable controversy. The Government's test discount rate is 5 per cent although the Forestry Commission's 'productive' plantations have, in the past, only been required to make a profit at 3 per cent. In contrast a discount rate of only 1 per cent is used in the harsh environment of Sweden. High discount rates favour shorter rotations and consequently conifers over broadleaved species. The discount rate used to test the profitability depends largely on the objectives of woodland management. For an owner largely concerned with amenity and conservation a stringent economic test is inappropriate and may only expect a return of 1 or 2 per cent. An owner more interested on returns on investment may select a 5 per cent discount rate and expect positive LEV's.

We have considered 18 management systems, shown in Table 1, ranging from intensive management of pure conifer species, through mixtures of broadleaves and conifers to low cost, low management intensity options involving natural regeneration or coppicing. Land Expectation Values were considered for all options at discount rates of 0, 2, 3, 4 and 5 per cent.

Profitabilities of management systems can be extremely variable, largely due to the following factors:

- i) Site quality in terms of soil and climate. This is readily reflected by the yield class of the species considered.
- ii) Choice of species suitable for the site.
- iii) Silvicultural system of management.
- iv) Prices for the sale of timber and fuelwood which can vary considerably on a local scale.
- v) Establishment and maintenance costs can be very variable, especially fencing.
- vi) Planting grants. FGS/BWGS (including natural regeneration).
- vii) Income tax rate, and the taxation schedule for purposes of tax relief. Schedules D and B.
- viii) Sporting rentals, which will be greatly influenced by the surroundings of the woodland.

and

- ix) Discount rate (0, 2, 3, 4 or 5 per cent in this study).

A computer program was developed to allow the calculation of the effects of any of the possible combinations of variables. Rapid calculation of LEV's enables a woodland owner to compare different strategies in a minimum of time thus comparing the profitabilities of alternative management options, closely matched to the circumstances of the owner.

Plantation Economics

The planting of conifers and broadleaves, either pure or in mixtures is the most common form of woodland establishment in this country. Pure conifer plantations are generally the most profitable options. Corsican pine, for example, has Land Expectation Values which are positive at a 3 per cent discount rate in most situations. At a 5 per cent discount rate the lower yielding crops can often make a loss. Corsican pine is generally a profitable option, providing establishment is successful, because of the consistent demand for its timber. Pure broadleaf plantings such as beech, however, rarely make a profit at 5 per cent and only under the favourable conditions of planting grants and tax relief will a positive return be made at 3 per cent. Mixtures of conifers and broadleaves such as Corsican pine/beech, have the advantage of earlier returns and a final crop which is broadleaved. Mixtures can usually make a profit at a 3 per cent discount rate, but at 5 per cent Land Expectation Values will only be positive with high yielding crops under the most favourable tax and grant situations. Similarly plantations of pure broadleaves can be far more profitable if early maturing species such as ash or cherry are included. A mixture of oak, ash and cherry can usually make a 3 per cent return on the investment, especially

Table 1 Summary showing LEV's (in £ at 1986 values) at 3 per cent discount rate for each option under mean yield and price levels

Option		YC	Tax Schedule B - Grants	Tax Schedule B + Grants	Tax Schedule D/B at 60% + Grants
Land expectation values at 3% in £/ha					
1.	Douglas fir	14	2150	2430	3640
2.	Corsican pine	12	1590	1870	2910
3.	Japanese larch	10	1400	1710	2690
4.	Sitka spruce	12	1550	1830	2830
5.	Douglas fir/oak mixture	14/5	930	1270	2100
6.	Oak	5	-660	- 80	590
7.	Corsican pine/beech mixture	12/6	540	900	1850
8.	Beech	6	-670	- 70	830
9.	i) Oak/ash/cherry mixture	5/6/8	- 60	520	1240
	ii) 30 year conversion to oak/ash/cherry	5/6/8	-130	520	880
10.	Coppice-with-standards	medium	380	-	1110
11.	Underplant with western red cedar	14	2300	2570	(3070)
12.	i) Convert to pure oak coppice	4.5	700	-	-
	ii) 30 year conversion to oak coppice	4.5	375	-	-
13.	Oak/ash group felling system	5/6	150	930	-
14.	Beech - natural regeneration	6	30	610	(1080)
15.	Planting simple coppice	5.5	-360	210	640
16.	Convert to simple coppice	5.5	1030	-	-
17.	Birch - natural regeneration	6	290	980	-
18.	Ash/sycamore - shelterwood system	6	820	1430	(1760)

Notes

1. Blanks signify situations in which grants and/or tax relief may not be available or suitable. 2. Brackets surround values where tax relief from schedule D may not be desirable due to other revenues being earned such as the removal of residual canopy. 3. Medium yield class for coppice-with-standards refers to a coppice yielding 5 m³/ha/yr declining as standards increase in size and average site quality for the oak standards.

if the full advantages of registration under the Broadleaf Woodland Grant Scheme and income tax relief on establishment costs under schedule D are obtained. The LEV's for the four plantation types described above are illustrated in Fig. 1.

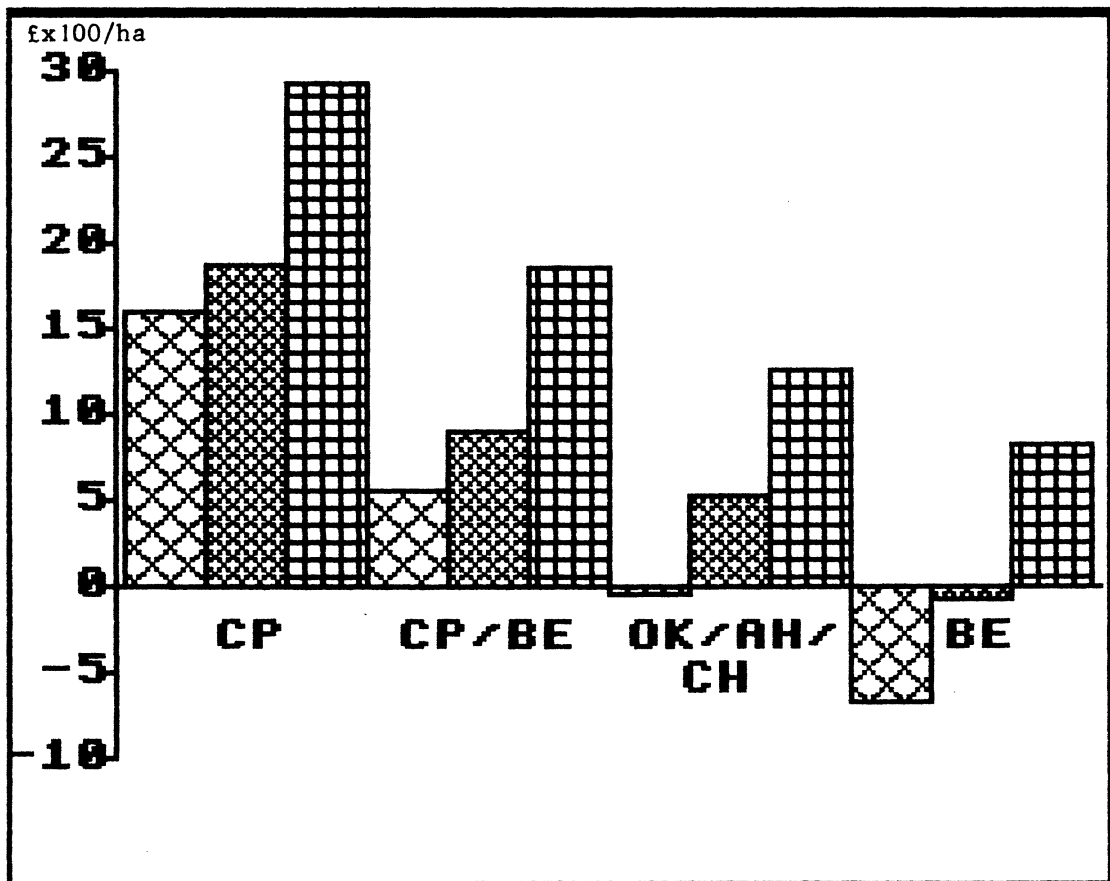


Fig 1 Land expectation values for four plantation options at 3 per cent discount rate, assuming average prices and yields. Three levels are presented: i) without grants or tax relief, ii) grants alone included, and iii) grants and tax relief included at 60 per cent.

Value of Produce

It is obvious that the prices obtained for timber and fuelwood strongly influence the profitability of woodland management. In our work we have tried to cover the range of prices for fuelwood and timber. Prices for both vary quite markedly from one region of Britain to another. For example central Wales has a large potential fuelwood supply, but demand is low and it is generally unprofitable to collect, convert and sell in the small quantities required by domestic users.

Five price combinations of fuelwood and timber values were considered and are shown in Table 2 for oak and Sitka spruce. This illustrates the influence that revenues from fuelwood can have on the profitability of oak plantations but also potentially for Sitka spruce if circumstances occur where fuelwood prices are high.

Table 2

Effects of timber and fuelwood prices on the Land Expectation Values of oak and Sitka spruce plantations (in £ at 1986 values)

a. Oak - YC 5

Timber Prices	Fuel Prices		
	Low	Medium	High
Oak - LEV (£/ha at 3%)			
Low	20	-	620
Medium	-	590	-
High	770	-	1220

b. Sitka Spruce - YC 12

Sitka Spruce - LEV (£/ha at 3%)			
Low	1350	-	2660
Medium	-	2830	-
High	3350	-	4060

Taxation and Grants

Planting grants, and tax relief on expenditure, have dramatic effects on the profitability of a woodland management system. The recent introduction of the Broadleaf Woodland Grant Scheme has encouraged far more planting of broadleaved species, illustrated in Fig. 2 is the situation for beech. Beech plantations will rarely be profitable at a 3 per cent discount rate unless aided by grants and tax relief.

Planting grants are helpful in covering the initial establishment costs, but it is tax relief on expenditure that can have by far the greatest effect on profitability.

The obvious implication of this is that woodland owners in the high taxation bracket obtain far greater tax relief on expenditure (under schedule D) than do owners with lower incomes. In general terms forestry is a more profitable investment if you are rich. Woodland owners on lower incomes, such as many farmers, have less resources available for harvesting and primary processing of produce. This, coupled with the frequent marketing difficulties of small scale forestry, makes the planting of new crops relatively unattractive. Economies of scale work against the small woodland ownerships; if the management of such woodlands is to be encouraged, some form of incentive is needed to help bridge the income gap between establishment and first revenues. This incentive would ideally take the form of an annual management grant, which would assist in maintaining a positive cash flow throughout the rotation and ensuring that good management is continued after establishment. This form of grant aiding has been suggested by various bodies (Denne, Brown and Abel 1986; NFU 1986).

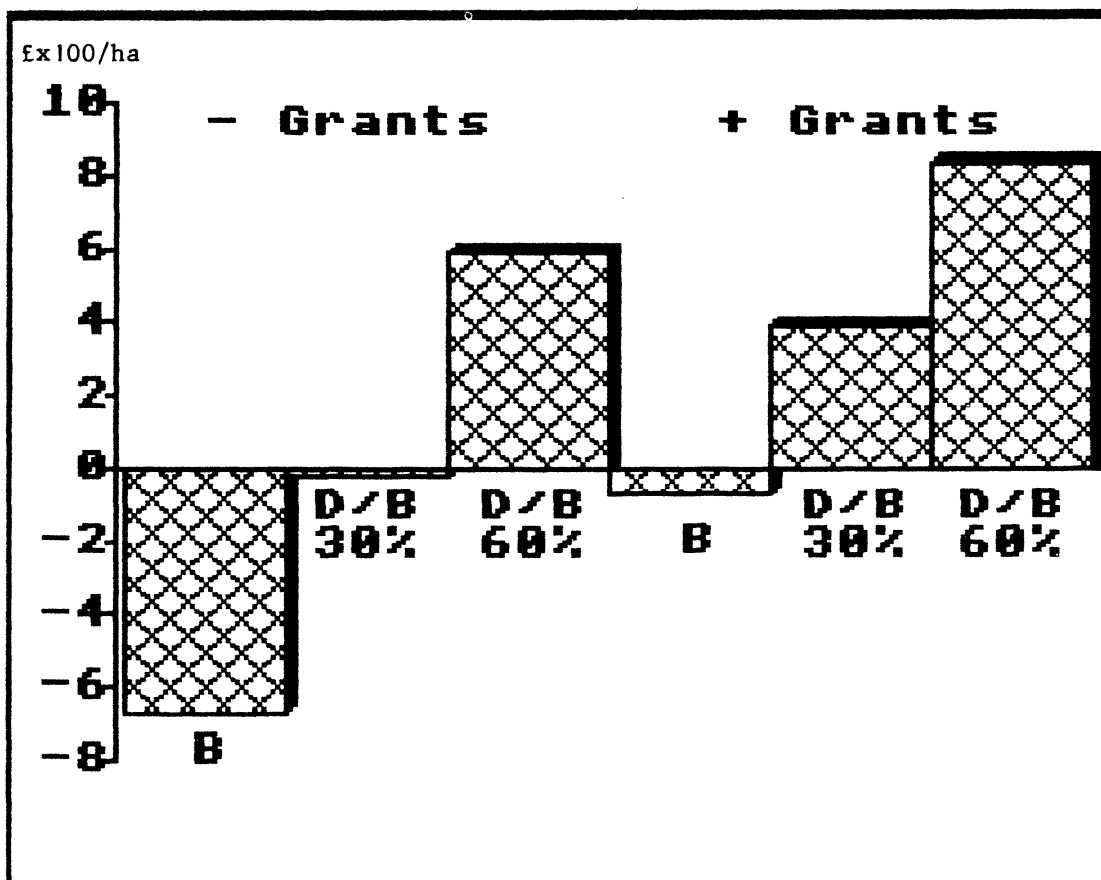


Fig 2 Effects of tax relief and planting grants on the land expectation values of beech plantations at 3 per cent discount rate. Two groups are presented of with or without planting grants, three levels are expressed within each of income tax assessed under i) schedule B for entire rotation; ii) schedule D switching to B before first rotation at a tax rate of 30 per cent or iii) at 60 per cent.

The introduction of the Broadleaved Woodland Grant Scheme, which offers a higher grant rate than the older Forestry Grant Scheme, does improve the profitability of broadleaved systems. For example, a group felling system for oak and ash, involving planting small groups of about 0.5 ha and accepting natural regeneration can be reasonably profitable at a 3 per cent discount rate due to the high level of planting grants.

Low Cost Silvicultural Systems

Without the benefits of tax relief on establishment costs and planting grants, many of the low cost options involving natural regeneration or coppicing are inherently more profitable than the higher cost plantation systems. This is illustrated in Table 3 for beech established by natural regeneration rather than planting. The assumption made is that 60 per cent of the stocking is provided by natural regeneration with the remainder planted with native hardwood whips. Without tax relief on expenditure the natural regeneration option attains a higher LEV irrespective of the inclusion of planting grants. The retention of part of the canopy during the regeneration phase, and its subsequent felling after satisfactory establishment will generate additional felling revenues (not included in the analysis). Consequently registration for taxation under schedule D is unlikely to be worthwhile. Unsuccessful attempts at establishment by natural regeneration however, can result in establishment costs which are equal if not greater than the costs for plantation establishment.

Table 3

Land Expectation Values at a discount rate of 3 per cent for beech established by planting or natural regeneration, and an ash/sycamore shelterwood system (in £ at 1986 values)

Grants:		+ Grants		- Grants	
Tax Schedule/Switch	B	D/B	D/B	D/B	D/B
Tax rate		30%	60%	30%	60%
Beech - Plantation	-70	390	830	-670	590
Natural Regeneration:					
i) Beech	610	-	-	30	-
ii) Ash/Sycamore	1430	-	-	820	-

Ash and sycamore regenerate freely in many areas and the encouragement of this by means of a shelterwood system (Pryor and Savill 1986), involving the gradual removal of the mature canopy, can be the most profitable broadleaf option especially if BWGS grants are obtained. This is despite tax relief usually not being available; again because felling the overstorey under schedule D is undesirable. This system is usually profitable at a discount rate of 3 per cent and also at 5 per cent for crops yielding at least 6 m³/ha/yr with planting grants.

The profitability of coppicing woodlands depends greatly on the value of fuelwood or other markets for small roundwood. As long as fuelwood prices are reasonable the management of existing coppice is usually profitable at the 5 per cent discount rate. This is due to the low level of costs involved in the management of existing coppice. LEV's, although positive, are rarely high. In contrast the establishment of a new coppice system can be very expensive and would either require planting grants and tax relief or very good prices for fuelwood to achieve a return of 3 per cent.

The effect of branchwood on profitability

The analyses described so far have all included additional revenues from the sale of lop and top (branchwood). In the example of coppice above we indicated the profitability of coppice management, which can be entirely dependant on the sale of wood for fuel. The revenues generated from the sale of lop and top can make significant contributions to the profitabilities of other silvicultural systems.

Potential fuelwood yields from forestry systems have been calculated in this study by the summation of branchwood and the volume of thinnings which command highest prices as fuelwood. The yields of branchwood as a proportion of total tree volume declines with age for conifers whereas the reverse is true for broadleaves. The volume of branchwood can consequently make up a significant proportion of total yield in the first thinning of coniferous species, and a large yield will also be produced in the final felling. The pattern of growth for broadleaved species is such that a small volume of branchwood is produced in the first thinning, but it steadily increases with age and large volumes are available at final felling age. Whereas branchwood yields can quite easily be estimated, the potential roundwood fuel yields from thinnings can be distinctly variable ranging from little or none to practically all of the thinning yield. The most important determining factor is the comparative prices of fuelwood and timber.

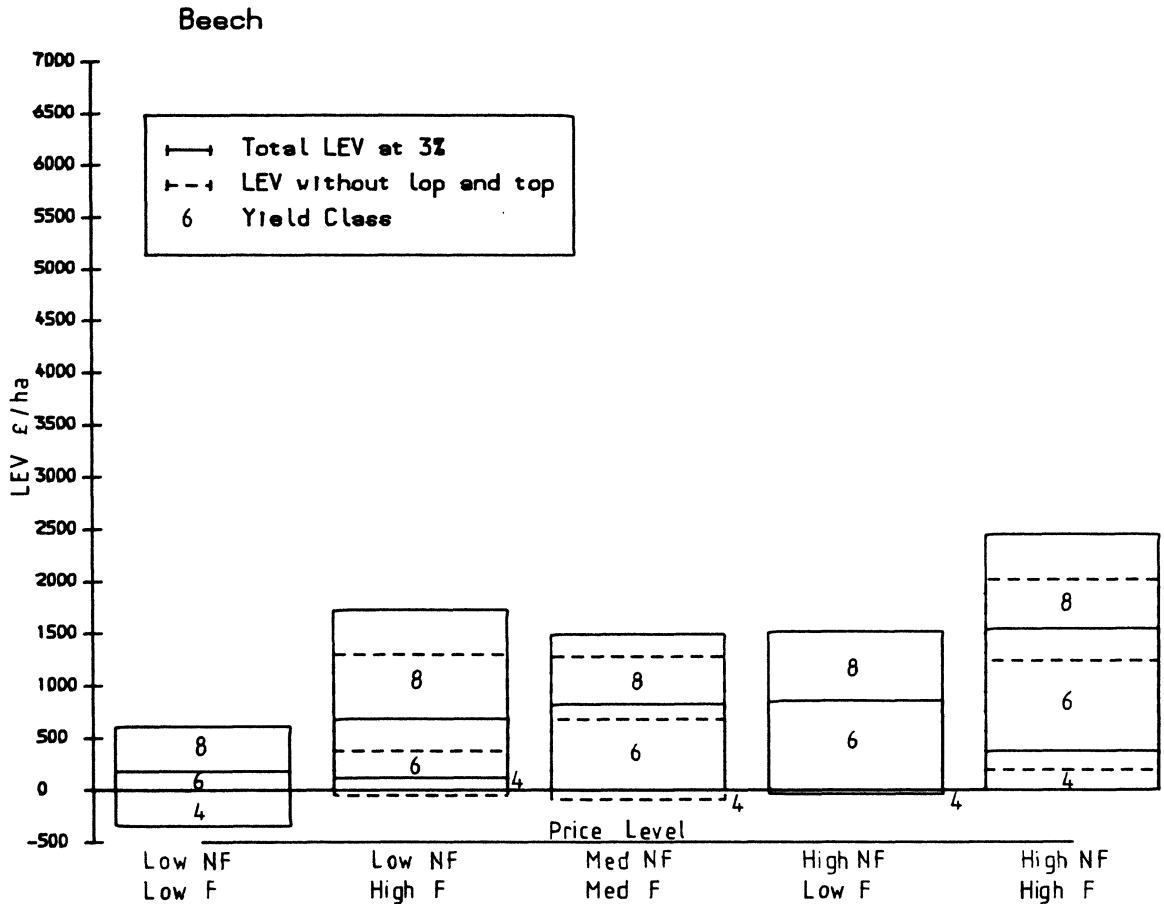


Fig 3 Land expectation values, at 3 per cent discount rate, for beech plantations at 3 yield classes and five price levels. The price level combinations refer to low, medium and high prices for timber (NF) and fuel (F) markets. LEV levels represented by broken lines show the profitability where lop and top is excluded from revenues.

The improvements to LEV's obtained through chipping branchwood for fuel is also determined by the relative prices of fuelwood and timber. The histogram in Fig. 3 shows LEV's for a beech plantation at a discount rate of 3 per cent for five different price combinations of fuelwood and timber. The values include planting grants at the lowest level and tax relief under schedule D (at 60 per cent) with a switch to schedule B before first thinning. The branchwood percentage is much higher for broadleaved crops and as initial LEV's are low, increases may be as great as 100 per cent, and can make the difference between a profit and loss at 3 per cent. In general, with lower fuelwood prices and higher yielding crops the proportional increase in LEV's will be reduced. The chipping of lop and top from pure broadleaves will increase LEV's in the order of 17 to 23 per cent for high and medium yielding crops at medium price levels for both fuelwood and timber.

Improvements to LEV's for pure conifer crops will be much lower (Fig. 4). Only in the unlikely situation of high prices for softwood fuel and low prices for timber will improvements reach 15 per cent.

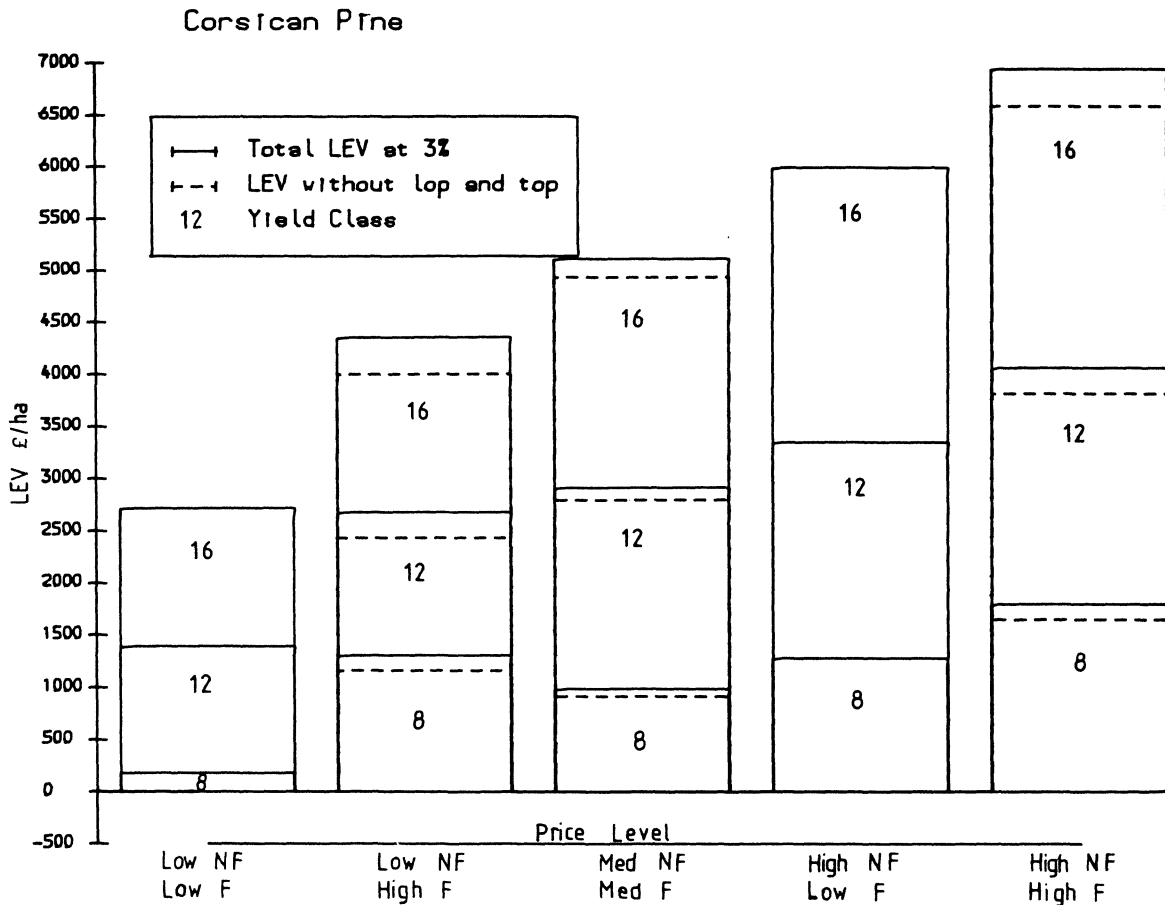


Fig 4 Land expectation values, at 3 per cent discount rate, for Corsican pine plantations at 3 yield classes and five price levels. The price level combinations refer to low, medium and high prices for timber (NF) and fuel (F) markets. LEV levels represented by broken lines show the profitability where lop and top is excluded from revenues.

Sporting Rental

Many woodlands owe their past and continued existence to their sporting value. Rentals for sporting can contribute significantly to the profitability of a management option. They commonly range from £2/ha/yr for a little vermin shooting to about £20/ha/yr for a woodland particularly suited to pheasant shooting. For example, for each £5/ha/yr sporting rental the increase in Land Expectation Value at 3 per cent would be £170/ha. The value of sporting rental will depend largely on the surroundings and age structure of the woodland, their extent and accessibility to hunting parties. The capital value of a woodland is also considerably improved by its suitability for sporting.

Comparative Profitabilities of Silvicultural Systems

Table 1 summarises the Land Expectation Values at a discount rate of 3 per cent for 18 management options under three tax and grant conditions: 1) without grants or tax relief; 2) grants included but no tax relief; 3) grants included and tax relief through election for income tax assessment under schedule D at 60 per cent switching to schedule B before first thinning. The most profitable management options, of those considered, are the pure conifer plantations. However these require an intensive form of management, and the initial outlay of expenditure may be large. Next in profitability are conifer/broadleaf mixtures which result in a final crop which is broadleaved,

these will not tolerate neglect in management. Finally broadleaved plantations can be profitable at a 3 per cent discount rate, but only with the most favourable levels of tax relief and planting grants. In such a situation the most profitable pure broadleaf option is the planting of oak, ash and cherry in mixtures. However, without the benefits of tax relief and planting grants, lower cost broadleaf options with a greater reliance on natural regeneration or using the retention of an overstorey to reduce weeding and other establishment costs are more profitable than pure broadleaf plantations. For example an ash/sycamore shelterwood system using natural regeneration can provide a good return in many cases.

If grants are available but tax relief is not, the group felling system of oak and ash can be very profitable due to the high grant level obtained for the small areas felled and replanted.

If fuelwood prices are reasonable, then systems such as the re-introduction of coppice management to neglected coppices and rehabilitating neglected coppice-with-standards woodland are very favourable, and require less intensive management. The establishment of new coppice of native species would normally require planting grants for LEV's to be positive at a 3 per cent discounted rate. Very low cost options, such as encouraging birch natural regeneration on relatively short rotations, can also be profitable when fuelwood prices are good.

Computer Program

So far we have discussed a selection of the management options considered, only comparing profitabilities for simple situation and ignoring many of the factors that affect profitabilities. The number of possible combinations of the variables is enormous. Even if they are restricted within sensible limits, the total number of combinations is well over a million for the 18 management options. It would be tedious and time consuming to carry out the calculation of LEV's by hand for the situations relevant to a woodland owner.

Land Expectation Values can be used to compare management options because they accurately reflect their relative profitabilities. It seemed sensible to assemble the data in the form of a computer program to allow rapid calculation of LEV's for a very wide range of possible values. The program which has been developed to run on IBM and compatible computers, allows comparison of different management options, closely matched to the individual situation of the woodland owner, enabling a choice to be made between different silvicultural regimes and commonly planted species.

The program can be very helpful in deciding between alternative management strategies. It provides a menu of the 18 possible options given in Table 1, and for each, it will allow decisions on expected growth rates, timber and fuelwood markets, discount rates, values of sporting rental, sale of lop and top, planting grants, and income taxation level. There is also a provision for alteration of the establishment costs assumed for each option. Table 4 shows the variables considered and the flexibility allowed for each.

Table 4 Determining variables included in the computer program

Variable	Levels
Management Option	18 options grouped as high, medium or low intensity
Productivity Level (Yield Class)	Low, medium or high productivity selection for each option
Produce Value	Five price level combinations for fuelwood and timber
Discount Rate	0, 2, 3, 4 or 5 per cent
Annual Management Costs	Low, medium or high
Revenue from Lop and Top	Included or not included at selected price level
Sporting Rental	None, low, medium or high
Grants	Five levels for appropriate grant scheme (BWGS of FGS)
Adjusting Establishment Costs	Increase or decrease from 0 to 99 per cent
Income Tax Rate	10 to 99 per cent inclusive

The output from the program is the list of the decisions taken, which is demonstrated for the oak, ash, cherry option below.

MANAGEMENT OPTION = Oak / Ash / Cherry.

- (1) YIELD CLASS = 5 / 6 / 8 cu.m/ha/yr
ROTATION LENGTH = 120 years
YEAR OF TAXATION SWITCH FROM SCHEDULE 'D' TO SCHEDULE 'B' = 25
- (2) MEDIUM TIMBER / MEDIUM-FUEL WOOD PRICES
- (3) DISCOUNT RATE = 3 %
- (4) MANAGEMENT COSTS = 8 /ha/yr
PRAIRIE VALUE UNDER SCHEDULE 'B' = 1/ha/yr
- (5) ADDITIONAL REVENUE FROM THE SALE OF LOP & TOP ? YES
- (6) SPORTING RENTAL = 8 /ha/yr
- (7) GRANT LEVEL FOR 10ha OR MORE, SCHEME BWG
- (8) PERCENTAGE ALTERATION OF ESTABLISHMENT COSTS = 0 %
- (9) LEVEL OF INCOME TAXATION = 28 %

LEV FOR SCHEDULE 'B' IN PERPETUITY = 789	HAVE ALTERED LOP & TOP
LEV FOR SCHEDULE D/B WITH TAX RELIEF = 1096	PREVIOUS LEV VALUE = 645
	PREVIOUS LEV VALUE = 952

TYPE A NUMBER BETWEEN 1 & 9 TO TO ALTER THE SITUATION DISPLAYED ABOVE.
TYPE 'P' FOR A PRINTOUT. TYPE 'X' TO EXIT TO MAIN MENU.

Two numbers are usually generated.

- i) The Land Expectation Value for a woodland registered under the schedule B income taxation scheme.
- ii) The Land Expectation value for a woodland managed with a change of taxation registration from schedule D to schedule B. The switch occurs prior to generation of first revenues, this allows tax relief on expenditure during the establishment phase.

These values can be compared against similar conditions in an alternative management option.

The program allows alteration of any of the variables chosen and recalculation of the result very rapidly. By doing this it is easy to get an empirical idea of the economic sensitivity of each variable in a particular management regime. The program and its usage is described more fully in a 'user guide' (Spilsbury 1987) and is available from Oxford Forestry Institute or Energy Technology Support Unit for the price of a floppy disk.

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NATURAL REGENERATION OF OAK

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SUMMARY

As a result of a study visit to western Europe, current practices in natural regeneration are described. Classical management as practised in French state forests contrasts with more progressive methods used on private estates. The importance of three aspects: the condition of the old crop, the coupes, and the treatment of the young crop, in particular the use of racks for access are emphasised.

Experiences in the natural regeneration of oak over almost 100 years in the Forest of Dean suggests that this is a viable alternative to clear felling and planting. Problems remain with sites which quickly become infested with weeds and experiments are soon to be established.

INTRODUCTION

During the autumn of 1985 I was fortunate in being able to spend some months studying the management of broadleaved forests in western Europe. Of the three months spent there, seven weeks were in France, one each in Switzerland, Germany and Denmark, and two days in Holland. By far the most common species encountered was oak.

Prior to these visits I had been dealing mainly with upland conifer forests, except for spells of two years that were spent in the Dean and New Forests. I was by no means an expert in the study subject, certainly not on natural regeneration. I therefore approached the subject with an open mind. I observed, questioned, and have recorded my impressions. Some of these may be false, or perhaps of limited application, both in the countries where they were seen and in Britain. This is bound to be the case after so short a study, in a limited number of forests.

NATURAL REGENERATION IN WESTERN EUROPE AND BRITAIN

It is often suggested that natural regeneration of oak, and for that matter beech, is rarely successful in Britain because both species are on the boundaries of their natural distribution. This may be so, but my superficial comparison suggests there are no great differences in physical conditions between Normandy and southern England. Nor are there better growing conditions in Denmark than in much of south-east Britain. Yet in Normandy and in Denmark natural regeneration of oak, beech and other broadleaved species is prolific. Also there are a number of instances where natural regeneration is successfully practiced in Britain. It seems that the differences are more related to the silvicultural expertise of the forester, and the continuity of forest management. In both respects Britain lags far behind its immediate neighbours in Europe.

OAK IN FRANCE

Oak is commonplace throughout France, and the two British commercial species Q. robur and Q. petraea, are found in all regions other than in the south-east. Much of the oak, especially on private estates, remains as coppice with standards, but there are now considerable areas that have been converted to high forest, particularly in the state forests. In these, the objective

is to produce the greatest volume of sawlogs of the highest value, and a number of oak forests are generally regarded as national monuments. Management of these state-owned oakwoods is based on 'classical' silviculture which involves:

- natural regeneration
- expensive and prolonged weeding and cleaning
- a late start to thinning, which tends to be light and often low
- rotations up to 250 years

Many private estates, but also some state forests, have adopted a more 'progressive' approach which aims at cheaper establishment and tending, and shorter rotations.

CLASSICAL REGENERATION OF OAK

Oak forests managed on classic lines were visited at Tronçais and Blois in central France; Ecouves and Reno Valdieu in Normandy, Nancy in Lorraine and at Liebos, Netherlands.

The process of regeneration was almost identical at all forests, with the exception of the timing of the seeding felling.

I think it is useful to recognise three phases in natural regeneration, and for the outcome to be successful it is important that due consideration is paid to all three.

These are:

- the condition of the crop to be regenerated
- the coupes
- the treatment of the young crop

CONDITION OF THE CROP TO BE REGENERATED

Two features distinguish the typical managed mature oakwoods in France from those in Britain. Firstly French oakwoods usually have a good understorey of beech or hornbeam. This keeps the forest floor clean and is said to keep the soil moist. Secondly, the long rotations and dense stocking typical in France results in the canopy being much higher than in Britain, and this must have a marked effect on the light reaching the forest floor. If British foresters wish to practice natural regeneration they must look to the crops to be regenerated perhaps 20-30 years ahead, and an even longer time-scale must be considered in relation to the establishment of an understorey. There is of course the possibility of using herbicides to control ground vegetation prior to seeding but a good understorey serves the same purpose and helps to keep the oak crop-trees free of side-branches, an essential for the production of high-quality timber.

COUPES

Foresters in the Office National des Forêts (ONF) are taught to avoid excessive dispersal of regeneration, and elaborate management systems ('affectations') have developed to ensure this is so. As in all aspects of forest management in ONF, the forester must aim to continue, and where possible to improve, the 'normality' of the forest.

The decision on when to commence natural regeneration is based on the frequency of mast years. In central and western France good mast is expected every four to five years, with some, often appreciable quantities in between. In eastern France, and further north and east, good mast years are less frequent and may occur every 10-15 years. In these latter situations it is usual to await a good mast year and the appearance of seedlings before starting felling. In the more favourable situations fellings are planned on an annual basis, with an increased programme in a good mast year.

The coupes consist of:

- a seeding felling
- one or more secondary fellings
- a final felling

There are, however, exceptions.

Seeding felling. This is preceded by the removal of the understorey. In the seeding felling it is usual to remove about 20 per cent of the canopy, except where soil working is the norm, and then up to 50 per cent may be removed. The seeding felling:

- removes invasive species such as hornbeam and birch
- removes trees of the principal species which exhibit poor form
- opens up the crowns of the seed trees
- throws some light on the soil

Soil working. This is not always required but, where done, a disc plough is commonly used, and it is best timed to coincide with the fall of the acorns, or immediately afterwards.

Secondary fellings. These progress at a rate determined by the success of the regeneration and the likelihood of damaging frosts. Also, pedunculate oak seedlings are less tolerant of shade, and may receive only one secondary felling. At Ecouves, Normandy, two secondary fellings appeared normal, but at Tronçais there may be four. It is said, however, that the best young crop of oak was obtained at Tronçais when only six years separated the seeding and final fellings. The decision on which trees to remove is usually determined by the presence or absence of seedlings under the tree's crown. However some foresters with an inclination towards marketing prefer to keep a parcel of fine veneer trees for their final felling.

Final felling. In oak the time scale from seeding to final felling varies, but is commonly from 10-15 years. A guide given at one forest was that the final felling should come when 70 per cent of the area is seeded. Certainly the ONF instructs its staff not to wait too long for complete stocking, but to fill blanks by planting. It should be remembered that under the silvicultural system most commonly practiced with oak, the Uniform Shelterwood System, the forester aims to produce a regular, even-aged crop throughout the compartment.

An exception to the general time scale of regeneration coupes, are the oakwoods in the valley of the river Adour. These are pedunculate oakwoods that are often flooded by snow melting in the western Pyrenees. Here, the foresters have found that a lengthy regeneration phase leads to a mass of weeds. They have therefore evolved their own local system in which there is only a seeding felling and a final felling, spaced by one or two years. On the most weedy sites they do not even attempt natural regeneration, but clear fell and plant.

TREATMENT OF THE YOUNG CROP

Lanier (1981) provides a first class description of the work of weeding and cleaning in French broadleaved woods, and a full translation of his paper would be great value to the numerous British foresters now becoming involved in the subject. It is generally considered that a basic requirement for the effective management of natural regeneration is a system of racks. Without these the dense thickets resulting from natural regeneration become impenetrable both to the forester wishing to inspect the progress of the crop, and subsequently to the men doing any weeding or cleaning. British foresters must learn this technique from the continent if natural regeneration is to become an alternative to planting.

In France, racks are usually cut by tractor-mounted swipes at 10 metre intervals soon after the first regeneration appears. Great effort is taken to set the racks parallel throughout the compartment at this early stage, as it becomes increasingly difficult and expensive to set them out when there is a thicket. In the Adour valley, racks are cut to leave three and a half metre wide strips of trees, this being the width that can easily be cleaned from the racks. In Denmark, racks were seen in some beech forests that left only one metre wide strips of trees. Foresters in Britain should be encouraged to make such racks, and to experiment with their spacing.

Weeding. Weeding is usually done by hook in France and this is because there are a number of things to be done. Firstly weed species and malformed trees of the principal species have to be cut from the regeneration. Strongly growing weeds, such as bracken and bramble, have to be cut from the regeneration and from unseeded areas, and the forest worker has the skilled job of adjusting the mixture of species. Today, foresters on the continent are generally aiming for a mixed crop, even in the upper storey. Depending on the relative rates of growth of the desired species, one or the other may have to be held back. In addition, the future understorey, beech or hornbeam, must be safeguarded, but not given too much scope to endanger the oak.

Cleaning. Annual weeding gives way to cleaning when the crop is some three to five metres tall. With the age of the regeneration varying by up to 15 years, a wide range of operations: planting, weeding and cleaning can occur in any one compartment at any given time. Cleaning should be done every six years according to most French foresters, and more frequently according to some Danish and Swiss foresters. In classic management, cleaning tends to be fairly negative operation, whereas in more progressive systems, cleanings are regarded as early thinnings. In classical cleanings, the forester concentrates on removing wolf trees or weed species and safeguards the understorey. In both approaches stress is laid on the waste involved in cutting out small trees, which would have been suppressed and died naturally. In Britain it can be observed that without closely-spaced access racks many trees have to be cut simply for the workers to get through the thicket.

In forests managed on more progressive lines mechanised weeding, usually using tractor-mounted swipes and boom-mounted hedge-cutters, is commonplace. Also by restricting work to the trees adjacent to the rack, only part, perhaps 40-50 per cent, of the compartment is treated. This is justified by the wide spacing, usually 12-14 metres, of the final crop, and the relatively low value of thinnings.

Economics of stand tending. Weeding and cleaning as practiced in state forests in France can be extremely expensive. Foresters are, however, prepared to accept such costs because the final crop has such a high value, and establishment costs are very easily covered by perhaps 15-20 per cent of

the sale proceeds. No account is taken of compound interest in calculating the financial return of the enterprise.

NATURAL REGENERATION OF OAK IN THE FOREST OF DEAN

Prior to Hill's Working plan of 1897 management in the Forest of Dean appears to have relied mainly on planting rather than natural regeneration, because of the poor quality and stocking of the old oak. He recognised the value of growing oak with beech, but was aware of the difficulty of keeping the proper balance between the two (Hill 1897). His recommendation for the natural regeneration of Lining Wood is of interest "it should be enclosed the wood has only to be slightly thinned by the removal of oaks and beeches with the lowest crowns. Then, on the acorn crop appearing, the soil should be hoed up, and a young crop of oak will result. This should be rapidly uncovered by two or three successive fellings of old wood at intervals of three to four years. Some beech may be naturally produced with the oak and indeed the young crop will be probably mixed from the beginning. In that case care will be necessary to see that sufficient number of oaks grow clear of the beech". A classic prescription for the regeneration of oak on the continent.

Osmaston (1915), in his plan, described most of the oak in the Dean as being without underwood, but with some notable exceptions. He recommended that oak should be limited to some 1,700 hectares of the forest, and that natural regeneration should be used where possible. By the time of his writing he would have had the benefit of the very large area of oak natural regeneration that occurred on Blakeney Hill. In pursuit of natural regeneration he prescribed that following a mast year the annual felling cut should be exceeded in the following two years. By the fourth year the seedlings should no longer be of use if not relieved of overhead shade. It is interesting that he recommended strip regeneration for oak, and that the strips should be no wider than 35 metres. Beech underplanting was recommended at 2.7 x 2.7 metres spacing for all oakwoods under 70 years.

As the experienced forest historian might predict, the next working plan, that of David Young (1926), recommended that oak should predominate throughout the forest and that the Uniform system should be used instead of strips. His observations led him to the following tentative conclusions:

- natural regeneration will last for two or possibly three years without additional overhead light
- lateral light which is not sufficient to preserve natural regeneration may be abundantly sufficient to encourage a strong growth of Holcus
- large trees suddenly isolated become shaky

He concluded the need for a nicety of judgement of the balance between preserving the regeneration and avoiding the strong growth of Holcus, and the need to remove mother trees as rapidly as possible after the second or third thinning. He recommended the maximum of shelter consistent with the maintenance of the young regeneration until it is complete, followed by a rapid removal of the mother trees. Regeneration in any compartment should extend to no more than 20 years, though 10 to 15 years would be better. He advised that due to the deprivations of mice and pigeons the first regeneration thinning should follow seed germination. He found difficulty in making recommendations for weeding other than to cut back bracken. Young wrote at great length of the beneficial effect of the woody undergrowth of any species on suppressing grass, and on the need to high prune where the understorey was lacking. He did point out the difficulty of keeping the beech understorey beneath the oak.

Following World War II the extensive wartime fellings were planted almost entirely with oak, unfortunately without a great regard for the soil and the likelihood of shake. After the late 1950s conifers became predominant until the Ministerial Direction of 1971. This, required that the proportions of conifers and hardwoods should remain substantially unchanged, and resulted in a resumed interest in natural regeneration. With planting, establishment had been slow, difficult and expensive.

More recently the approach can best be described as opportunist with one of the best oak crops of the period coming through planted Norway spruce. Certainly the results achieved over the past fifteen years give every hope for success, with the exception of the Highmeadow area. Here, where weed, particularly bramble, growth is very strong, the results have been exceedingly disappointing.

The problem of over-mature oak in the Dean remains unsolved, and indeed as the timber quality deteriorates, the problem gets worse. At present, some 770 hectares of the 2300 hectares of oak is over 130 years of age. However much of this old oak is of high conservation, amenity and landscape value, and so must be replaced slowly and carefully. It is proposed to use natural regeneration in the replacement of oak as far as possible, and it is pleasing that the Forestry Commission's Research Division is to investigate a number of aspects. Where the oak is shaken, mixed broadleaved crops will be encouraged, with beech predominating.

CONCLUSION

A study of continental practice, and the past and present experience in the Forest of Dean, suggests that natural regeneration can be an effective alternative to the planting of oak. Nevertheless difficulties remain, particularly in the relationship between light and the growth of trees and weeds. Also, cost effective methods of mechanical weeding/cleaning need to be developed here, as they have been in Western Europe. Foresters will quickly overcome these difficulties in order to perfect a system that has so many potential advantages over the traditional clear felling and planting, especially in terms of nature conservation (Peterken 1981). Not least, field foresters must observe, record and learn from their mistakes and successes. They must practice good silviculture. Their efforts must however be supported by a consistent policy, a plea so clearly made by Finlayson (1982).

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THE SILVICULTURE OF ALDERS IN GREAT BRITAIN

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THE ALDERS WORLD-WIDE

The species of the genus Alnus are deciduous trees and shrubs usually with erect stems and short branches of small diameter arising at acute angles from the stem in young trees and becoming right-angled with age. Thus in youth and middle age the crowns are usually pyramidal or conical in shape, whereas old trees are flat topped and have open crowns.

Natural Distribution

About 30 species are recognized but the status of several is dubious and the taxonomy of the genus is rather tangled. The alders occur naturally throughout temperate parts of the northern hemisphere and extend to the mountains of south America. Some species of mountains and high latitudes are shrubs or small trees. Examples are A. firma and A. maximowiczii from Japan and Manchuria, A. maritima, A. rugosa, A. sinuata and A. tenuifolia from north America, and A. viridis from Europe. All these rarely exceed 8 or 9 m in height and are usually smaller. Several species develop into tall trees, especially when growing on fertile sites. These include A. hirsuta, A. japonica, A. nepalensis and A. nitida from Asia; A. rhombifolia and A. rubra from north America; A. acuminata from central and south America; A. glutinosa and A. incana from Europe. Another group, A. cordata, A. orientalis and A. subcordata, are native in southern Europe and the Mediterranean region; these make good trees often exceeding 18 m tall.

Cytology, Genetics and Breeding

According to Darlington and Janaki Ammal (1955) the basic chromosome number x of the alders is 14. Some species and varieties within species have 42 or 56 chromosomes indicating the existence of polyploid series. Bean (1972) lists 10 cultivars of A. glutinosa, six of A. incana, three of A. firma and two of A. tenuifolia; many of these are leaf variants. Triploid alders have been produced in Sweden (Wright, 1976).

Alders are monoecious and bear regular, apetalous male and female flowers. Flower buds normally form in late summer, enlarge early in spring and open just before or with the leaves; exceptions to this sequence are A. nitida, A. nepalensis and A. maritima which flower in autumn. The species that have been studied are normally cross pollinating although it seems that they can also be self pollinated (McVean, 1953). Pollination is by wind and the techniques used for isolating female flowers and pollinating them artificially are similar to those already used on a large scale in breeding birches, poplars and willows. It is probable, though not absolutely certain because of polyploidy, that most species could be hybridized successfully, but as Zobel and Talbert (1984) point out, "the goodness of a hybrid depends on the goodness of its parents" and it is essential to examine the genetic variance in the species to be used as parents before embarking on a programme of hybridisation.

Species with the wide and fairly continuous distribution of, for example, A. glutinosa, A. incana and A. rubra can be expected to include ecotypes and clines but these have not been examined thoroughly. The provenance trials with A. glutinosa and A. rubra now in progress in Britain, Germany, the United States and several other countries are revealing variation associated with geographical origin. The interest in forest biomass as a source of fuels has caused the International Energy Agency to coordinate seed collections for provenance trials of several alder species. The work of the International Union of Forestry Research Organisations (IUFRO) has caused collaborative provenance research to become well organised so information of value to practising foresters should soon become available. Esegu (1984) examined the early growth of several provenances and progenies of black alder in Britain and found variation in height growth and rate of biomass production between them.

The alders are promising subjects for improvement by selection and breeding. They flower at an early age, controlled pollination is simple and the number of seeds produced by individual 'cones' is high. There is also an alternative route to genetic gains through vegetative propagation because the alders can be multiplied by cuttings, tissue culture and even cell culture. However an ageing effect, similar to that in birch rapidly reduces the success of vegetative propagation.

Physiology

Features of the alders that are important to their silviculture are the rapid early growth, an ability to form symbiotic associations with species of Frankia to fix atmospheric nitrogen, and the relatively short span of healthy life.

Two reasons for the rapid height and diameter growth of young alders are the speedy development of a large area of leaves and the long period in leaf, which permits full use of the growing season. But some risks attend this. For example, there are reports of A. glutinosa being damaged by late spring frosts and southern provenances of A. rubra are vulnerable to autumn frosts and winter cold.

All the alder species are able to form root nodules containing actinomycetes which can fix di-nitrogen from the air. The potential value of nitrogen fixation in forestry practice can be seen in the improved nitrogen nutrition of un-nodulated trees growing in mixture with alder and in increased concentrations of nitrogen in the soil. When alders colonise bare soil the rise in nitrogen is accompanied by a rapid increase in soil organic matter and an associated reduction in the bulk density of the surface layers of mineral soil. Miller (1983) has reviewed knowledge about the association between alder and Frankia species and some of the facts he gathered may be summarised thus:

1. When combined nitrogen in the soil is low the fixed nitrogen is evidently not capable of maintaining levels of nitrogen in the tree.
2. The fixation of nitrogen requires much energy (1.3 grammes of dry matter for each gramme of nitrogen). When combined nitrogen in the soil is low the growth of nodulated plants will be depressed because of the energy demanded by fixation.
3. There is a close parallel between the pattern of demand for nitrogen and the rate of fixation throughout most of the growing season.
4. Some combinations of host and endophyte work better than others.

Despite the fixation of nitrogen, nutrient-uptake and accumulation in alders does not differ much from that of other tree species. The rate of decomposition of alder leaves is not exceptional. It should also be noted that the roots of alder commonly bear mycorrhizae.

Concerning the third feature that has been mentioned, Evans (1984) writes ... "It is quite frequently observed that in both pure and mixed plantations of alder, some trees die back at the young pole stage. Sometimes this dieback becomes serious and the stand fails". This phenomenon was discussed by Peace (1962) who reported that in Europe A. glutinosa suffers most from crown die back whereas in Britain it is serious only in A. rubra where it occurs frequently once trees are 12 to 15 years old. Peace considered that the large number of fungi associated with dieback suggests that it has a physiological basis but he found it difficult to suggest a common detrimental factor. However, when trees are growing under very wet conditions the growth of roots is restricted and a fall in the water table leaves the shallow root system in dry surface soil and produces symptoms of drought. Under these conditions crown dieback frequently occurs.

Ecology and Soils

The very wide distribution of several species of alder and their frequent treatment as weeds means that reliable assessments of their ecological status are quite hard to find. The most that can be said with certainty is that they are pioneers, generally light demanding but sometimes moderately shade-enduring and capable of coppicing strongly when young but not from older stumps. A. incana appears to be the only species that produces suckers.

The alders occur in pure stands and in mixture with broadleaved and coniferous species. Not all of them have deep root systems or possess wind firmness. Thus the roots of A. rubra tend to be quite shallow and spreading and basal bowing of the stem is common in western north America. A. nepalensis is reported to be damaged by wind.

The alders will tolerate a wide range of site conditions provided moisture is plentiful and is not stagnant. They usually occupy slopes watered from above, ravines, valley bottoms and alluvial sites near rivers and streams. They can invade newly disturbed soils and areas recently clear felled or burned. Their widespread occurrence and plentiful production of light seed means that alders occupy sites with soils ranging from acid to alkaline and from deep well-drained sands to shallow, compacted clays. But large, well-developed and long-lived specimens are most frequently found in deep alluvial flats (Godet, 1980) while short-lived trees of short stature occur on upland sites and deep peats. In its natural habitat A. cordata occurs on poor rather dry calcareous soils but it is most at home near slowly moving ground water and this is so for most, if not all, thirty species.

Growth in Plantations

Regular production of seed, easy plant production, good survival on planting, vigorous early growth and good coppicing power when young have made several species of alder important plantation species in temperate, Mediterranean and tropical highland regions (National Academy of Sciences, 1980). Plantations are usually managed on short rotations for fuel or small round wood but some are intended for timber. The species most used in plantations are A. acuminata in Costa Rica, Columbia, Bolivia, Peru and southern Chile, A. glutinosa in Europe and USA, and A. nepalensis in northern India, Burma and Hawaii. A. rubra has been used on a small scale in Europe and New Zealand.

Although it is common to specify 1+1 or 1u1 stock for planting, more reliable indications of survival after planting are the state of the root system and root collar diameter. The roots do not vary much in size and should consist of a dense fibrous mass; it is probably an advantage if they are well supplied with nodules. Suitable dimensions for planting stock are 46 to 60 cm tall with 10 to 15 cm root collar diameter. Such plants can readily be produced in two years if the seed is sown in peat blocks and seedlings are raised under polythene in polyhouses.

Initial spacing in pure plantations is commonly 2 x 2 to 2.5 x 2.5 m but closer for some methods of biomass production. The tree alders must be thinned early if production of small sawlogs is desired. When thinning is delayed the dominants do not respond. The branches of some of the more shade-enduring species tend to persist in plantations and large branches can be accompanied by depressions in the stem below the point of origin. Epicormic shoots can be troublesome in A. glutinosa.

The tree alders are also planted in mixtures. Everard (1986) reports that in Holland alder is planted with ash to shelter the latter in the early years and is then cut out six years after planting. In Denmark, Everard saw Christmas trees of Abies nordmanniana being grown under scattered alder which provided frost protection and also improved the colour of the foliage of the silver firs. Further south in Europe alder is used to provide frost protection to young oak, and in parts of Belgium and Germany poplar plantations are commonly underplanted with A. glutinosa.

Growth and Yield

Young alders of several species grow rapidly to 15 m. One of the quickest is A. rubra which attains 10 m in 10 years on the British Columbian coast, and in consequence suppresses natural regeneration of Douglas fir and western hemlock. On dryer sites in the mountains 10 m in 20 years is common. A. glutinosa is capable of 18 to 20 m in 18 to 20 years on fertile alluvial sites but more commonly reaches these heights in 25 to 30 years, the corresponding stem diameter being 30 centimetres. A. incana has attained 18 to 21 m in 25 to 30 years in Britain. In its native habitat in the north west Himalaya A. nitida is reported by Bean (1972) to be 30 m tall but the accompanying stem diameters of 300 to 450 cm are hard to believe!

Miller (1983) has gathered together published information about yields of woody biomass above ground. Current annual increment reaches its maximum at 10 to 12 years, the yields of biomass ranging between 10 and 14 dry tonnes per hectare per year. Assuming a basic density of 0.44, Miller (1983) suggested that the maximum mean annual volume increment for the tree alders is 16 to 17 m³/ha.

Mitchell et al. (1981) measured three stands of A. glutinosa in the Dee valley of Scotland and obtained the yields of biomass shown in Table 1.

TABLE 1 - Growth of A. glutinosa in the Dee Valley, Scotland

Age (years)	Yield Class m ³ /ha/yr	Biomass Yield dry tonnes/ha	Annual Yield of Biomass dry tonnes/ha/yr
12	6	29.6	2.5
18	10	87.2	4.8
22	14	211.4	9.6

All three stands are growing on marshy sites with slowly moving ground water.

Protection and Resistance to Disease and Insects

Generally the alders are vigorous and healthy when young and remain so in their native habitats for up to 40 years. The main problems of dieback and attack by the scale insects Chlonaspis salicis appears to be associated with their use as exotics.

Among the pathogens which may damage the alders are the honey fungus Armillaria mellea, and Didymosphaeria oregonensis which causes stem cankers on several species in western north America. Several members of the genus Taphrina can distort the leaves, young shoots and female catkins.

Despite statements that alders are not preferred browse for deer when only few broadleaves are available they can rapidly be destroyed.

Timber Properties

All species of alder produce diffuse-porous timber which is pale when first cut but soon darkens to red on exposure to air and dries to light reddish-brown. The sapwood is not distinguishable from the heartwood. The grain is normally straight while texture varies with species - A. rubra and A. rhombifolia are fine and even-textured whereas A. glutinosa tends to be coarse. There is usually no odour and the surface of the timber is lustrous.

Schedules have been devised for kiln drying those timbers which are regularly available in commerce; they have the reputation for drying well and fairly rapidly. When dry alder timbers are reasonably stable in use. Sap stain and fungal infection are rather common in un-dried timber.

Average timber densities range from 0.32 (320 kg/m³) for A. nepalensis through 0.39 (390 kg/m³) for A. rubra to 0.54 (540 kg/m³) for A. glutinosa. A. acuminata can reach 0.60 (600 kg/m³). Thus most species of alder produce timbers of light to medium density and strength. They are moderately useful for wood bending.

The timbers are not naturally durable when used in exposed positions but most are durable under water and so are often used for river piling. An exception to this is A. incana. Although the heartwood is perishable it is permeable to preservatives. Alder timbers also take stain well. Being light and even-textured the timbers are easy to work and finish by hand and machine but some tend to bruise easily when processed by wood-turning machines.

When the timber is available in large quantities, as with A. acuminata and A. rubra, it is used for many purposes. In central and south America, A. acuminata is used in general construction, including bridges and river piling. The timber of several species is suitable for boxes and crates and in the manufacture of plywood. A. rubra is used in the American furniture industry. The good turning properties are very commonly exploited to produce shoe heels, clogs, bobbins and small items. The strong fibres result in pulp that can usefully be blended with that of conifers. The timber of all species of alder makes good firewood because it burns evenly. The charcoal is also of good quality.

General Assessment

This is a personal judgement: I think the alders are not really well understood except perhaps in Europe and particularly in France (Lanier, 1986). They are useful, ubiquitous, resilient but not really appreciated by foresters. In northern Europe, western north America and central and south

America they are plentiful and therefore used in commerce. In Britain they are neglected and virtually unknown. The next section attempts to show why this is so.

THE PRESENT STATE OF ALNUS SPECIES IN BRITAIN

Black alder

The information in the Cambridge data-bank of Quaternary fossil plant records was used by Godwin (1975) to provide an outline history of British woodlands during the last 10,000 years, Before Present (BP) called the Flandrian Period. The pollen of black alder is the sole species of the genus in the fossil plant records.

During the pre-Boreal and Boreal climatic periods, from 10,000 to 7,000 years BP, pollen of alder was only thinly represented, but at the end of the Atlantic climatic period from 7,000 to 5,000 BP there was a swift and permanent expansion of alder pollen counts as a consequence, Godwin (1975) suggests a climatic change to warm, wet, oceanic conditions. Existing woodlands became diversified by a mosaic of alder stands on burnt areas, along stream and river banks and on flood plains.

From 2,000 BP, during the sub-Atlantic climatic period, forest clearances became progressively more extensive as the Iron Age gave way to the period of Roman occupation. Black alder appears to have quickly re-established itself on felled woodland sites over large areas of northern Britain and also in the native pine woods of Scotland following fires and gales (Steven and Carlisle, 1959). In eastern and south-eastern England the greatly diminished figures for alder pollen during the sub-Atlantic period may reflect intensive cultivation and drainage, and one major cause of the very reduced and scattered occurrence of alder now seen in Britain is the widespread use of drainage in agriculture.

Despite all this black alder is still widely distributed throughout the British Isles from sea level to 500 m where the water table is constantly high. On marshland which is not permanently flooded alder forms dense pure stands, and it grows best where the pH is above 6.0; hence especially fine trees are found in the Peak district of England. Good natural or semi-natural stands of black alder also occur on wet ground overlying acid rocks as well as on limestone (Beckett and Beckett, 1979). There are several small but good stands in the Dee valley of Scotland.

Black alder is a regular constituent of scrub woodlands where it occurs with ash, the two native birches, willows and sessile oak. The concentration by British foresters on afforestation of the uplands with conifers during the past 60 years has caused several broadleaved species to be neglected and the alders have not been widely planted; but where there has been a steady local demand for turnery wood and charcoal black alder has been grown. Its popularity has increased in recent times because of its good growth on sites verging motorways and major roads, abandoned heaps of industrial waste, dumps of fly ash and reclaimed land. There are perhaps 10,000 ha of alder in Britain - 40 per cent in England, 28 per cent in Wales and 32 per cent in Scotland.

Brown (1871) in the fourth edition of 'The Forester' thought rather little of black alder, but 90 years later, Anderson (1961) argued that the alder should be more widely used. He described the silvicultural characters of the black, grey and Italian alders. To these can be added red alder from western north America which has been tried on peat soils by the Forestry Commission (MacDonald et al. 1957).

At present between 1.5 and 2.0 million alders are planted each year in Britain. They rank equally with ash and the willows among broadleaved species at about six per cent of the total planted. The great majority are used for shelter and in landscaping industrial and urban areas. Foresters are making little use of the alders but some potentially useful research is being done and some additional influences are at work that are likely to improve their position.

First there are interesting results from the joint Forestry Commission/Institute of Terrestrial Ecology trial of mixtures planted at Gisburn on an exposed upland site in the north Pennines (Lines 1982). Norway spruce, Scots pine, oak and black alder were planted pure and in mixture with each of the others in 1955. After 26 years the Norway spruce and oak had benefited from being mixed with Black alder but it must also be said that Scots pine has so far proved to be the best 'nurse' species.

Secondly, there is the recent assessment made by Malcolm et al. (1985) of a trial established to study the growth of Sitka spruce and red alder when planted pure and in mixture on a surface water gley soil developed over glacial till of low porosity. The pure and mixed crops were planted in 1962 at Lennox forest near Glasgow and the mixture consisted of alternate plants in each line. The effects of drains 60 cm deep on depth of water table and tree growth were also examined but the results obtained are not discussed.

The red alder seedlings were damaged by frost and had to be replaced in 1964, but despite the two year difference in age, browsing by deer in 1967 and an attack by a scale insect, the alder rapidly overtook the Sitka spruce although survival was only 60 per cent. At 10 years some of the spruce were being suppressed by the alder so that, at 20 years, its top height was less in the mixed than in the pure crops.

Analysis of concentrations of the major nutrients in the foliage of spruce in 1971 suggested that the red alder was affecting the nitrogen status of the spruce. This was confirmed in 1973 when the foliage of spruce growing in mixture with alder had significantly higher concentrations of nitrogen than pure spruce. But the assays made in 1980 failed to show a significant difference in nitrogen 18 years after planting; moreover by that time phosphate levels in the foliage of spruce mixed with alder were lower than in pure spruce. The main effect of red alder was seen in greatly improved nitrogen status of the organic (LFH) layers and the top five centimetres of the mineral soil. The quantity of nitrogen rose at a rate almost comparable with standard fertilizer applications even when alder formed a minority in the mixed crop. Red alder also appeared to enhance total phosphate in the upper soil horizons. In addition, alder roots had penetrated to a depth of one metre while spruce roots remained in the top 20 centimetres.

The third influence at work is the strong interest in biomass production (Miller 1983, Mitchell et al., 1981). Species like the alders which are easy to establish, grow rapidly when young and coppice after harvesting appear promising for short rotation plantations producing biomass for energy. The tolerance of the alders to a wide range of soil types makes them suitable for planting on small areas of under-used land on farms. Miller (1983) has produced models of nutrient cycling in alder plantations grown on 5, 10 and 20 year rotations and this approach makes their management much simpler and more like that of a farm crop.

The fourth influence which may stimulate greater use of the alders is the increasing wish of forest managers to introduce a small and permanent element of broadleaves with the larger spruce forests of the uplands for game management, conservation of wild plants, birds, animals and amenity. Some possible ways of doing this are described in the final section of this paper.

Alnus cordata, the Italian alder, was introduced to Britain in 1820. It is a native of southern Italy and Corsica and has been used in France as a pioneer species in re-afforestation; it is from that country that its reputation for tolerance of comparatively dry soils has come. In Britain, the Italian alder has grown well on a variety of soils, including heavy calcareous boulder clays, and loamy soils over chalk, but it does not tolerate sites with low pH and does not appear to be so tolerant of dry soils as in France.

Alnus incana, the Grey alder was introduced to Britain in 1780. It has been more widely planted than A. cordata and has been used in pure plantations to produce turnery wood and also as a nurse for oak, beech and western red cedar. An early example in Britain of benefit from the extra nitrogen produced by alder comes from Friston Forest in Sussex, where a checked plantation of ash was invaded by suckers of grey alder and responded by growing quite vigorously (MacDonald et al. 1957). Plantations of grey alder on wet, but fertile clays in the midlands of England grow well, and produce a useful timber suitable for turnery, although rather soft. When mixed with sycamore both species grow rapidly and the grey alder attains stem diameters of 30 cm in 30 years.

Alnus rubra, the Red alder is being tested by the Forestry Commission on upland afforestation sites in Scotland and northern England (Lines, 1976). It was introduced to Britain in the latter half of the nineteenth century and its extensive latitudinal range in western north America makes a study of provenance variation essential before it can be used suitably in Britain. It is too soon to know whether the earlier disappointments with this species reported by MacDonald et al. (1957) will be overcome in the present trials.

Two defects which are common to most exotic alder species are stem pits below large branches, and the occurrence of splits or cracks which greatly reduce the value of the timber. Black alder does not appear to suffer from this latter defect, but grey alder, red alder, and Italian alder plantations usually contain damaged trees.

FUTURE USE OF THE ALDERS

Although the potential usefulness of alders as site improvers and as nurses on the chalk soils, peaty gleys and clay sites is recognised, their wider use on such sites is hampered because:

1. They are widely considered to be weeds and their silvicultural characters are not well understood. Thus alders are sometimes planted on swampy ground that is poorly aerated, with little preparation of the site; or they are planted in small groups in the midst of conifers for 'amenity' but given little weeding or protection. In both cases poor specimens result, money is wasted and the potential of the species is not realised.
2. There is an understandable reluctance to use alder in mixtures which create silvicultural problems, so that the cost of raising the principal species rises and the yield of timber per hectare is lowered. The disparity in early height growth between alders and the major conifers is so great that it is difficult to design intimate mixtures which avoid suppression of the latter - unless the alders are thinned heavily or felled at six or seven years, and certainly before ten years.
3. The timber is useful but does not possess outstanding features. It will satisfy local demands for turnery and fuel but is unlikely to attain national status.

Possible uses in the lowlands

To deal first with 'lowland' sites there are several possibilities:

1. In the bottoms of small valleys with fertile soils derived from calcareous rocks (where poplars have been planted in the past), mixtures of alder and ash would recreate a natural tree community and promote the growth of good ash.
2. On banks of rivers and flat areas likely to be flooded, black alder in mixture with selected willow clones will conserve the banks, protect the habitats and produce some useful timber.
3. As a nurse for oak on sticky clays.
4. On rendzinas and shallow calcareous soils generally as a component of mixed woodland worked under the group selection system.
5. For the production of biomass for fuels. This modern version of an old concept is still in the development stage but even in areas that are intensively farmed, between two and five per cent of the land is in small parcels that are virtually unused at present.

Possible uses in the uplands

In the 'uplands' there are two possibilities. The first is to plant alder in mixture with birch and other broadleaves to diversify and enrich the larger areas of conifer forests, providing habitat for birds and permanent woodlands for use in the management of deer. The potential for this is most evident in the south-west peninsula, parts of Wales, the Borders and the western Highlands of Scotland. Such plantations, ranging from 5 to 20 ha in extent, would recreate the natural woodland communities of birch and alder that once existed widely, especially on clay soils, and add greatly to the amenity of upland forests. I emphasize that these mixed deciduous woodlands are intended to aid management and create permanent stands that will regenerate naturally in the face of pressure from grazing and browsing animals.

The second possibility in the uplands is to use alder in mixture with spruce as one line of attack on the problem of instability on exposed sites with peaty gleys and clay soils. I am not suggesting that these mixtures will automatically be more stable: the present evidence is against this idea. I do suggest that alder and birch are likely to be useful as soil improvers and in association with improved methods of ground preparation, help to ensure the long term future of spruce on heavy textured soils.

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THE IMPACT OF ROE DEER, RABBITS AND GREY SQUIRRELS ON THE MANAGEMENT OF BROADLEAVED WOODLANDS

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INTRODUCTION

Roe deer (*Capreolus capreolus*), rabbits (*Oryctolagus cuniculus*) and grey squirrels (*Sciurus carolinensis*) can severely reduce the productivity of broadleaved woodlands. Roe deer and rabbits affect the early growth stages by browsing tree shoots and can severely retard or prevent growth. Most tree species are susceptible. Grey squirrels affect pole stage crops by stripping the bark from the main stem, the crown and the base. Beech and sycamore are most affected (Rowe, 1984).

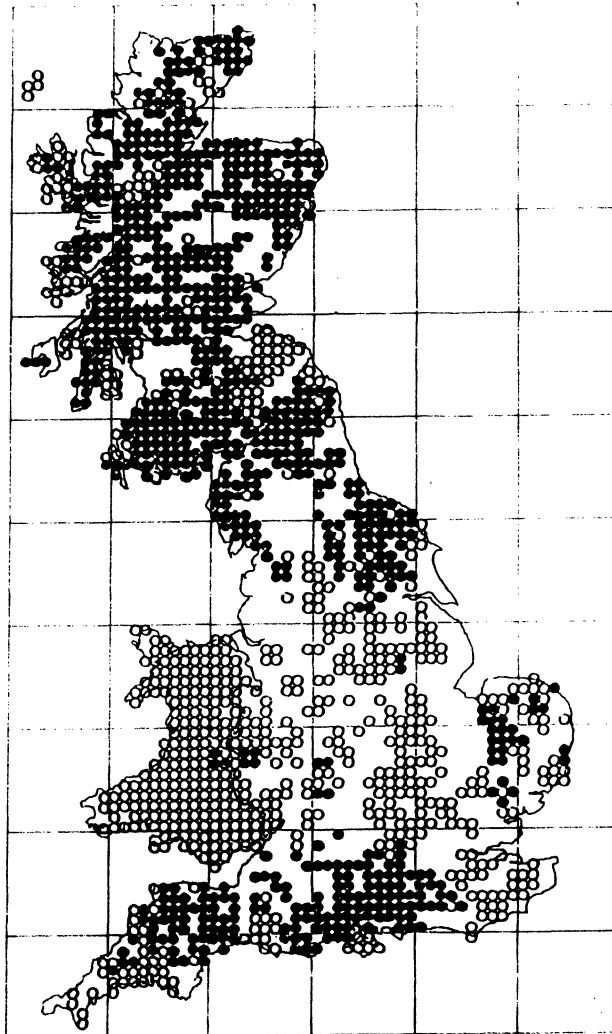


Fig. 1. Distribution of roe deer (*Capreolus capreolus*). Dots show locations of Forestry Commission land in 10 km grid squares; closed dots indicate that roe deer are present in the area.

Roe deer are the most widespread of British deer (Fig. 1). They can quickly colonise the favourable young stages of woodlands and achieve very high densities in the mixed woodlands of lowland Britain (Staines and Ratcliffe, in press). Rabbits are ubiquitous throughout Britain (Arnold, 1984). Grey squirrels continue to expand their range (Fig. 2) particularly in the north of England and Scotland. They are ubiquitous in lowland broadleaved woodlands. This paper assumes a management objective of controlling damage. It can be achieved either by directing control measures at reducing the impact which the animals have on the crop or by direct control of the animal population itself. With grey squirrels population control has been shown to cause a reduction in damage, but the relationships between animal density and reduced impact is not clear for most species and any such relationship is unlikely to be linear. Damage may also be affected by factors other than density. This paper examines our current knowledge and discusses management options.

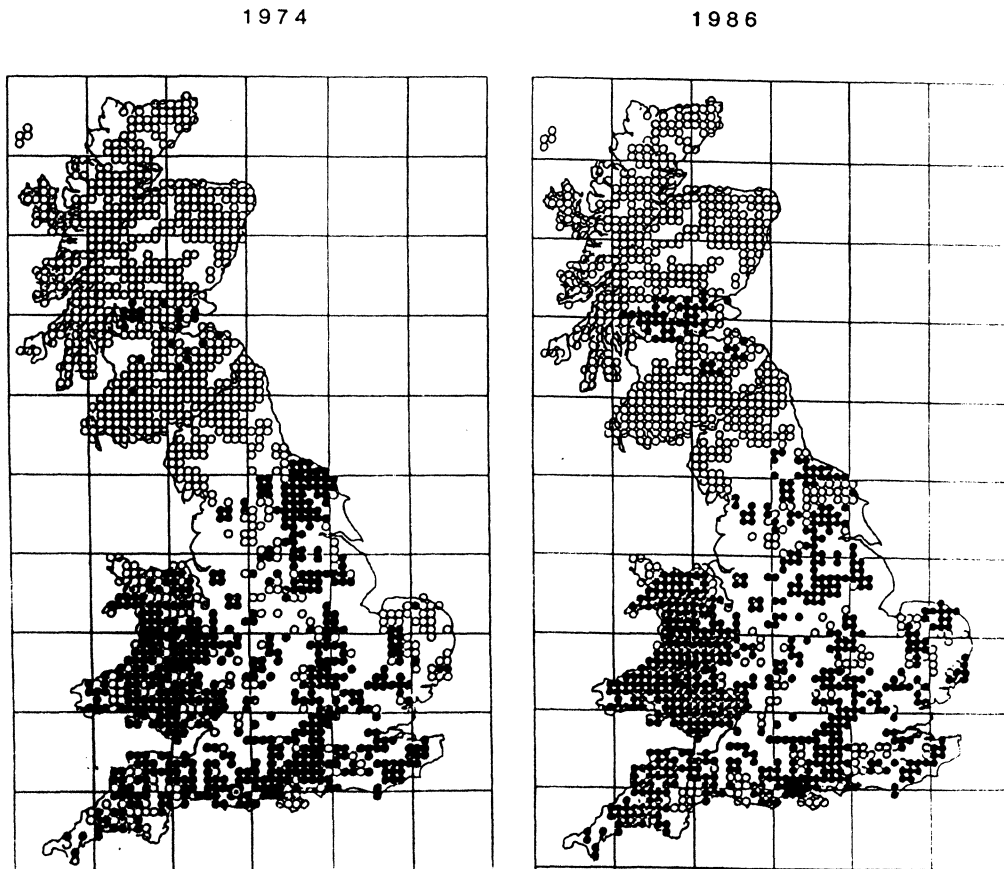


Fig. 2. Distribution of grey squirrels in 1974 and 1986. Dots show locations of Forestry Commission land in 10 km grid squares; closed dots indicate that squirrels are present in the area.

VULNERABLE WOODLANDS

Currently there are 9821 hectares of broadleaves in the 0-5 year old age class, the majority being in England, where 2255 hectares of new planting and 5370 hectares of restocking are vulnerable (Table 1). Most of this area is at risk from both rabbit and roe deer damage. About 175000 hectares of broadleaved woodland are currently in the 10-40 year old age class (Fig. 3) which is at most risk from grey squirrel damage (Rowe 1984).

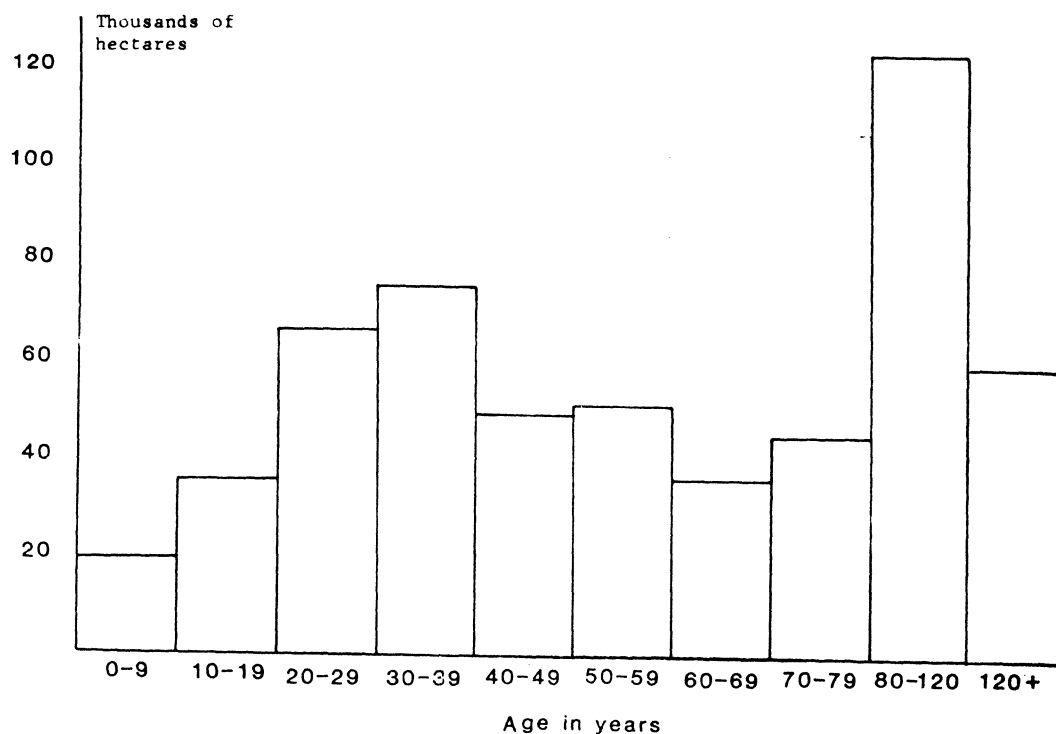


Fig. 3. Area of broadleaved high forest in Great Britain by 10 year age classes, as at 1980.

Table 1 Broadleaves: New Planting and Restocking less than 5 years old in State and Privately owned forests.

	New Planting (ha)	Restocking (ha)	Total (ha)
England	2255	5370	7625
Wales	295	339	634
Scotland	869	693	1562
Great Britain	3419	6402	9821

Source: Forestry Commission Annual Reports

Table 2 Effects of Roe Deer density on plant diversity

<u>ROE DEER DENSITY</u>	<u>EFFECT</u>
<u>NO./km²</u>	
1.5	Slight effects on composition
3.0)	Marked depression of diversity
5.0)	and loss of sensitive species
6.0	Heavy browsing on Sitka spruce

Note: Densities of 15 to 25 roe per km² are common

Table 3 Impact of Fallow Deer at a density of one deer per hectare on vegetation cover

<u>SPECIES</u>	<u>GRAZED</u>	<u>UNGRAZED</u>
% Cover		
<i>Pteridium aquilinum</i>	100	30
<i>Rubus fruticosus</i> agg.	-	35
<i>Rosa</i> spp.	-	10
<i>Juncus conglomeratus</i>	4	24
<i>Agrostis tenuis</i>	70	1
<i>Holcus lanatus</i>	15	-
<i>Hedera helix</i>	-	4
Trees/ha		
1969	125	106
1978	188	6643
1985	298	5497

Source: How (1986)

ROE DEER

The impact of herbivores is not generally confined to the tree crop. There is evidence that most broadleaved plants or parts of plants below browse height are affected by browsing at roe deer densities of 3 to 5 per square kilometre (Kraus, 1985) (Table 2). Where the conservation of plants, lepidoptera and song birds is an important management objective, deer may present a major problem. The impact of a group of fallow deer (*Dama dama*) held at a very high density of one per hectare in an enclosure in the New Forest, was compared with an adjacent ungrazed enclosure (Table 3).

With grazing, a marked depression of plant diversity occurred and palatable plants like bramble disappeared completely. This and the complete absence of a shrub layer caused large differences in the invertebrate and bird faunas (How, 1986). The density of trees (almost entirely broadleaves) was between 18 and 35 times greater in the ungrazed plot. The reduction in the number of trees per hectare in the ungrazed plot in 1985 was due to self-thinning.

The control of numbers and breeding potential can only be achieved by killing sufficient females during the open season to balance the annual increment from reproduction and immigration. Reproductive performance in roe deer populations varies considerably in relation to habitat quality (Ratcliffe and Rowe, 1985) and the number of animals to be removed from populations to prevent further increase can be related to performance (Fig. 4). Between 20 and 35 per cent of roe deer populations must die or emigrate each year if populations are to remain stable. In a low performance population at Thetford Forest in Norfolk, density was estimated at 20-24 roe deer per square kilometre and a cull of 2-4 breeding age females was considered necessary to balance the annual population increase (Ratcliffe & Rowe, 1985). This equates with a total cull of about 6 deer/km² (Fig. 4). Greater numbers must be killed if a decrease in density is required.

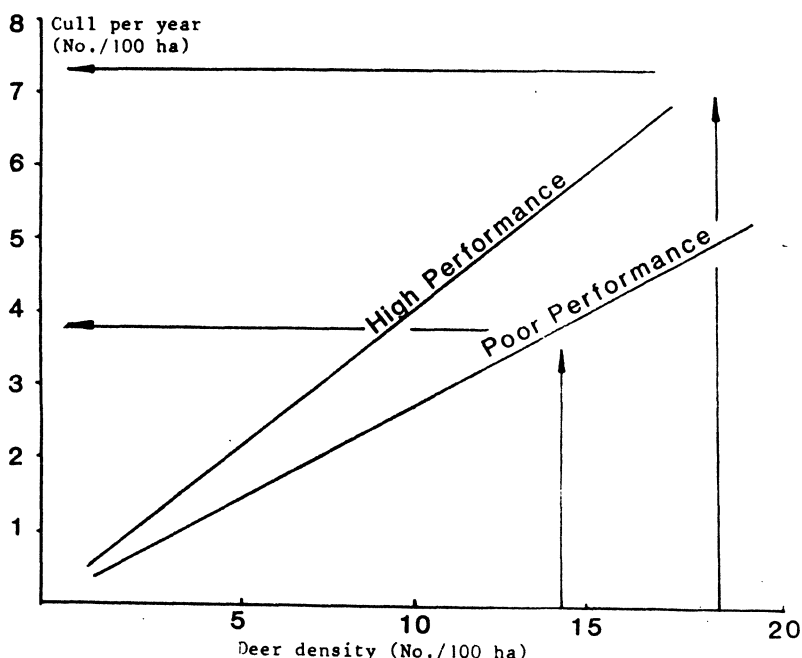


Fig. 4. Culls required to maintain stable roe deer populations (from Loudon 1980).

It is important to consider the possible sequence of events in the absence of control. Density will only continue to increase in these circumstances if the habitat can support more deer. If the population is at a density at which density-dependent regulation is causing a reduction in fertility or high mortality, or if some social mechanism is limiting numbers (Klein and Strandgaard, 1972), then populations will clearly not increase beyond the carrying capacity. However, the important consideration is that the threshold density at which roe deer populations will regulate their own numbers is considerably higher (> 20 deer/km²) than the level at which broadleaved trees will suffer damage (< 5 deer/km²).

RABBITS

Rabbit populations nationally suffered a severe reduction in numbers, but little reduction in range, following the introduction of myxomatosis in 1953 (Ross and Tittensor, 1986). From 1960 to 1970 numbers remained very low but since then they have increased considerably in some areas, particularly in the south and east of England, and to a lesser extent Wales and south-west England (Trout *et al.* 1986) (Fig. 5). The evidence for these increases has been obtained from the analysis of rabbit bags from the National Game Census (Trout *et al.* 1986), which is believed to reflect the trend in numbers. A more detailed study at North Farm, Hampshire has shown an actual increase in rabbit numbers from 1955 which approximates to an increase of 14 per cent per annum (Fig. 6) (Sumption and Flowerdew, 1985).

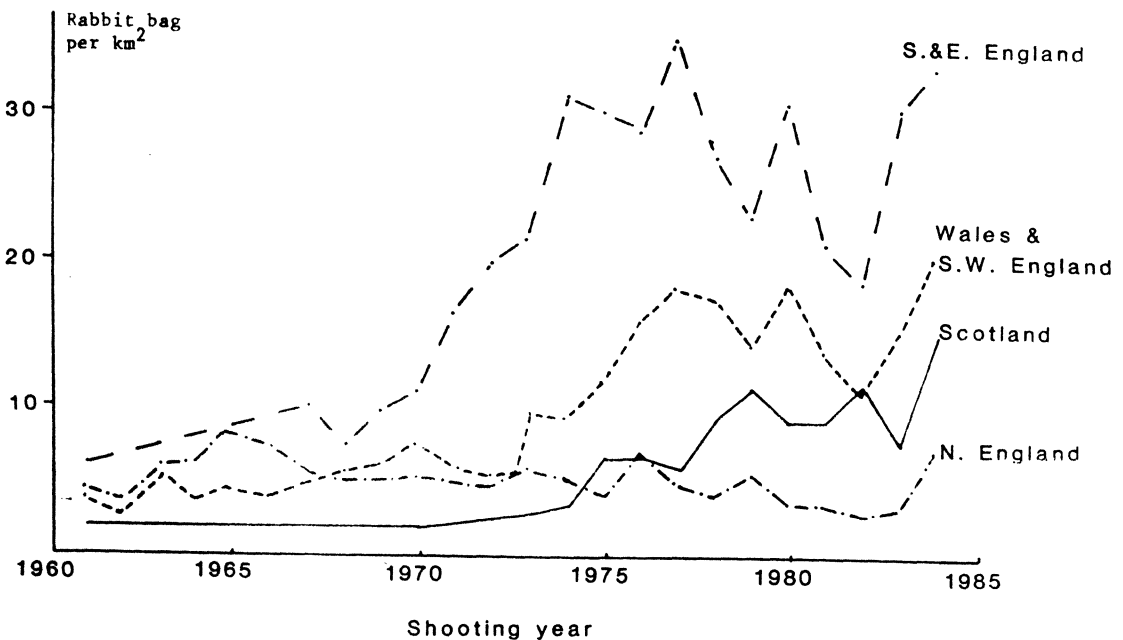


Fig. 5. Recorded rabbit bags from the National Game Census in Great Britain, 1961-1984. (from Trout *et al.* 1986).

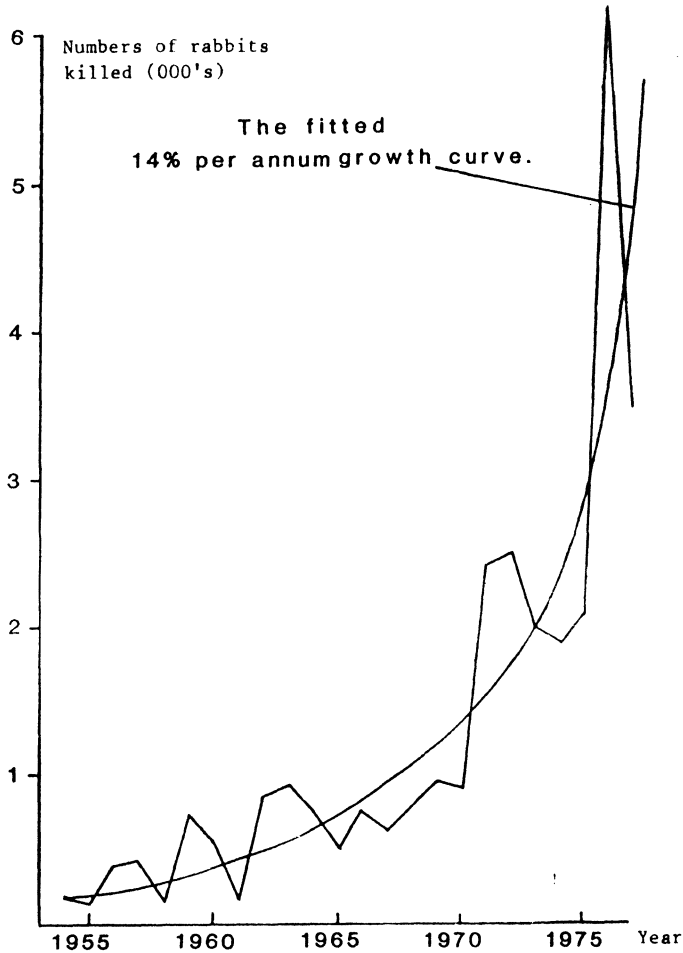


Fig. 6. Annual kill of rabbits at North Farm, Hants.
(from Sumption and Flowerdew, 1985).

Trout *et al.* (1986) concluded that rabbits have become more abundant over the last 20 years and shooting bags and indices of rabbit numbers are not declining, indicating that the carrying capacity has yet to be reached. It seems unlikely in the light of this evidence that myxomatosis will continue to have a controlling effect on rabbit populations, particularly in the lowland areas of England where most broadleaved forestry occurs.

Consequently, the need to protect young trees will continue and may increase with the predicted increase in lowland broadleaved afforestation.

GREY SQUIRRELS

Grey squirrel damage can be reduced dramatically by effectively reducing the number of squirrels occupying woodlands in and around vulnerable crops (Rowe 1980; Gurnell and Pepper in press). Being arboreal creatures they are impossible to exclude by fencing or individual tree protection and therefore population control assumes a higher relevance than for roe deer and rabbits. Grey squirrel numbers fluctuate dramatically in response to the periodicity of heavy mast years and its consequence on breeding success (Gurnell and Pepper in press). High spring densities are associated with high levels of damage to trees during May to July.

Since the introduction of warfarin in 1973, poisoning to control grey squirrels (Grey Squirrels (Warfarin) Order 1973, made under the Agricultural (Miscellaneous Provisions) Act 1972), considerable increases in the number of squirrels killed have been estimated in state forests (Fig. 7). The number killed annually is unlikely to reflect actual squirrel numbers because of annual variations in reproduction and survival and to differing levels of control effort. Grey squirrels are a robust opportunist species and there is no evidence that their impact on broadleaved trees will change dramatically from current levels. Any increased emphasis on broadleaved afforestation in lowland Britain should therefore anticipate the future problems associated with grey squirrels.

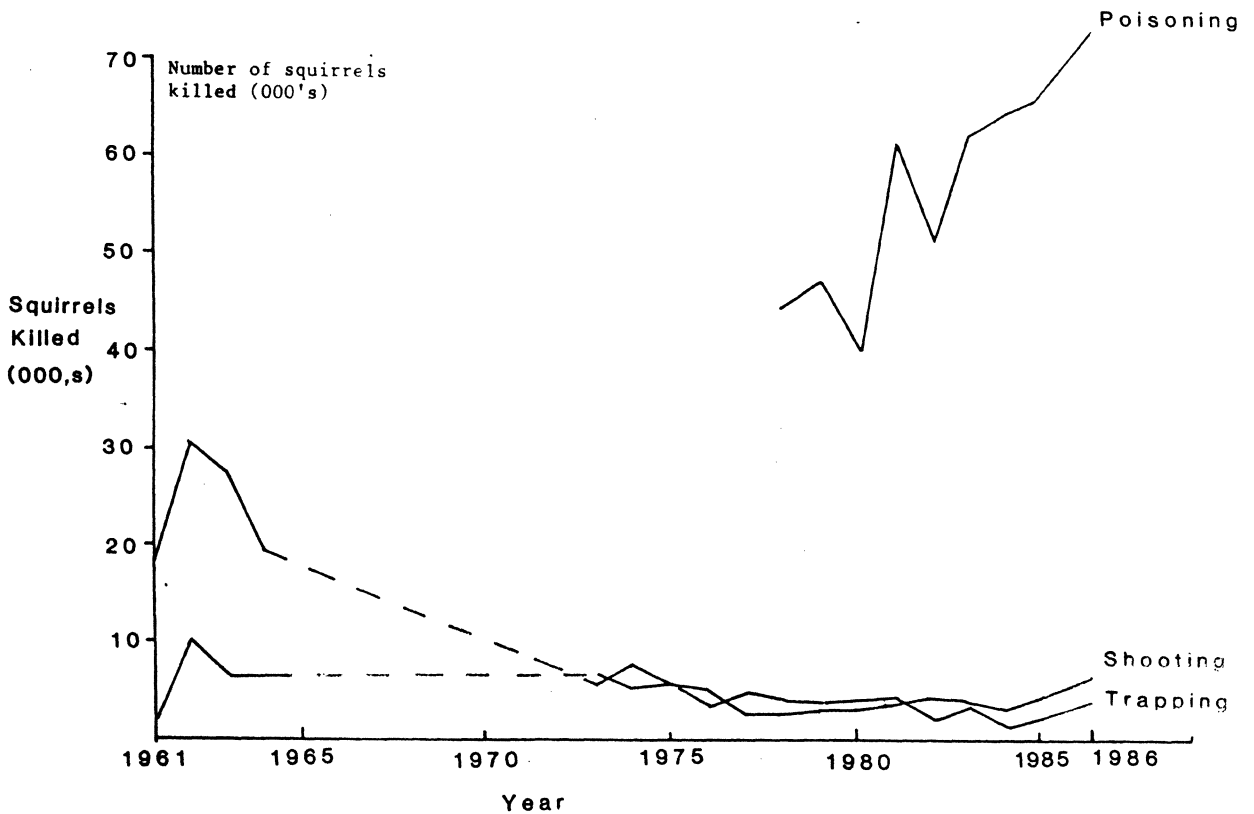


Fig. 7. Numbers of squirrels killed in state forests. (from Gurnell and Pepper, in press)

REDUCING IMPACT

Roe deer can possibly be controlled by shooting in small woods, but on large areas, especially where dense cover is available, it is virtually impossible to regulate numbers by shooting and populations will regulate their own density by immigration and mortality (Ratcliffe and Rowe, 1985). The localized heavy shooting of roe deer in and around vulnerable areas may reduce their impact but will not necessarily control their numbers.

Rabbit numbers are most effectively controlled by gassing (Pepper 1976), but rapid recolonisation can occur and this method is often used in conjunction with some form of physical barrier.

Roe deer and rabbits can be physically excluded from plantations by fencing (Pepper and Tee, 1986), individual tree guards (Pepper, Row and Tee, 1985), or by chemical repellents (Pepper, 1978). Fifty-six proprietary chemical repellents have been tested in the field against deer and rabbits since 1965, of which only three have shown limited value (Table 4). Both Aaproduct and Dendrocol 17 are toxic to actively growing plants and can only be recommended for winter application. Therefore, no protection is offered to new spring growth which is so often damaged by deer and rabbits.

Table 4 Recommended Chemical Repellents

Name	Conditions for Use
Aaproduct	Winter application only against deer, hares and rabbits.
Dendrocol 17	Winter application against deer only.
Fowikal	Only effective for 6 weeks then re-apply. Use to protect, trees, shrubs and roses in gardens from deer.

Fencing is expensive but costs can be minimised with the use of spring steel (Pepper and Tee, 1986). The careful choice of specification can also considerably reduce costs. For example, a fence 0.75 m high is as effective in excluding rabbits as the conventional 0.9 m fence (McKillop, Pepper and Wilson, 1986). Equally the specification of tree guards should suit the protection required. The choice between fencing and individual tree guards is governed by the area of plantation to be protected. Hovevar (1971) used a formula to calculate the Critical Area Index (CAI):-

$$CAI = \frac{CmP}{NCt}$$

NCt

where, Cm = fencing costs per metre

Ct = individual tree protection cost

P = length of fence

N = number of trees per hectare.

A critical area index greater than one indicates a preference towards individual tree protection, while an index of less than one indicates fencing as the most economical option. An example of this approach compares roe and rabbit fences at different tree densities (Fig. 8).

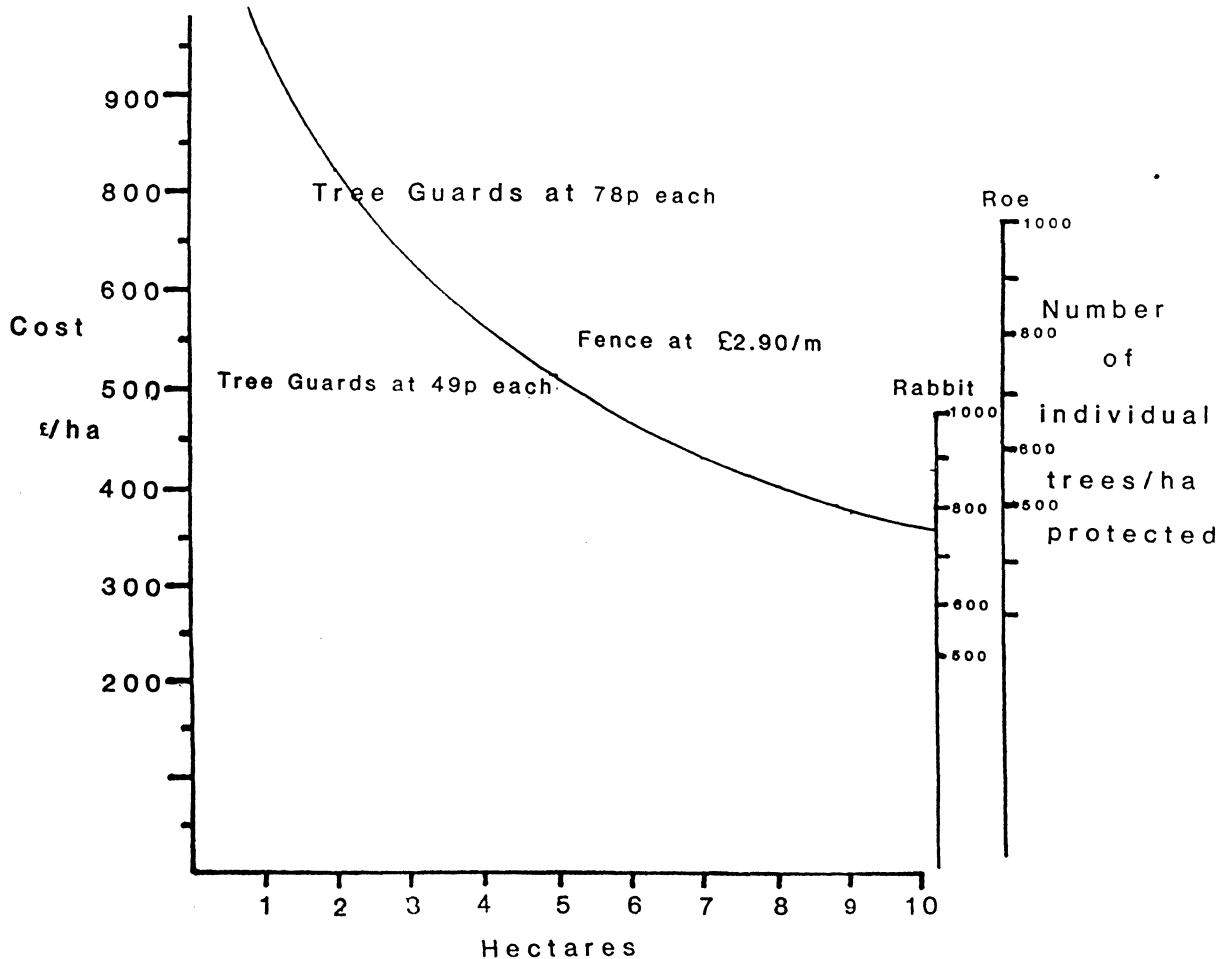


Fig. 8. Cost of rabbit/roe deer fence compared with individual tree protection.

Grey squirrels are currently best controlled by use of warfarin poison (Rowe, 1980). However in some areas notably those counties in which red squirrels are present, the use of warfarin is prohibited and cage trapping is the best alternative. This is an effective but more costly and more labour intensive method and therefore only applicable to smaller areas. Grey squirrel control is most effective if landowners can co-operate in the organisation of squirrel control groups (Forestry Commission, 1986).

CONCLUSIONS

Roe deer and rabbits can cause severe damage to broadleaved trees and plant communities, particularly during the early stages of plantation growth. It is unlikely that their numbers can be effectively controlled by shooting over large areas of woodland, though local control of roe deer may be possible if they are heavily shot on and around vulnerable areas. The most effective way to reduce the impact of roe deer and rabbits on broadleaved trees is by fencing, or by individual tree protection. The decision as to which of these options to take depends upon the presence of important sensitive plant communities and on the size of the area and the number of trees to be protected (Fig. 8).

Grey squirrels may be considered to be a greater problem to lowland broadleaved forestry than either roe deer or rabbits, because trees are vulnerable to damage for a greater period (about 30 years), and because damage occurs to older, and therefore more valuable trees (cf. Table 1 and Figure 3). Damage is most effectively reduced by well organised squirrel control immediately prior to, and during the damage period. This can be achieved by using warfarin or by cage trapping.

The use of poison in the countryside should never be considered an ideal solution, even though the risks to other forms of wildlife are low (Rowe, 1980). Research is needed to ensure that more acceptable, but equally effective methods of living with grey squirrels are developed. In the shorter term the ability to predict years of high potential grey squirrel damage, from signs of early breeding shows promise both in reducing the costs of control and in restricting the use of poisons to particular years (Gurnell and Pepper, in press).

The effective establishment of broadleaved woodlands in areas with roe deer and rabbits will probably continue to rely heavily on the use of fences and individual tree protection. Future research should continue to aim at reducing the costs of these options.

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8 January 1987
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