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Guide to Upland Restocking Practice

Edited by A J Low

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FRONT COVER Replanting a clear felled area at Coed-y-Brenin, north Wales. *(E5097)*

GUIDE TO UPLAND RESTOCKING PRACTICE

Edited by
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1. Introduction

In the coniferous forests of upland Britain, the scale of clear felling has increased substantially in recent years. Planting to restock felled areas currently amounts to some 6500 ha per annum, or about 28 per cent of the total area planted each year in upland forests by State and private forestry interests. The level is expected to rise substantially over the next 20 years, particularly in State forests, as post-war plantations reach maturity or are felled prematurely after windthrow damage occurs.

When a forest area is being replanted there is an opportunity to change the species and species distribution in order to improve yield, landscaping or wildlife conservation. It may also be possible to provide more adequate site cultivation or drainage than was possible for the first rotation. However, the problems involved in re-establishing a tree crop after clear felling are often substantially different from those affecting establishment in the first rotation. Site conditions both above and below ground are likely to have been modified in various ways by the growth of the first crop and by the presence of adjacent unfelled plantations. The presence of stumps and brash may restrict access, limit cultivation and drainage options and hinder the actual planting operation (Figure 1). It is also necessary to make allowance for increased risk of damage by insects, fungal pathogens and browsing mammals.

Failure to take account of the various differences between first and second rotation planting, and to adopt the most appropriate techniques, can lead to difficulty in establishing satisfactory replacement crops. Recent surveys have indicated that results are often less than satisfactory, involving high costs, lengthy establishment periods and inadequate stocking densities. It was therefore decided to produce the present guide with the aim of providing practical advice to forest managers on all important aspects of upland restocking practice. The various sections which follow are based on the best available information, and have been prepared by staff of the Forestry Commission's Research and Development and Forest Management Divisions. The treatment of each topic is deliberately brief and concentrates on the important points to be taken into consideration. In cases where more detailed information is readily available from another publication this is indicated in the text. Where appropriate, general guidance is given on the relative costs of treatment options. It is felt, however, that detailed cost comparisons are a matter for the local manager who is in the best position to take account of constraints imposed by local site conditions and management objectives.

2. Interaction of harvesting and restocking

The organisation of harvesting operations in clear felling can affect the cost of subsequent restocking. The forest manager should bear in mind the possible interaction between harvesting and restocking phases, and aim to minimise their combined costs.

The size and shape of the area to be restock-

Figure 1. A site on which replanting is hampered by the substantial dense accumulation of Sitka spruce lop and top.

ed can lead to economies of scale in various restocking operations; these can be especially important for fencing and mechanical ground preparation. Consideration of both harvesting and restocking costs seems likely to favour large felling coupes of fairly regular shape (although landscaping requirements may impose constraints – see Section 3). Coupe size and shape can also influence site microclimate (e.g. by creating frost hollows); and the successive annual felling of adjacent areas will favour a population build-up of insect pests.

Careful consideration should be given to the job specification in harvesting work, as failure to do so can cause major restocking problems. The cut-off diameter should be as small as is practical, stumps should be cut low, tops should be cut into short lengths, and treatment of dead or otherwise unmerchantable material should be specified. There should be close supervision to ensure compliance with the job specification; unextracted logs, needlessly high stumps, and unprocessed tops cut to an excessive diameter can be obstacles to man and machine, represent a waste of saleable timber, and provide additional breeding material for insect pests. The harvesting of windthrown areas will inevitably involve difficult working conditions, necessitating particular care with job specification and supervision if the site is to be left in a suitable state for subsequent restocking operations

Various 'organised felling methods' for timber harvesting have been developed in recent years; in all of these methods there is a formal separation of timber produce and brash into distinct zones (Figure 2). Their use can provide various important benefits during harvesting, including greater safety for workers, improved ergonomics, higher outputs during felling and extraction, less waste as produce is clearly visible to the operator of the extraction machine, and, in difficult soil conditions, improved access for wheeled machines on mats of thick brash. The implications of organised felling methods for restocking will vary; work in the brash-free zones will be easier but may be more difficult within the brash zones. If brash is to be treated (for example by burning, chopping, or raking into heaps), the zoning is likely to assist the brash treatment, but is otherwise likely to hinder site preparation by scarifier or plough. Traditional felling methods tend in practice to produce an uneven brash cover, resulting in local concentrations which often conceal unextracted produce and in consequence may be as much of a hindrance as the brash zones in organised felling. If brash concentrations produced by organised felling do cause serious restocking problems, the costs of delaying replanting until brash has partially broken down, or of treating the brash are, on many sites, likely to be small compared with the advantages gained during harvesting from use of organised methods. Brash treatment options are discussed in Section 4.

The extent of manual felling and conversion seems certain to diminish as processors and harvesters are introduced. It is generally possible to concentrate the brash ahead of such machines in a belt 3–4 m wide, leaving much of the site brash-free. As the harvester or processor and then the extraction machine pass over the brash, it tends to be crushed and mixed with soil, leading to its rapid breakdown. However, as harvesters are not yet equipped to treat stumps with chemicals and it is inevitable that some brash-covered stumps will be overlooked during follow-up manual treat-

Figure 2. A recently felled spruce area showing zoning of produce and brash. *(E3744)*

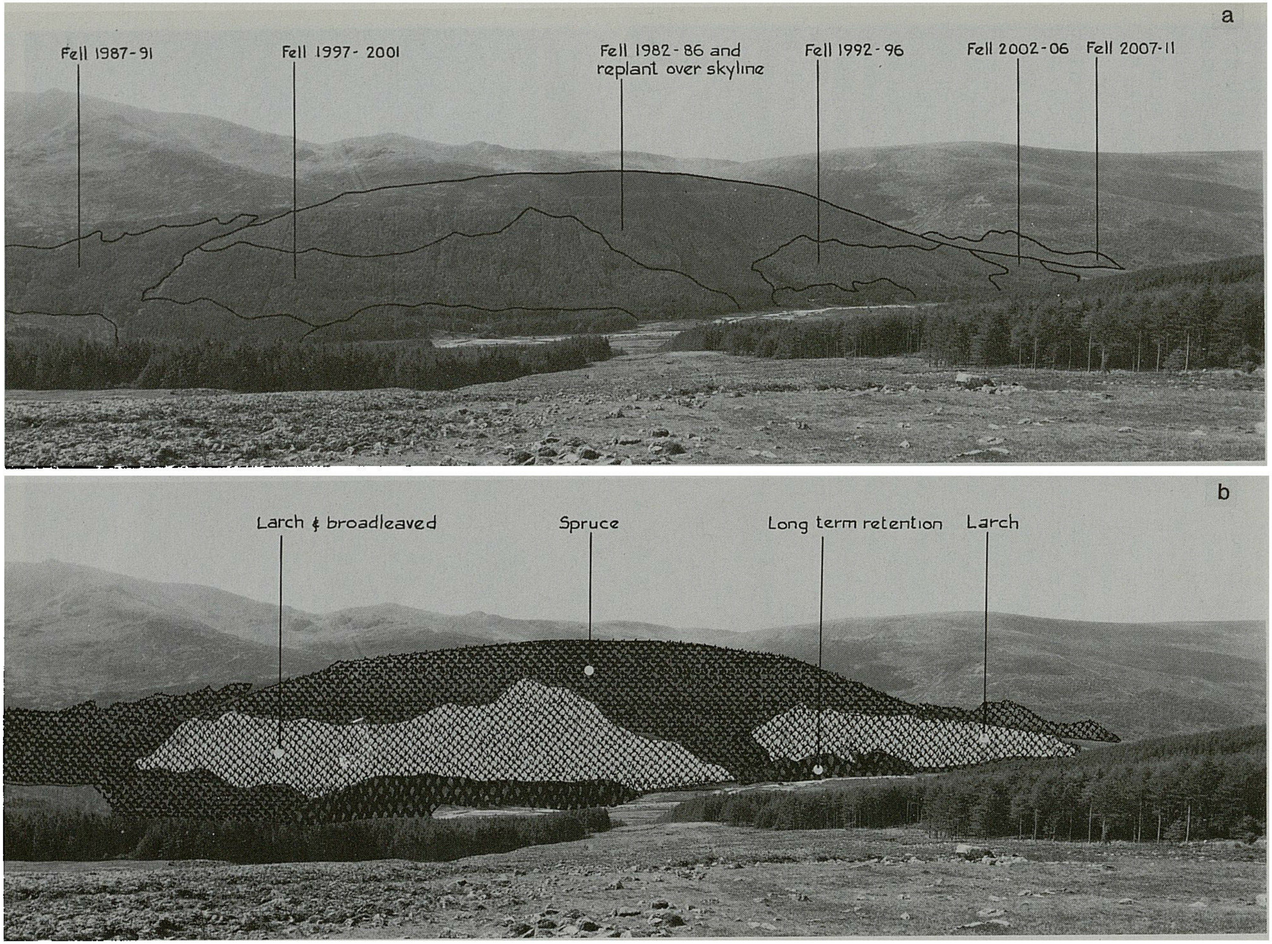

Figure 3. Felling and replanting design for part of Ennerdale Forest (Cumbria):
(a) pattern of coupes and approximate felling dates, (b) proposed species pattern and improvements to external boundaries.

ment, there may be a risk of *Heterobasidion annosum (Fomes annosus)* infection and subsequent damage to the replanted crop.

In wetter areas, and particularly on soft soil types, the original drainage system is likely to be seriously disrupted by the passage of harvesting machinery, and by brash accumulations. The provision of temporary culverts, using lightweight piping, will reduce damage to main drains. Site damage due to rutting and soil compaction will be minimised if harvesting operations on wet sites can be carried out during the drier seasons. However, it is inevitable that on wet sites substantial work will be necessary to re-establish a suitable drainage system.

3. Forest design considerations

Landscape design

Clear felling and restocking provide important opportunities for improving the appearance of the forest by the correction of previous bad design and the introduction of more varied stand appearance and tree size (Figure 3). The development of a well-designed pattern of successive felling coupes and a varied age structure is essential to obtain such an increase in visual diversity. The appearance of restocking is so dependent on both shape and timing of felling coupes that they must be designed together. A compromise between the demands of landscape, wildlife conservation, harvesting, restocking and management is needed. The balancing factor should be cost, related to the quality and visibility of the site. Forest landscape design is discussed in detail in Forestry Commission Booklet 44 *The landscape of forests and woods.*

Design principles

Of the numerous factors which affect forest design, shapes related to landform, scale and diversity are fundamental principles for the achievement of a satisfactory appearance.

Shape is of paramount importance, especially that of external boundaries and felling coupes. These edges have the greatest visual impact due to the combined effect of tree heights and their shadows and colour contrast. In both cases they should be irregular, diagonal to the contour and reflect the shape of the ground by rising uphill in hollows and falling downhill on convex slopes. The extent of these inflexions should increase with the size and prominence of the hollow or convexity. Visually intrusive geometric effects should be avoided and in particular:

- long straight edges,
- right angles,
- parallel edges,
- symmetrical shapes,
- vertical boundaries (perpendicular to contours),
- horizontal boundaries (following contours).

The most appropriate *scale* depends on the amount of landscape which is visible. It will normally increase with the vertical height, breadth of view and distance to the observer. When a number of viewpoints are involved, scale often needs to be changed gradually from one part of the landscape to another; e.g. it should usually be greater at hill top level and decrease towards the valley floor.

Diversity depends on the number of different features within the landscape. The apparent uniformity of the forest should be reduced by revealing open space, views, crags, rocks, water and scrub, and creating felling coupes and a varied age structure. Where possible, variation in tree species (including broadleaved) should be used to reflect patterns and colours of vegetation outwith the forest.

Felling design

The following points are important when implementing the above principles:

1. Where short views are important the apparent scale of large coupes can be reduced by adopting a very irregular shape or by retaining areas in the foreground to be felled when restocking behind is established.
2. The apparent scale of coupes can be increased in the long view by extending felling to include the forest edge.

3. A calculated risk of windthrow may need to be accepted to achieve a satisfactory design. Wherever possible, coupe boundaries should follow windfirm edges that are sympathetically shaped to landform. Visually intrusive windfirm shapes should be avoided.
4. Skylines should either appear completely open or as solid forest; diffuse belts and scattered trees appear out of scale and should be avoided.
5. With cable crane systems currently capable of working to 650 m from roadside it should seldom be necessary to leave intrusive belts of trees at the upper margin on steep slopes. Where this is unavoidable the belt should be broken into groups by partial felling
6. The practice of screening coupes with narrow belts of trees is intrusive and should be avoided. Well placed groups of trees will reduce the impact of lop and top and give a more sympathetic landscape composition.
7. Scattered single trees should not normally be left standing within a coupe, but well-formed individuals can be retained provided they form coherent groups.

Replanting design

Replanting layout should include any necessary improvements to external margins. The screening of open spaces, views, crags, water, broadleaved trees and other features should be avoided by leaving land unplanted.

Species layout should follow the same design principles as felling and coincide with coupe boundaries as closely as possible. Where site and cost permit, some larch should be used to provide colour diversity and seasonal change. It should be positioned on convexities to highlight landform, with evergreen species simulating shadows in hollows. Broadleaved planting is best located in irregular groups along lower edges to link with trees in surrounding farm land, and in association with water, e.g. extending up the sides of main water courses.

Design method and techniques

While contour, soil and stock maps, aerial photographs and crop information are needed for planning, accurate sketches based on photographs are essential for design work. Besides information on crop details the following factors should be recorded on a contour map or sketch as a basis for design:

- hollow and convex slopes (represented respectively by upward and downward arrows),
- existing intrusive design,
- features to provide diversity,
- areas suitable for larch and broadleaved species,
- existing and potential recreation facilities,
- potential deer control areas.

All the information should then be analysed to identify problems, opportunities and priorities. Design should be carried out on the main sketched view, then checked and adjusted from subsidiary views in the following order:

1. Complete set of felling coupes.
2. Timing of felling coupes.
3. Improvements to external boundaries.
4. Species layout.

If extensive improvement to the external boundary is needed it may need to be carried out before the felling design. Examination of various options will usually be required to produce the best compromise between appearance, wildlife conservation, harvesting, management and economics.

Wildlife conservation

Diversification of forest structure and, to some extent, of coniferous tree species will benefit wildlife as well as landscape, and this should be recognised when formulating and evaluating forest design proposals prior to felling.

Arranging felling and restocking to increase the range of plantation age classes will increase the diversity of habitat and wildlife. In particular, the longer that selected windfirm stands can be retained the more valuable they become for wildlife, especially if they have been well thinned from an early age to develop deep crowns and, preferably, some form of shrub layer or ground vegetation. 'Edge effect' is generally considered to be an important conservation feature and therefore small irregular felling coupes are likely to be more beneficial than large regular ones. Where it is practicable to retain isolated mature trees, these provide valuable raptor perches, and the retention of some wind-snapped or dead trees of more than 30 cm dbh will encourage cavity-nesting birds.

As well as being a valuable planning aid, forest conservation maps prepared beforehand are helpful at the operational level for identifying sites of high conservation value, where, for example, brash should not be spread, timber stacked or heavy mechanical plant operated. Felling operations should avoid damaging badger sets; and where clumps of trees in which raptors nest cannot be retained, felling should be timed to avoid the nesting and fledging period. The richer grassy flushes and those other open areas previously identified as having uncommon plant or animal species or communities should remain unplanted, and adjacent restocking should be kept well back.

The most valuable conservation feature of the felling and restocking stage is the opportunity it presents not to restock certain areas. Areas of low yield (due to exposure, rock, bog, etc.) or difficult extraction (small steep slopes) can provide long term open habitat or natural scrub of high value to wildlife, with little loss of revenue – although in some cases natural regeneration of conifers may need to be cut out. Open areas are necessary for deer culling, and therefore deer glades created specifically for this purpose and areas left open primarily for wildlife conservation can perform a dual role.

The most important areas to consider, however, are stream and lake margins. In some instances these will be uneconomic to restock, but even where this is not so they should be left unplanted, and any natural broadleaved trees or shrubs retained (Figure 4). This provides the best environment for water life, and also for plants and animals generally in what are usually sites with higher than average wildlife potential. Opportunities should be taken to increase water areas wherever possible at low cost, for example by damming suitable streams where they are crossed by road-lines.

Forest roads are also important for wildlife. Like streams and rides they have a large edge to area ratio, and in addition include a large proportion of disturbed ground which favours regeneration of certain plant species. At restocking, efforts should be made to reconcile the maximisation of this wildlife potential with the operational requirements of the road-line.

As commercial broadleaved plantations will not be a significant feature of upland restocking, natural broadleaved growth should be favoured wherever practicable and should not be underplanted with conifers. In addition, where groups of native broadleaved species can be created by the side of streams and lakes and along road and ride sides this will add very considerably to the diversity of plants and animals, especially birds. Such planting will be protected more economically in conjuction with neighbouring restocking than it could be separately. Of the conifers, Scots pine and larch provide the greatest opportunity for wildlife diversification.

Some conservation measures will conflict with other forestry considerations – for example, small coupe size with efficient machinery use or ease of deer control, and natural regeneration of broadleaves with commercial conifer establishment – but the conservation requirements should be included in the overall appraisal. Further information is available in Forestry Commission Booklet 29 *Wildlife conservation in woodlands.*

4. Site preparation

Treatment of logging residues

The quantity of stem and branchwood left on the site after clear felling will depend on the species, age, spacing and vigour of the previous crop, with large, heavy-crowned trees causing the worst problems. The presence of dense branchwood accumulations and of large pieces of stemwood is usually more important than the overall quantity as such. Pieces of wood in excess of about 1 metre in length impede the passage of machinery, and this, together with the presence of high stumps, can necessitate a banksman with a chainsaw which

Figure 4. An example of good streamside planting, with the edge of the coniferous tree crop set back from the stream, and retention of broadleaved trees and shrubs. Elibank Forest, south Scotland.*(ED1036)*

greatly increases the cost of mechanical site preparation. Much can be done to alleviate this problem at little extra cost by applying suitable standards during harvesting (see Section 2).

Harvesting systems which involve the organisation of brash into dense 'windrows' or zones (Figure 2), to facilitate conversion and extraction, can lead to particular restocking problems. Small increases in efficiency during harvesting can give rise to large financial gains, and it is therefore more fruitful to devise ways of dealing with branchwood accumulations during the restocking phase than to argue that harvesting systems should be changed to avoid its deposition in an inconvenient manner. Where the brash layer is too thick to plant through, and too wide to leave unplanted, a number of options need to be considered:

1. Chop the brash using a rotary flail or similar device. Although expensive, this treatment can be very effective for brittle pine and Douglas fir branchwood on sites which permit the use of a tractor, but on spruce sites the cost is generally prohibitive, since spruce brash is resilient and difficult to chop.
2. Redistribute the brash. A variety of buckrakes, excavators and scarifiers can be employed to achieve this. The longer the brash is left before treatment the easier and cheaper it will be to achieve the desired effect.
3. Burn the brash. Piling is usually necessary before burning and if done manually can be

very expensive. If the brash is sufficiently concentrated in windrows and the weather conditions are suitable it may be possible to burn without piling. (Note that if burning is carried out there may be some risk of the replacement crop being damaged by the fungus *Rhizina undulata* – see Section 13.)

4. Plant the intervening rows before weeds invade, and plant the windrows some years later when the brash has subsided. The risks here are that an uneven stand is produced, leading to poor timber quality and increased harvesting costs, and that the windrows may harbour pests.

5. Leave the site for 2–5 years and then plough or scarify. Either form of cultivation will suppress the weeds and improve conditions for early establishment. The passage of the machinery will be easier the further it is removed from the time of felling, since the stumps and brash will become brittle, and this will reduce the actual expenditure in establishment, although there will be a sacrifice in discounted revenue as a result of the site remaining unproductive for several years.

6. Leave the site for, say, 5 years, treat with herbicide prior to planting, and plant without cultivation. This may be appropriate on the more freely-draining sites where cultivation confers less benefit, and depending on the relative costs of cultivation and herbicide application. Again the site will remain unproductive for a period, and the partially decayed brash may hinder selection of suitable planting locations.

Drainage

Forest drainage is only required on soils with drainage impeded by an ironpan or indurated layer, or on impervious soils such as the peats and gleys.

Clear felled sites often possess a drainage system inherited from the previous rotation; unless this is wholly unsatisfactory it may be possible to reinstate it with relatively modest expenditure, particularly if main drains were protected by temporary culverts during harvesting. Especially on impeded soils, the old root channels will provide a certain amount of drainage, particularly where the roots have penetrated the ironpan or induration. Under these circumstances new drains should only be put in to tap wet hollows and spring lines. On impervious soils the site will also have been modified by the previous rotation, and water movement may be much enhanced, particularly on peat soils. Heavy clay gley soils are very difficult to drain because of limited lateral water movement, and the maintenance of a drainage system with drain intensity no greater than 100 m/ha is recommended.

Cultivation

The main purpose of cultivation is to provide favourable planting positions. The provision of bare mineral soil, especially when shaped into a ridge or mound, confers the following benefits:

1. Increased mean daily soil temperature.
2. Warmer conditions at night and therefore reduced risk of frost damage.
3. Local drainage on wet sites which further improves temperature conditions, provides an aerated rooting medium, and encourages the mineralisation of nutrients.
4. Easier identification of the planting position, which reduces planting and weeding costs.
5. Ground cover removed, which helps to discourage the Large pine weevil *(Hylobius)*.
6. The removal of weeds, thus reducing competition for moisture and light.

These benefits are essentially short-term; long-term amendment of site conditions by lowering the water table and increasing the depth of rootable soil by ploughing has not been convincingly demonstrated. Indeed, the drainage system remaining from the first rotation will be destroyed by ploughing and will need to be replaced.

Stumps and logging residues cause a great deal of wear on tractor tyres or tracks and also create large peak tractive loads by impeding the passage of a plough. As a result, in order to plough at all, deep-going ploughs are required so that stumps are lifted rather than met at their point of greatest resistance, and this necessitates the use of tracked tractors rated at 140 kW (190 hp) or more. Single mouldboard ploughs (S60/T90/m – see Forestry Commission Leaflet 70 *Forest ploughs)* mounted on Caterpillar D7 or similarly sized tractors have been used to produce a form of 'complete' ploughing, turning each plough ridge into the previous furrow (Figure 5). This technique has been used particularly on the heathlands for cultivating ironpan and podsolic gley soils not adequately cultivated at the time of afforestation. It promotes a high degree of nitrogen mineralisation and avoids the root restriction associated with spaced furrow ploughing with a single mouldboard plough. However, outputs achieved are extremely low and costs therefore high. Recent experimental results suggest that growth benefits may not be maintained in the long term, but it remains possible that improved long-term crop stability benefits may justify such treatment.

Double mouldboard spaced furrow ploughing can be achieved on most sites using a D60/T90/t plough on a Parkgate 'Humpy' carriage trailed behind a Caterpillar D6, which can be fitted with low ground pressure apical track shoes for use on soft or boggy ground. This type of ploughing provides the widest possible rooting platform between the furrows, and should not therefore prejudice stability to the same extent as spaced single furrow ploughing.

On wet clay soils, tracked excavators with long-reach booms can be used to produce six rows of mounds ('dollops') 2 m apart between excavated drains at approximately 15 m spacing. These mounds provide good planting sites with a minimum of root restriction (leading to

Figure 5. The result of deep complete ploughing on an ironpan soil in north-east Scotland after clear felling of the initial Scots pine crop.*(N2847)*

later stability benefits) and a more than adequate drain intensity. However the technique is costly, and likely to be justifiable only on impervious soils. Similar results might be achieved more cheaply in the near future with the use of continuous-acting mounding machines developed in Scandinavia and now under trial in Britain.

Scandinavian scarifiers of various types are also being tested in Britain for restocking site preparation on well drained mineral soils (Figure 6). The 'Leno' patch scarifier has already achieved a measure of success in providing suitable screefed patches, and in an experiment on a brown earth soil in north Scotland gave an improvement in survival and growth equal to that achieved by double mouldboard ploughing, but at much reduced cost.

5. Species choice

When selecting species for replanting purposes, the forest manager will often be faced by many of the constraints which affected species choice in the first rotation, but there are also likely to be some new opportunities as well as new limitations. He will often have as a guide the actual long-term performance of several species on different site types within his locality, although this information must be used with caution as the seed origin, ground preparation and later treatment may not have been optimal. The original ground vegetation (e.g. *Molinia* or *Calluna* moorland) may have been markedly changed by the influence of the first crop. Depending on the size of felling coupes, there may now be greater side shelter than at the start of the first rotation. However,

Figure 6. Bräcke patch scarifier towed by frame-steered skidder and showing the paired rotors which produce screefed patches for planting. Blairadam Forest (Fife).

some restocking sites may also have an increased risk of frost caused by the effect of surrounding stands on cold air movement. If stumps of the first rotation are heavily infected by *Heterobasidion (Fomes),* some species are unsuitable (see below and Section 13 – Pathological considerations). Damage by deer (both roe and red) on many sites is likely to be far greater that at afforestation and may be the main factor determining species choice.

Conifers

In most circumstances, Sitka spruce is likely to be the first choice for replanting in upland forests because of its high growth potential, adaptability to a wide range of site conditions, tolerance of deer browsing, and general purpose timber. However, the use of other species may be suggested by site conditions, established timber markets, a desire for greater species diversity, and landscaping considerations. Points for and against various alternative coniferous species are summarised in the table on pages 15 and 16.

Broadleaved species

Site conditions in upland forests rarely favour the use of broadleaved species for commercial wood production. Where such use is regarded as feasible, the approach adopted should be similar to that for broadleaved restocking in lowland forests (see Proceedings of the 1982 symposium *Broadleaves in Britain: future management and research,* edited by Malcolm, Evans and Edwards and Forestry Commission Bulletin 62 *Silviculture of broadleaved woodland)* and will not be further considered here.

As indicated in Section 3, native broadleaved species such as alder, birch, oak, rowan and willows have an important role in enhancing landscapes and enriching wildlife habitats in upland forests. When introduced by planting, these species can be difficult and expensive to establish, although they may subsequently grow well. It must be remembered that in comparison with coniferous species on similar sites, young broadleaved trees are generally more demanding of moisture and nutrients, more sensitive to early competition and more susceptible to climatic and animal damage. The use of large planting stock and planting at close spacing in compact groups facilitates establishment, protection measures and any necessary tending. On the other hand, broadleaved species (especially birch, rowan and willows) will often seed naturally into an area after clear felling, if given protection from browsing and fire. When broadleaved growth is required for landscape or conservation reasons it is therefore worth taking considerable care to preserve any existing broadleaved trees when a coniferous crop is felled.

6. Planting stock specification and handling

It is difficult to over-emphasise the importance of obtaining suitable well-handled planting stock and maintaining it in optimal condition until it is planted. Agents which act to reduce the survival of planted stock act more strongly on poor or disabled plants than on healthy, well-balanced specimens. It follows that the use of stock which is below standard will result in increased beating up, weeding and protection, and that the penalties will be most severe on difficult sites and in adverse seasons. Clear felled sites are generally more difficult than sites for afforestation because of the presence of forest pests, stumps and slash.

The most common cause of planting failure is the development of an imbalance between the amount of water lost through the foliage in transpiration and the amount that can be taken up through the roots, leading to excessive moisture stress. There are several ways in which this imbalance can arise, for example as a result of root damage during the various stages of plant handling, or of competition from grass weeds for available moisture. The choice of plant type, size and handling method is guided for the most part by the need to minimise moisture stress after planting.

Comparison of alternative coniferous species

Species	For	Against
Sitka spruce (SS) *(Picea sitchensis)*	High growth potential, yielding general purpose timber. Silvicultural requirements well known and can be grown successfully on a wide range of sites. Resistant to wind exposure. Tolerates substantial deer browsing pressure.	Requires nutrient/herbicide input or use of species mixture on poorest sites. Possible excessive reliance on a single species in upland forestry. Unsuitable for frost hollows. Poor stability on sites with high water table.
Norway spruce (NS) *(Picea abies)*	Better seed origins now available than used for older stands. Some are very late flushing and suitable for frost hollows. High growth potential on fertile sites. General purpose timber.	Sensitive to wind exposure. More susceptible than SS to deer browsing and bark stripping. Unsuitable for sites with much *Fomes,* and for low fertility sites.
Scots pine (SP) *(Pinus sylvestris)*	Improved strains now available (but still only moderate growth rate). Well-known useful timber. A native species, with conservation and landscaping value. Silvicultural requirements well known. Useful for nursing SS mixtures on drier nutrient-deficient sites.	On wet coastal uplands may suffer needle loss and snow damage. Attractive to deer when young, but thick bark later offers protection. Unsuitable for heavy soils.
Lodgepole pine (LP) *(Pinus contorta)*	Selected seed origins of known performance now available. Low nutrient requirements. Timber end uses similar to Scots pine, but growth rate usually higher on the same site. Alaskan origins useful for nursing SS on poor sites.	Much more susceptible to deer damage than SP. Some origins more sensitive to severe exposure than SS. May suffer *Panolis* attack on some site types. Modest growth potential usually restricts use to very poor sites.

Comparison of alternative coniferous species—*continued*

Species	For	Against
Douglas fir (DF) *(Pseudotsuga menziesii)*	High growth potential on better freely drained sites. Best seed origins now known. Yields strong timber but end uses more specialised than for spruces.	Establishment more difficult than SS. Very susceptible to deer browsing and *Hylobius*. Stem form generally poorer than SS. Unsuitable for exposed or low fertility sites and for rich sites with poor drainage.
Western hemlock (WH) *(Tsuga heterophylla)*	High growth potential even on sites rather dry for SS. Tolerates shade. Timber end uses similar to spruces.	Very susceptible to deer browsing and bark stripping. Frost and exposure sensitive. Liable to *Calluna* check. Stem form usually poorer than SS. Unsuitable on sites with much *Fomes*.
Grand fir (GF) *(Abies grandis)*	Very high growth potential of best seed origins. Tolerates drier sites than SS. Relatively free from attacks by insects and fungal pathogens. Stem form excellent. Shade tolerant.	Timber less strong and logs of lower value than SS, with risk of drought crack on some sites. Exposure sensitive. Very susceptible to deer browsing and bark stripping.
Hybrid larch (HL) and Japanese larch (JL) *(Larix* x *eurolepis* and *L. kaempferi)*	Valuable for landscaping and conservation purposes. Rapid early growth gives short economic rotation on better freely drained sites. A useful nurse for SS on poor sites. Timber dense and strong, similar to DF. HL preferable to JL when available.	Low yield potential, particularly on low fertility sites. Poor form in exposed conditions. Susceptible to deer browsing when young, but thick bark affords later protection.

Type of stock

Bare-rooted planting stock is in general use for both restocking and new planting in upland Britain. Trials of various forms of containerised stock have shown that these will rarely provide an acceptable alternative in terms of early survival or cost.

The young trees are raised in open nurseries, and are either transplanted or undercut during development to ensure that the root system is compact and fibrous, and to limit shoot growth so that a high root:shoot ratio is produced. For a given root:shoot ratio, and for height up to about 30 cm, plants of a given specification survive and grow better the larger they are since large plants have greater reserves of water and nutrients, and a smaller leaf area:stem volume ratio. However, large plants often have a smaller root:shoot ratio than small plants, and are more difficult to plant in such a way that the roots are not distorted and are properly in contact with the soil. Furthermore, increasing size increases the cost of producing, transporting and planting the plants. Nevertheless, larger plants are sometimes needed to avoid overtopping by weeds, particularly when planting is not on plough ridges or other raised positions. An overall minimum height of 15 cm is recommended, with 30–40 cm plants to be used where significant weed competition is expected.

The size of a plant root system is difficult to assess objectively, and so root collar diameter (RCD) is usually taken as an indicator since it is related to the size of the root system. The 'sturdiness' of a plant can be defined in terms of RCD relative to 'height' ('height' being taken as the shoot length between the root collar and the tip), and standards for forest trees are given in Forestry Commission Bulletin 43 *Nursery practice*, page 4, Tables 1 and 2. For upland restocking purposes these should be regarded as *minimum* standards and trees of larger RCD used wherever possible, e.g. a 22 cm high Sitka spruce transplant with a 4 mm RCD would be a more suitable candidate for restocking purposes than one with a 2.5 mm RCD as specified in the tables for this height. The conditions on an upland clear felled forest site are considerably more testing than the experimental conditions which produced the data for the tables.

Plant handling

Plant handling includes all operations from lifting in the nursery until the plants are planted in the forest. Lifting, transport and storage are dealt with in FC Bulletin 43, pages 86–91. From the moment they are lifted the roots of barerooted stock are subjected to mechanical, heating and drying damage that will effectively reduce their root:shoot ratio by the time of planting. Douglas fir, the larches and *Abies* species are particularly susceptible to such damage and require high handling standards. It is not difficult, however, to keep damage within acceptable limits if the following points are borne in mind during the organisation and operation of the handling system:

1. Tearing or bruising of roots reduces the effective size of the root system and its ability to regenerate. Damage will be minimised if plants can be packaged in rigid containers.
2. Plants can heat up because the circulation of air between the bags or bundles is restricted; because sunlight is allowed to reach the packaging material (in particular, clear polythene bags heat up as a result of the 'greenhouse effect'); or because of being transported in high ambient temperatures without the protection of an insulated container.
3. Drying can be prevented by packaging in a sealed, waterproof material such as polythene or waxed cardboard. During insecticide treatment or interim storage when plants are not packaged, they must be kept moist at all times, irrigating if necessary. Once the normally dark, moist appearance of the roots has become dull and turned to a lighter colour, serious damage has already been caused.
4. Plant tissues are less easily damaged by both heating and drying when they are fully dormant. It is often assumed that plants will be dormant between the setting of the terminal bud in autumn and budburst the following spring, but many forest trees fail to become frost-hardy until the end of November, and

commence root growth in March, some weeks before bud-burst. In consequence, plants should be treated as being fully dormant only between the beginning of December and the end of the following February, and thus the period during which handling is relatively safe is very short. When plants are handled on a large scale this safe period must be extended by prolonging dormancy through the use of cold-storage.

5. Plants must be put into a cold-store only when fully dormant. Cold-storage temperature must be carefully monitored and not allowed to rise above 2° C.

6. The number of temporary storage operations, i.e. when the plants are 'heeled-in' ('sheughed'), must be kept to a minimum.

7. Planting position, pattern and method

Position

It is important to choose a planting position which is appropriate to the site type, and which will provide the plant with microsite conditions conducive to rapid early root growth. On the peats and gleys the water-table can be within 10 cm of the surface for most of the year, with anaerobic conditions toxic to roots below this level. In such circumstances, the root system must be planted shallowly in a raised, locally drained position close to a stump on uncultivated ground, or on a mound or ridge created by cultivation equipment. On dry mineral soils, all that is necessary is to notch the plants directly into the ground surface after screefing or chemically removing any competing vegetation. On very dry sites, the plants must be put in deeply, with the root collar perhaps 5 cm below the surface.

The presence of concentrations of logging residues (see Figure 1) can lead to poor planting. A sharp spade with a straight handle (e.g. the 'Mansfield' or 'Schlich' spade) must be used to penetrate the brash layer and this can lead to excessively deep planting on waterlogged sites. Furthermore, it can be very difficult to firm the plants and this may result in the creation of air pockets below the ground that allow the roots to dry out. Where the brash is very dense, the best solution is to burn, chop or redistribute it before planting.

In all situations where planting is difficult because of site conditions, this should be recognised in the method of organising and paying the planters so that they are not encouraged to sacrifice care for speed. Allocation of individual work areas and payment on a unit area basis will ensure that the work of each planter can be properly inspected. Inspection should involve more than a count of the number of plants per hectare; it is necessary to lift plants occasionally in order to check that root systems are not broken or distorted and that they are well spread out in aerated material. In the uplands, conifers are vulnerable to windthrow especially on the wetter soils, and the expected rotation length and financial return can be greatly reduced. The ultimate pattern of the root system is determined in the first few years after planting and influences long-term stability; it is therefore important that the planting position should, as far as possible, allow unrestricted symmetrical root development, and that this should not be prejudiced by distortion or damage to the root system during planting.

Spacing

Tree spacing at the time of establishment ultimately influences timber properties through its effects on wood density, number and size of knots and the size of the juvenile core, as well as affecting establishment and harvesting costs. Recent evidence for Sitka spruce indicates that the yield of timber suitable for load-bearing structural use declines as spacing increases between 0.9 × 0.9 m and 2.4 × 2.4 m spacing, in such a way that spacing beyond 2 × 2 m cannot be recommended given current prospects for marketing. The decline is thought to be more important for the inherently low density spruce than for the higher density pines, larches and Douglas fir. Recommended *established* stocking densities are therefore 2000 stems/ha (approximately equivalent to

2.2 × 2.2 m spacing) for higher density conifers and 2500 stems/ha (equivalent to 2.0 × 2.0 m spacing) for the spruces.

Method

Every effort must be made during planting to avoid root drying, and this means irrigating 'sheughs' if necessary, and only removing one plant at a time from the planting bag, plants being most vulnerable on dry, windy days. For this reason culling must not take place during planting, but should be carried out under controlled conditions at the nursery or forest depot.

Where there is no cultivation prior to restocking, the aim should be to plant in rows running straight up and down the slope, with deviations only to ensure that the planting position takes advantage of the most favourable microsite conditions. The preferred method is to cut a vertical 'L' or 'T' notch using the spade to hinge back the soil, allowing the plant to be inserted with the roots evenly spread. In heavy brash, a single vertical notch is all that may be possible but great care must be exercised to close the notch completely by reinsertion of the spade alongside it.

Mattock planting may be appropriate for hard, dry areas, especially on sloping ground, using the adze blade to screef away the vegetation, cultivating the patch with the pick, and finally opening a planting hole with the adze. On ploughed peaty soils, it may be possible to use the semicircular spade technique for planting in the centre of the spoil ridge.

8. Beating up requirements

When considering the necessity for replacing early failures it is important to bear in mind that the aim will normally be to achieve an established crop of acceptable density and evenness of stocking. In the case of Sitka spruce the recommended established stocking density is 2500 trees per net ha at age 5 years, while for pines, larches and Douglas fir a density of 2000 trees/ha is acceptable. It is important to beat up promptly because delay will give replacements little chance of keeping up with the original trees and so lead to uneven stand development. Reasons for high losses (in excess of 10 per cent) should be investigated in order to allow improvement of methods or mitigation of adverse factors prior to beating up. It will not normally be worth continuing to replace losses on an individual tree basis for more that 3 years, unless a faster growing species can be used (e.g. larch for beating up pine or Douglas fir). Making good large gaps can continue for longer provided that adjacent trees are not likely to overtop and shade out the replacements.

9. Natural regeneration

Most of the conifer species planted commercially in the uplands, including Sitka spruce, can produce prolific natural regeneration under favourable circumstances (Figure 7). Good seed years however occur only once in 3–10 years depending on species, and it is not possible to predict this occcurrence with accuracy. Norway spruce so rarely produces adequate quantities of seed under British conditions that significant natural regeneration is unlikely. Predation of the seed of a number of conifer species by seed wasps can reduce the amount of viable seed fall, and the occurrence of the Douglas fir seed wasp *Megastigmus spermotrophus* is so general that Douglas fir regeneration is effectively restricted to particularly good seed years. Hybrid larch does not breed true and the use of natural regeneration for this species will lead to a decline in vigour and form.

Recruitment from naturally regenerated seedlings can at times reduce significantly the need to beat up planted crops. However, British forest managers have rarely sought to use natural regeneration as an alternative to planting for restocking felled areas in upland conifer plantations. Insufficient is known about the combination of site conditions required to promote its successful establishment, and it would frequently impose unacceptable constraints on harvesting plans if attempts were made on any significant scale to synchronise fellings with heavy seed years. The possible use of any system involving the retention of seed trees is highly restricted by the likelihood of the latter being windthrown. Furthermore, it can take several years after felling for the establishment of an acceptable stocking level over the whole of a clear felled area, and the achievement of this may in fact be prevented by the rapid development of weed growth on more fertile sites.

Conditions favourable to the establishment of natural regeneration

Some naturally regenerated conifer seedlings can be found on most clear felled sites, the number per hectare being related more to previous management practice than to inherent site conditions. Premature felling of the parent stand reduces the amount of seed available. Young seedlings are vulnerable to desiccation, mammal damage and weed competition, and benefit from a certain amount of shelter and shade, although they cannot survive in dense shade. It follows that mature stands which have been heavily thinned or contain pockets of windthrow are most likely to provide favourable conditions for natural regeneration. The clear felling of a mature, cone-bearing stand may also give rise to a dense carpet of seedlings, although this may be distributed unevenly and concentrated mainly in brash covered areas.

Scarifiers have been developed in Scandinavia primarily for the encouragement of natural regeneration through redistribution of the lop and top to improve the uniformity of stocking, and provision of strips or patches of bare mineral soil. A regime designed to encourage natural regeneration would involve a combination of heavy thinning, seeding or shelterwood fellings, and scarification.

Figure 7. Dense natural regeneration of Sitka spruce on a clear felled peaty gley site in Clocaenog Forest, north Wales.

Management of established natural regeneration

In some forest areas, notably in mid Wales and south Scotland, dense stands of natural Sitka spruce seedlings have appeared spontaneously, and it is necessary to consider how best to manage these. Stocking is often in the region of 10 000 – 100 000 stems/ha, and the reduction of stand density through natural mortality is a slow process. Competition restricts diameter growth severely whilst having relatively little effect on height growth, so that naturally regenerated stands are likely to have a low mean diameter and commensurately low sawlog content within a normal rotation, unless some respacing is carried out. Since the stand closes canopy at a very early stage, there is an increasing penalty to pay in terms of reduced volume production the longer this respacing operation is delayed, because growth of the favoured trees will have been retarded by competition during the period between canopy closure and respacing.

Respacing poses a number of practical problems, and, depending on timing, may involve the use of chemicals, clearing-saws or chainsaws as follows:

1. Height <1 metre. The stand may be sprayed with herbicide either in bands or using two passes at right angles to leave small clumps at 2 m centres. At present only paraquat as 8 litres 'Gramoxone 100' diluted to about 400 litres/ha applied during the growing season can be recommended, although research into the use of glyphosate with suitable additives is giving promising results. The operation will cheaply provide for access to carry out selective respacing at a later date.
2. Height 1 – 3 metres. Respace using a clearing-saw. In many instances there is difficulty in cutting below the bottom live whorl of branches, and these branches can turn upwards and eventually compete with the chosen crop trees. This problem can be avoided by painting the cut stumps with glyphosate (1 part 'Roundup' to 1 part water) immediately after cutting. Time of year does not seem to be important.
3. Height >3 metres. Respace selectively using a chainsaw. The difference in height between any regrowth from stumps and the remaining crop is usually sufficient to ensure the suppression of the former, making herbicide treatment unnecessary.

Stumps greater than 2.5 cm in diameter must be treated with urea to prevent infection by *Heterobasidion (Fomes)*. This requirement influences the choice of respacing method when so many stumps are involved, and will tend to favour delaying respacing until natural mortality has reduced the number of stumps which must be treated. Costs must be evaluated in each situation, but in general even the full cost of respacing a stand >3 m tall using a chainsaw is likely to compare favourably with the compounded cost of planting, protecting and maintaining normal transplant stock. As a result, acceptance and subsequent treatment of spontaneous natural regeneration may be an attractive option if the species and provenance of the parent stand are acceptable. The opportunity to introduce genetically improved stock must be foregone, but against this there is an opportunity for a high level of selection during respacement.

10. Fertiliser treatment

Investigations into the nutritional requirements of second rotation stands are at a relatively early stage but indications are that, for a given site, nutrient deficiency problems will, at worst, be similar to those encountered in the first rotation and will frequently be considerably reduced. No examples have yet been found of nutrient deficiency being worse in the second rotation than in the first.

The nutrient relations of the site may be affected by the previous crop in three ways:

1. There is normally a considerable litter layer on the site, decomposition of which may provide a valuable source of nutrients in the first few years of the successor crop's life.
2. Originally present weed species like *Calluna vulgaris* may have been shaded out and so will not form part of the recolonising vegetation following felling.

3. On peat soils, particularly following a Lodgepole pine crop, considerable shrinkage and cracking of the peat may have occurred, creating conditions which may be more favourable for mineralisation of the organic matter.
The effect of these is generally to create conditions leading to improved nutrient status of the successor crop.

The following recommendations are based on results to date from fertiliser experiments in Sitka spruce plantations on second rotation upland sites.

Fertile mineral soils. Brown earth, surface water gley and ironpan soils which originally carried a vegetation cover of grasses, herbs and bracken and where the first rotation was often a relatively high yielding crop of Sitka spruce or Douglas fir. Such sites generally occur on former 'in-by' agricultural land and lower valley slopes and are unlikely to show any worthwhile benefit from fertiliser application.

Heathland mineral soils. Ironpan soils, podsols and gley soils which originally carried vegetation dominated by *Calluna vulgaris* and where the first rotation was often composed of pine and larch stands. Generally, fertiliser application at time of restocking is not worthwhile on such sites, but consideration should be given to application of phosphatic fertiliser (e.g. unground phosphate rock at 450 kg/ha supplying 60 kg P per ha) in the early establishment stage (around years 6 to 10). On Old Red Sandstone areas around the Moray Firth, and on the poorest, most quartzitic Dalradian rocks, *Calluna* may rapidly re-invade restock sites, requiring some form of chemical control (see Section 11). In the worst situations elimination of the *Calluna* will not be sufficient to cure nitrogen (N) deficiency problems in spruce crops and repeated N top-dressing (e.g. urea at 330 kg/ha – supplying 150 kg N per ha) will be required to ensure satisfactory growth. On such sites consideration should be given to replanting with spruce/larch or spruce/pine mixtures rather than with pure Sitka spruce, or to the continued use of pure pine crops.

Peaty gleys. On the more fertile peaty gleys, with *Deschampsia/Molinia/Juncus* vegetation, growth of first rotation spruce stands would normally have been good without fertiliser applications. On the less fertile *Calluna / Molinia / Eriophorum / Tricophorum* peaty gleys, growth in the first rotation was probably relatively poor in the absence of fertiliser applications. In both situations, fertiliser application at time of restocking is not generally beneficial but consideration should be given to application of P to the shallow-phase peaty gleys or phosphate/potassium (PK) to sites with deeper peats (>30 cm peat) around years 6 to 10. (The PK mixture is applied at 650 kg/ha and provides 60 kg P and 100 kg K per ha.)

Deep peats. Information on deep peat restocking is limited but indications are that the growth of Sitka spruce following a first rotation of Lodgepole pine will be very good on deep peats and that no fertiliser at time of restocking will be required. As with peaty gley soils, consideration should be given to application of P or PK around years 6 to 10.

Estuarine gleys. The gley soils derived from the Estuarine deposits in the North York Moors area are exceptions to the rule that fertiliser application at time of restocking is unlikely to be worthwhile. On these very phosphate-deficient soils, application of P at planting is essential to ensure satisfactory growth, and a further P top-dressing will probably be required around year 8.

Guidance on appropriate fertiliser materials is given in Forestry Commisson Leaflet 63 *Fertilisers in the forest; a guide to materials.*

11. Weed control measures

Weeds may already be present under an open canopy at the time of felling and since the completion of a felling coupe may take some years, weeds have often recolonised part or all of the site by the time of restocking. Methods for controlling weeds using herbicides are given in Forestry Commission Booklet 51 *The use of* *herbicides in the forest*. However, it is useful here to highlight some particular aspects of weed control on clear felled sites.

Grasses

Grasses compete strongly with newly planted transplants for water, nutrients and light. Under the sometimes hostile conditions prevailing on clear felled sites, spring-planted transplants suffer from water-stress immediately after planting, and it is important to ensure that this is not exacerbated by grass competition. The best solution is to apply a herbicide before planting which will keep the planting position weed-free for the first growing season. The opportunity to apply chemicals before planting (or beating up) should not be missed, since it enables non-selective chemicals to be used at high rates without danger of crop damage. Weeding later in the year serves mainly to eliminate competition for light in that year, although there may be some carry over effect in the following year. However, the benefit conferred by absence of moisture competition is normally only of importance during the first growing season. Hand weeding does nothing to eliminate moisture competition since grass roots are not killed and even the effect on competition for light can be short lived, so that chemical weeding with a herbicide capable of killing the whole grass plant is the preferred method.

After the initial establishment stage it is important to ensure that small trees do not become smothered by weeds, and that trees used for beating up are planted into weed-free spots. The number of weedings and the length of the weeding period will be increased if small plants are used, if the plants suffer animal damage, or if they are otherwise debilitated in a way which reduces survival or early growth.

Calluna

Clear felling on former heathland sites may be rapidly followed by *Calluna* re-invasion as mentioned in the preceding section. Where this occurs, chemical control using 2,4-D or glyphosate may be required to prevent heather check developing in replacement spruce crops.

Woody weeds

Coppice regrowth of unwanted tree species or of *Rhododendron ponticum* can be troublesome in some areas. In many cases it is difficult to find suitable selective herbicides for use after replanting has been done, and it is therefore best to tackle the regrowth *before* the new crop is planted. This usually necessitates postponing replanting for a full season after felling to allow the regrowth to come into full leaf, and then treating this new foliage with a suitable contact herbicide in late summer. Planting can then be done in the following spring. Where there is scattered growth of *Rhododendron* beneath a mature crop it is worth applying herbicide treatment in advance of felling.

12. Protection against Pine weevil and Black pine beetles

When coniferous crops are felled the young plants used for restocking are almost invariably at risk from attack by *Hylobius abietis,* the Large pine weevil, and *Hylastes* species, commonly called Black pine beetles. These are the only insect pests of general importance at the time of restocking and they call for routine preventive measures. In both cases the common name is misleading. The Pine weevil breeds readily in stumps and felled material of all common conifers and is able to inflict heavy damage on young plants of all such species; it also attacks young hardwoods on occasion. There are six British species of *Hylastes;* some of these are found more commonly on pines and one of them more commonly on spruce but members of the genus will attack all common conifers.

Both *Hylobius* and *Hylastes* are endemic in established woodlands throughout Britain, breeding in windblown trees and in stumps and material left lying after thinning. In these circumstances, adult Pine weevils feed on the thin bark of twigs in the crowns of trees but their numbers are usually too small for the damage to be significant; adult *Hylastes* species feed either in breeding material, so long as it remains suitable, or in the roots of crop trees. When clear felling and replanting take place the tree stumps provide a sudden large increase in breeding material for both insects, which is rapidly exploited, while the only thin bark in fresh condition available is that of the new plants. These are then liable to be heavily attacked by adult Pine weevils feeding on the stem from the root collar upwards (Figure 8) and by adult Black pine beetles tunnelling in the main part of the root system from the root collar downwards. The resultant girdling quickly causes the death of young trees.

The period for which freshly cut stumps remain suitable for breeding varies with their size and the conditions for deterioration of cambium. In general small stumps are rapidly exploited, sometimes within a single year, while larger stumps may support a population build-up over several years. The fact that stumps

Figure 8. Pine weevils feeding on a young Scots pine.*(D6406)*

eventually become unsuitable as breeding material has, in the past, been used as a method of avoiding attack – a fallow period of 5 years before replanting being recommended. Such a delay does not make good use of land and may result in the development of excessive weed growth by the time of planting; furthermore it would not be effective in the case of contiguous fellings over a period of years.

The life histories of both Pine weevil and Black pine beetles are such that attack by the adults may occur throughout the active season, sometimes continuing until late into the autumn. However there is a tendency for two peaks of Pine weevil attack to occur – one in spring and one in late summer. As already indicated, attacks by *Hylobius abietis* and *Hylastes* spp. can occur together as the result of similar response to circumstances, but damage due to *Hylastes,* being below ground, is easily overlooked.

Further information on these insects is available in Forestry Commission Leaflet 58 *The large pine weevil and black pine beetles.*

If adequately protected against damage by Pine weevil and Black pine beetles, healthy transplants will usually grow in 2 or 3 years to a size at which damage is unlikely to be serious; by this time too the local population may well be dwindling. In the first instance, adequate protection of planting stock requires treatment with an insecticide at high concentration prior to planting. This should be effective throughout the first season and should normally give reasonable protection in the second season. Where there is heavy and persistent insect attack this initial protection may need to be supplemented by further treatment of plants in the forest 1 to 3 years after planting. The following recommendations for these treatments are based on those given in Forestry Commission Booklet 52 *The use of chemicals in forest and nursery.*

For treating plants prior to planting, first prepare a tank or large drum with the required quantity of Gammacol or an emulsifiable concentrate (e.c.) formulation of gamma HCH diluted to 1.6% with water. To ensure adequate dispersal begin by mixing the concentrate in a few litres of water only, then dilute to the required volume. Loosen the bundles of transplants, shake off all loose soil particles and immerse the upended bundles in the mixture to cover the tops and up to a quarter of the main roots but *not* the fibrous root systems. The bundles should be agitated sufficiently to ensure coverage of the plant surfaces. Remove the bundles and allow surplus insecticide to drain back into the tank, avoiding contact between the insecticide and the root systems which should at the same time be protected from desiccation. Before planting out or exposing plants to wet weather it is essential that the insecticide deposit be dry. Heel-in plants, under cover if necessary.

The insecticide solution should be stirred at frequent intervals while in use and particularly after rest periods. Dipping will of course reduce the volume of liquid in the tank but it also reduces the concentration of solution disproportionately and this loss should be made good by adding additional concentrate at intervals. For example, if 1500 l of solution are used the concentration will fall from the initial 1.6% by approximately 0.1% for every 30 000 plants dipped; and replenishment by adding an appropriate quantity of concentrate would be recommended after every 120 000 plants dipped (i.e. when the concentration is likely to have fallen to 1.2%). The overall volume loss should also be made good, using fresh 1.6% solution of the chemical.

After a period of dipping a sludge of soil and insecticide will have formed in the bottom of the tank; this and any surplus solution must be disposed of safely, particular care being taken to ensure that insecticide cannot find its way into water courses. (See Ministry of Agriculture, Fisheries and Food Booklet B2198 *Guidelines for the disposal of unwanted pesticides and containers on farms and holdings.)*

Where supplementary protection of plants in the forest is required individual plants should be sprayed in dry weather to run-off with an e.c. formulation of gamma HCH at 0.125% in water directed at the stems. Overall application of insecticide to the planted area with a mistblower or ultra-low volume device is not a satisfactory treatment method.

Dipping in insecticide at high concentration has been the standard method of providing initial protection against *Hylobius abietis* and *Hylastes* spp. over the past 30 years. Gamma HCH used in this way can produce phytotoxic effects, usually in the form of a small reduction in growth over the first year or two compared with that of unprotected plants; exceptionally there may be more severe effects but it then often seems that other factors such as spring drought, plant handling and quality of plants, and planting techniques are also involved. There is some evidence that e.c. formulations of gamma HCH are more phytotoxic than Gammacol, particularly in the case of Douglas fir. On the other hand the e.c. formulations maintain more stable solutions in water so that there is not such a heavy settling of insecticide into the sludge at the bottom of the dipping tank. The choice of formulation should be made by the forest manager in the light of local experience.

Manual dipping may not be the most efficient way of applying insecticide to very large numbers of plants and Forestry Commission staff are currently investigating alternative methods of treating lifted plants, as well as testing alternative insecticides for efficacy and possible phytotoxic effects.

13. Pathological considerations

At the present time the majority of losses on restocking are caused by factors such as poor plant handling or herbicide misuse which can be grouped together under the term 'cultural malpractice', and which are largely avoidable by management action. On the other hand, losses due to diseases or to climatic extremes are relatively insignificant. Some of these problems are unpredictable and therefore unavoidable but those caused by *Heterobasidion annosum (Fomes annosus), Armillaria* species, *Rhizina undulata,* and frost, can either be avoided altogether or can be mitigated by management action.

Heterobasidion annosum

Appropriate stump treatments should be used throughout the life of the crop and at final clear felling. Ploughing before replanting does not obviate the need for treatment of clear felling stumps and is unlikely to affect adversely the degree of control achieved.

Managers should determine whether *H. annosum* is already established in the crop to be felled. In the case of spruces, larches and hemlock its presence will be shown by butt decay in the final crop but care should be taken, especially in Norway spruce, to distinguish decay caused by *H. annosum* from decay associated with extraction wounds which is usually caused by other fungi. Severe butt-rot is unlikely to be evident in Douglas fir but root-rot may have given rise to windthrow and fruit bodies would normally be present on stumps in infected crops. Damage in pine may be harder to identify at the clear felling stage since attacks are confined to killing and do not cause rot. Moreover, killing attacks usually occur in young crops and typically subside as the crop ages, leaving gaps as the only clue to earlier damage. In these circumstances recent thinning stumps should be examined for the presence of fructifications which, in open crops, tend to be hidden under grass or brash.

On severely infested sites, which are most likely to be those with one or more previous conifer rotations, it might be necessary to consider the use of Douglas fir, Grand fir or even hardwoods in order to reduce losses in the replanted crop. Eradication of *H. annosum* by stump removal is unlikely to be justifiable in the uplands. Forestry Commission Leaflet 5 *Fomes annosus* provides further information.

Armillaria species

Several species of *Armillaria* are present in Britain, but not all of them are pathogenic; suppressed trees, and trees killed by other agents, frequently become colonised by non-pathogenic species. For this reason *Armillaria* can be disregarded unless there is evidence that killing attacks occurred in the previous crop. Where severe attacks have occurred consideration should be given to use of relatively resistant species such as Douglas fir, *Abies* species or hardwoods. For further information see Arboricultural Leaflet 2 *Honey fungus.*

Rhizina undulata

Serious losses can occur after small fires in pole-stage Sitka spruce in the uplands, but there is no information on the risk of damage to newly planted trees following brash burning on felled areas. Death of young trees in restocked areas has been reported on a number of occasions from lowland forests, suggesting the possibility that the paucity of damage records from the uplands may be more a reflection of the relatively low level of restocking so far, and the avoidance of burning, rather than the true potential of this disease. If it is considered desirable to burn brash on clear fell sites it should be done on a small scale until the risk of damage can be established. Further information is given in Forestry Commission Leaflet 65 *Group dying of conifers.*

Frost

In upland areas subject to severe late spring frosts young Sitka spruce has been killed to ground level on a number of occasions during the last 10 years. Use of southerly origins, such as Washington and Oregon, should be avoided on these sites.

14. Wildlife damage and control measures

The most widespread and important forms of damage by vertebrate animals on upland restocking sites are the browsing of leading shoots by roe, red or sika deer and bark-stripping by red or sika deer. Locally serious browsing damage can be caused by hares, rabbits, voles and feral goats, and also by domestic sheep.

Deer

Trees are seldom killed by deer, though attempts to browse newly planted stock can result in trees being pulled out of the ground. Most species of trees may be browsed by deer, but vary in palatability and therefore in the degree to which they will be damaged. Species also vary considerably in their ability to recover from browsing damage.

Sitka spruce, the most widely planted species, may suffer extensive browsing damage (Figure 9) but usually makes an effective recovery. Compensatory growth may result in trees recovering quickly and possibly 'catching-up' in growth with their unbrowsed neighbours. Once Sitka spruce has reached a height of 80 – 120 cm its susceptibility to browsing damage declines significantly. Multiple leaders may result from the browsing of a leading shoot, though a single shoot usually attains dominance.

Figure 9. Typical result of repeated deer browsing on a young Sitka spruce tree. Note multiple leaders and strong fresh growth from just below the most recent damage level.

In extensive areas of Sitka spruce where red or sika deer are present, up to 1 per cent of trees may suffer bark stripping damage each year during the vulnerable thicket and polestage periods, though wound recovery is usually rapid and little fungal entry is apparent. On a local scale, outbreaks of bark stripping damage to Sitka spruce may involve up to 20 per cent of the crop, though such occurrences are infrequent. The bark of Sitka spruce is apparently much less palatable to deer than that of Lodgepole pine and Norway spruce, which often suffer widespread and severe damage. In Norway spruce this may be followed by severe fungal invasion and often by windsnap. Hence both Lodgepole pine and Norway spruce crops may need to be fenced in forests with red or sika deer populations.

Larches, Silver firs and Douglas fir are also susceptible to browsing and bark stripping damage but little quantitative information is available. Scots pine may be browsed severely at an early stage, though it frequently recovers and is unlikely to suffer from bark stripping, making it a possible alternative to Lodgepole pine on suitable sites. Any broadleaved trees planted will suffer severely from browsing.

The size of clear fell coupes may well influence the way in which they are used by deer and in consequence the amount and distribution of browsing damage after replanting. Red and sika deer prefer to remain close to cover and will concentrate their activity around the edges of large restocking areas. The effect is much less marked with roe deer, presumably because their smaller size ensures that ample cover is available for them throughout such areas at an early stage. Pre-thicket and thicket stage crops will support the highest densities of roe and red deer respectively, and restocked areas close to crops of this age will therefore be exposed to the highest risks. If information is required on the extent of damage present, this can be obtained using the survey procedure described in Forestry Commission Leaflet 82 *Assessment of wildlife damage in forests.* Where significant numbers of trees have been destroyed, beating up will be required to ensure an adequate stocking density. The consequences of differing amounts of browsing or bark stripping damage are less easy to evaluate, and the degree of protection which can be justified must be based on a subjective appraisal of the probable economic effects of the damage on the final crop.

There appears to be no simple relationship between damage levels and deer numbers. Red deer densities of 5–15 deer/km^2 and roe deer densities of 10–40 deer/km^2 are commonly encountered in coniferous upland forests with a wide range of age classes. The control of woodland deer populations at these densities requires the killing of 3–5 red or sika deer and 4–8 roe deer/km^2 each year with at least 50 per cent of the cull being of females. Experience suggests that this is possible to achieve for red and sika deer, especially where access is good, but that it is unlikely to be achieved over large areas of upland spruce forests for roe deer. It is therefore recommended that for roe deer most effort should be placed on local control in and around the vulnerable areas, while aiming for more general control of the red and sika deer population within the forest (and if necessary giving special attention to the vicinity of restocking areas).

To reduce deer damage, felling coupes should be as large as possible, particularly where red and sika deer are concerned. Shooting on restocked areas should be most intensive during the first summer when deer may pull out the newly planted trees, particularly on restocked areas close to pre-thicket stage crops. The open nature of newly restocked sites makes shooting easier and access by rangers or stalkers is seldom a problem. However, in order to facilitate future deer control grassy herb-rich areas and stream sides should be selected at the time of planting and left unplanted as deer glades.

Attitudes to the use of fencing to protect Sitka spruce restocking areas against deer vary widely between regions and depend largely on local experience. In some localities no fencing is done while in others it is considered impossible to establish trees without fencing against both roe and red deer. These differences may well be related to other factors such as soil fertility, weed growth, plant size and coupe size. Any species diversification away from Sitka spruce is likely to increase damage levels and make fencing essential, although in the case of broadleaved planting, individual tree protection may be feasible. Fencing cost per unit area will be minimised if regularly shaped areas in excess of 40 ha are involved, but this may not be attainable for landscaping and other considerations. Fencing methods and materials are described in Forestry Commission Forest Record 80 *Forest fencing.*

Sheep

As a result of boundary fence damage or neglect during the first rotation, it is not uncommon for domestic sheep to have entered and become hefted within forest areas. Where this has occurred serious browsing damage (comparable with that produced by deer) can result in replanted areas unless the sheep are removed from the forest and boundary fences made good, or are excluded by fencing individual restocked areas. The most appropriate course of action will depend on local circumstances and relative costs.

Other animals

Voles occasionally cause widespread and severe stem girdling damage on restocking sites, usually in years of peak vole densities. Poisoning with warfarin can be effective in controlling numbers but is costly, labour-intensive and unlikely to be practicable over large areas. Dying trees are often the first sign of a vole peak, by which time the population is in natural decline and the damage has ceased. If prevention is to be achieved, constant vigilance is required in early spring to detect rising densities; the best course may be to delay planting or beating up until the population has declined.

Damage by rabbits, hares, feral goats,

blackgrouse and capercailzie may occasionally become a problem. The gassing of rabbit burrows is recommended (see Forestry Commission Leaflet 67 *Rabbit management in woodlands),* but where the problem is particularly serious fencing may be required; and where access for gassing is difficult one may need to resort to snaring, ferreting, netting, or shooting. The shooting of hares and feral goats may sometimes be necessary. Capercailzie and blackgrouse damage is seldom extensive and unlikely to warrant control measures.

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