Reducing Pesticide Use in Forestry

PRACTICE GUIDE

Forest Research

Forestry Commission

Forestry Commission

Practice Guide

Reducing Pesticide Use in Forestry

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Forestry Commission: Edinburgh

First published in 2004 by:
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Edinburgh EH12 7AT

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ISBN 0 85538 617 7

WILLOUGHBY, I., *et al*. (2004).
Reducing pesticide use in forestry.
Forestry Commission Practice Guide.
Forestry Commission, Edinburgh. i–iv + 1–140 pp.

Keywords: alternatives to pesticides, browsing mammals, environmental impact, fungicides, herbicides, insecticides, insects, integrated forest management, pathogens, pesticide reduction, pesticides, rodenticides, weeds.

Printed in the United Kingdom
on Robert Horne Hello Matt

FCPG015/FG(KMA/ECD)/NMS-3500/APR04

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Acknowledgements

The following made helpful comments on the text: Gary Kerr, Paul Tabbush, John Budd, Norman Day, Fiona Kennedy, David Williamson, Crispin Thorn, Stephen Smith, Colin Edwards, Joan Webber, Bill Rayner, Alan Harrison, Donald McNeill, Bill Jones and Garin Linnington. Useful editorial comments were provided by Jenny Claridge. Typing services were provided by June Bell, Mavis Peacock, Sue Stiles and Sally Simpson.

Contents

Appendices

Managers are advised to seek expert advice if they are unsure about any aspect of pest or weed identification or management.

Forest Research run a Disease Diagnostic and Advisory Service for advice on all aspects of tree diseases and disorders, including identifying the nature of the problem, its consequences and the need for any action. Telephone 0131 445 6943 for enquiries relating to trees established north of the Humber/Mersey line; 01420 23000 south of the Humber/Mersey line. Full details of the service are available on the Forestry Commission website: **www.forestry.gov.uk/forest_research**

For advice on all aspects of woodland management including managing pest and weed problems, users are advised to contact a Chartered Forester – the Institute of Chartered Foresters holds a register of qualified members, and they can be contacted on 0131 225 2705, or via their website **www.charteredforesters.org**

Alternatively, for specific advice on pesticide operations, contact a BASIS registered professional advisor. A list of qualified advisors is available from BASIS on 01335 343945, or via their website **www.basis-reg.co.uk**

Forest Research Disease Diagnostic and Advisory Service

Advice on specific aspects of the text of this guide is available from:
Forest Research
Alice Holt Lodge
Farnham
Surrey
Tel: 01420 23000
Email: ahl@forestry.gsi.gov.uk.

Introduction

Pesticide use in the UK is governed by a tight regulatory framework, details of which are given in Appendix 1. In addition, UK Government and European Union policy is to minimise pesticide use as far as possible. The code of practice for the safe use of pesticides for non-agricultural purposes obliges managers and operators to consider whether, in any given situation, pesticide use is really necessary. In addition, reduction and, where practical, eventual elimination of pesticide use is a requirement for some voluntary certification initiatives such as the *UK Woodland Assurance Standard*. It is vital therefore that forest managers give timely and serious consideration to non-chemical methods of pest and weed management.

The main aims of this guide are:

- To provide information on, and encourage the use of, non-chemical methods of pest and weed control.
- To provide a decision framework which can be used for all major pest and weed control problems in British forestry.
- To help managers reduce the risk of damage to the environment.
- If chemical use is unavoidable, to assist managers in keeping such use to the minimum level necessary, consistent with good practice.

This guide is not intended to replace detailed advice on pesticide use contained in sources such as Forestry Commission Field Book 8: *The use of herbicides in the forest*, and Field Book 14: *Herbicides for farm woodlands and short rotation coppice*, the HSC Code of practice on *The safe use of pesticides for non-agricultural purposes* and specific product labels. These remain essential reference texts which detail good working practice when dealing with pesticides, and their use within an integrated decision-making process for pest and weed control is highlighted in this guide. Similarly, this guide does not attempt to replace existing advice on pest, disease or weed identification. It does, however, provide references and sources of expert advice for this essential step within the decision process.

How to use this guide

The simplest way to use this guide is to complete the decision recording sheet on page 3 by working through the decision keys on pages 4 and 5. The decision keys list the steps that are necessary in planning a pest, disease or weed control operation. The rest of the guide acts as a reference source to support this process, and is split into two main parts. In Part 1, sections 1.1 to 1.3 deal with managing pests and diseases, vegetation and wildlife respectively. Each of these sections consists of an introduction that sets the context for the general problem as it affects British forestry (e.g. vegetation), followed by subsections on specific problems (e.g. bracken, woody weeds). For each specific problem the background, consequences and options for control are detailed. Options for control are split into 'take no action', 'avoid the problem' and 'take remedial action'. Remedial action measures are tabulated and include information on efficacy, environmental risk and cost. If a chemical method of pest or disease control has to be adopted and a choice of product exists, Part 2 gives guidance on selecting those with a lower risk of negative impacts on the environment. An optional decision aid that may assist in this process is provided in Appendix 4. References and further reading are given at the end of each section. A checklist detailing good working practice when using pesticides is provided on page 130. Throughout the text active ingredients of pesticides are generally referred to rather than formulations, in order not to give the impression of product endorsement when there are two or more pesticides with the same approval status and active ingredients.

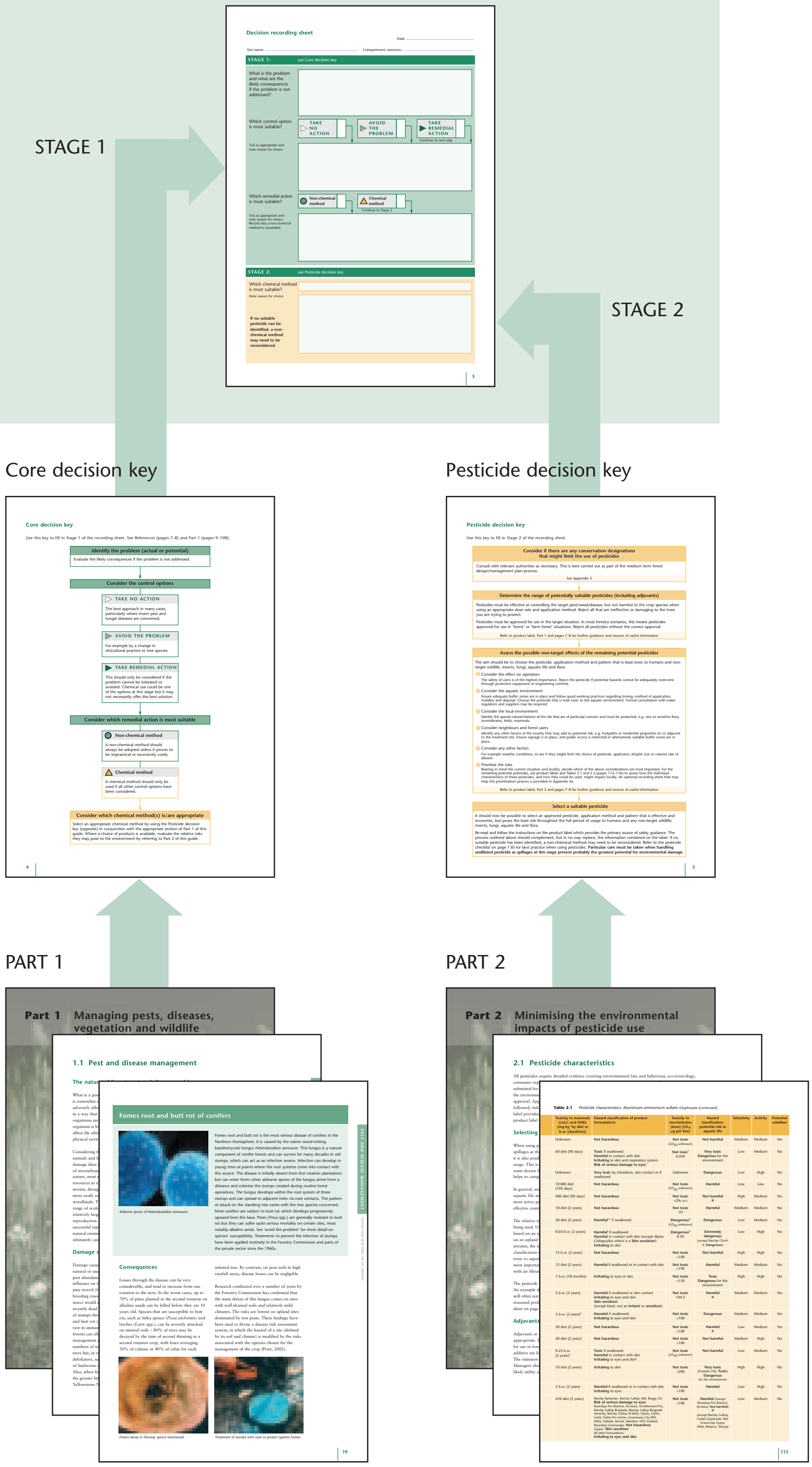
Further copies of the decision recording sheets and pesticide decision key are available from:
www.forestry.gov.uk/pesticides

Structure of the guide

Decision recording sheet
[page 3] should be archived for future reference.

Decision keys
[page 4–5] use the keys to aid the completion of the Decision recording sheet

Parts 1 and 2
of the guide give supporting information and sources of further advice to aid the decision making process



Decision recording sheet

Completed by: .... Date: ....

Site name: .... Compartment name/no.: ....

STAGE 1: use Core decision key

What is the problem and what are the likely consequences if the problem is not addressed?

Which control option is most suitable?

TAKE NO ACTION	AVOID THE PROBLEM	TAKE REMEDIAL ACTION
		Continue to next step

Tick as appropriate and note reason for choice.

Which remedial action is most suitable?

Non-chemical method	Chemical method
	Continue to Stage 2

Tick as appropriate and note reason for choice. Record why a non-chemical method is unsuitable.

STAGE 2: use Pesticide decision key

Which chemical method is most suitable?

Note reason for choice.

If no suitable pesticide can be identified, a non-chemical method may need to be reconsidered.

Archive this sheet in a safe place for future reference.

Core decision key

Use this key to fill in Stage 1 of the recording sheet. See References (pages 7–8) and Part 1 (pages 9–108).

Identify the problem (actual or potential)

Evaluate the likely consequences if the problem is not addressed.

↓

Consider the control options

▷ TAKE NO ACTION

The best approach in many cases, particularly where insect pest and fungal diseases are concerned.

▷ AVOID THE PROBLEM

For example by a change in silvicultural practice or tree species.

▶ TAKE REMEDIAL ACTION

This should only be considered if the problem cannot be tolerated or avoided. Chemical use could be one of the options at this stage but it may not necessarily offer the best solution.

↓

Consider which remedial action is most suitable

● Non-chemical method

A non-chemical method should always be adopted unless it proves to be impractical or excessively costly.

△ Chemical method

A chemical method should only be used if all other control options have been considered.

↓

Consider which chemical method(s) is/are appropriate

Select an appropriate chemical method by using the Pesticide decision key (opposite) in conjunction with the appropriate section of Part 1 of this guide. Where a choice of products is available, evaluate the relative risks they may pose to the environment by referring to Part 2 of this guide.

Pesticide decision key

Use this key to fill in Stage 2 of the recording sheet.

Consider if there are any conservation designations that might limit the use of pesticides

Consult with relevant authorities as necessary. This is best carried out as part of the medium term forest design/management plan process.

See Appendix 2

↓

Determine the range of potentially suitable pesticides (including adjuvants)

Pesticides must be effective at controlling the target pest/weed/disease, but not harmful to the crop species when using an appropriate dose rate and application method. Reject all that are ineffective or damaging to the trees you are trying to protect.

Pesticides must be approved for use in the target situation. In most forestry scenarios, this means pesticides approved for use in 'forest' or 'farm forest' situations. Reject all pesticides without the correct approval.

Refer to product label, Part 1 and pages 7–8 for further guidance and sources of useful information

↓

Assess the possible non-target effects of the remaining potential pesticides

The aim should be to choose the pesticide, application method and pattern that is least toxic to humans and non-target wildlife, insects, fungi, aquatic life and flora.

? Consider the effect on operators

The safety of users is of the highest importance. Reject the pesticide If potential hazards cannot be adequately overcome through protective equipment or engineering controls.

? Consider the aquatic environment

Ensure adequate buffer zones are in place and follow good working practices regarding timing, method of application, mobility and disposal. Choose the pesticide that is least toxic to the aquatic environment. Formal consultation with water regulators and suppliers may be required.

? Consider the local environment

Identify the special natural features of the site that are of particular concern and must be protected, e.g. rare or sensitive flora, invertebrates, birds, mammals.

? Consider neighbours and forest users

Identify any other factors of the locality that may add to potential risk, e.g. footpaths or residential properties on or adjacent to the treatment site. Ensure signage is in place, and public access is restricted or alternatively suitable buffer zones are in place.

? Consider any other factors

For example weather conditions, to see if they might limit the choice of pesticide, applicator, droplet size or volume rate of diluent.

? Prioritise the risks

Bearing in mind the current situation and locality, decide which of the above considerations are most important. For the remaining potential pesticides, use product labels and Tables 2.1 and 2.2 (pages 112–116) to assess how the individual characteristics of these pesticides, and how they could be used, might impact locally. An optional recording sheet that may help this prioritisation process is provided in Appendix 4a.

Refer to product label, Part 2 and pages 7–8 for further guidance and sources of useful information

↓

Select a suitable pesticide

It should now be possible to select an approved pesticide, application method and pattern that is effective and economic, but poses the least risk throughout the full period of usage to humans and any non-target wildlife, insects, fungi, aquatic life and flora.

Re-read and follow the instructions on the product label which provides the primary source of safety guidance. The process outlined above should complement, but in no way replace, the information contained on the label. If no suitable pesticide has been identified, a non-chemical method may need to be reconsidered. Refer to the pesticide checklist on page 130 for best practice when using pesticides. **Particular care must be taken when handling undiluted pesticide as spillages at this stage present probably the greatest potential for environmental damage.**

References and useful sources of information

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Diseases and disorders of forest trees.
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How to obtain the publications

HSE/HSC publications are available from HSE Books, tel: 01787 881165, www.hsebooks.com/books

MAFF publications are available from Defra, tel: 08459 335577, www.defra.gov.uk.

SEPA guidelines are available from:
www.sepa.org.uk/guidance/ppg/ppghome.htm

All the Forestry Commission and UKWAS publications listed above or elsewhere in this guide that remain in print are available either to download from the Forestry Commission website: **www.forestry.gov.uk/publications** or:

Forestry Commission Publications
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LS23 7EW

Tel: 0870 121 4180
Email: forestry@twoten.press.net

To arrange for access to, or copies of, Forestry Commission publications that may no longer be in print, or to other journal articles referred to elsewhere in this guide, contact the Forestry Commission library at:

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Alice Holt Lodge
Farnham
Surrey GU10 4LH

Tel: 01420 23000
Email: library@forestry.gsi.gov.uk

Other books listed above are available from good booksellers.

Part 1 Managing pests, diseases, vegetation and wildlife

1.1 Pest and disease management

The nature of forest pest and disease problems

What is a pest organism? The term pest, whether applied to pathogens, invertebrates or mammals is somewhat subjective. In this guide it will be used to cover any of the damaging agents that can adversely affect trees. Trees interact with many organisms, but it is only when they affect the tree in a way that is detrimental to a particular objective, for example timber production, that the organisms are defined as pests. Pest problems do not necessarily arise simply because the pest organism is living in or on the tree. There are often multiple interactions to consider that will affect the ultimate status and impact of a pest. Frequently, these interactions include features of the physical environment, as well as other organisms at the same or different level of the food chain.

Considering that plant-feeding invertebrates have the greatest abundance and diversity among all animals and have colonised virtually all ecosystems, it is surprising that they do not cause greater damage than is already observed worldwide. To a large extent, this is because of the co-evolution of invertebrates, their host plants and the natural enemies that prey on the plant consumers. In nature, most species are in balance and it is relatively uncommon for over-exploitation of resources to take place; however, catastrophic influences, such as wildfires, strong winds, snow storms, droughts and floods, can change the natural balance, often favouring herbivores that can more easily exploit the weakened plant resources. This is particularly the case for forests and woodlands. The various attributes of trees, such as longevity, great size, availability of a wide range of ecological niches for colonisation and widespread distribution, enable them to tolerate relatively large insect and fungal populations without significant impacts on growth and reproduction. A shift in the balance towards invertebrate herbivores can result in rapid and successful reproduction when the invertebrates outstrip both the food supply and the ability of natural enemies to regulate them. In such situations, invertebrates can reach pest status and can ultimately cause extensive tree mortality.

Damage caused by indigenous pests

Damage caused by indigenous pests on native trees can occur for a variety of reasons, either natural or under the influence of man. Although natural catastrophic events and their effects on pest abundance cannot be avoided, it is anthropogenic factors that have probably had most influence on the potential for developing pest status. For example, some insect pests, such as the pine weevil (*Hylobius abietis*) are problems only in managed plantations where large quantities of breeding resources, in the form of fresh stumps, are made available directly after tree felling. This insect would normally be an opportunist, relying on the relatively uncommon appearance of recently dead trees arising from environmental events or natural succession. Similarly, the creation of stumps through thinning and clearfelling operations in conifer woodland can allow Fomes root and butt rot (*Heterobasidion annosum*) to increase greatly within a stand, whereas the disease is rare in unmanaged stands. Even apparently unrelated events that on first sight appear to benefit forests can ultimately lead to increased pest outbreaks. A compelling example is the fire management campaign in the USA and Canada in which steps have been taken to reduce the numbers of natural fire events. Ostensibly, these measures appear to aid longer survival of existing trees but, in reality, fire control has changed natural succession towards tree species favoured by defoliators, such as the spruce budworm (*Choristoneura fumiferana*). The frequency and severity of budworm outbreaks have increased significantly since the fire suppression campaigns began. Also, when fires do take place, their intensity is much greater than it was in the past because of the greater litter layer that is now present. This was the cause of the serious, tree-killing fires in Yellowstone National Park in the USA during 1988.

Indigenous pests can also cause problems on introduced trees. The failure of some apparently suitable trees to thrive in Britain may be due, at least in part, to the effects of indigenous pests. When a tree fails at the outset, little is lost. More significant losses occur in situations where an introduced species is planted on a large scale and is then attacked by a native pest. The elevation of pine beauty moth (*Panolis flammea*) from a widespread but uncommon insect on Scots pine (*Pinus sylvestris*) to a major tree-killing pest on lodgepole pine (*Pinus contorta*) is linked entirely to extensive planting of the latter, non-native species in Caithness and Sutherland.

Damage caused by introduced pests

Many of the most serious pest problems on indigenous trees have resulted from the movement of the causal organisms from one region of the world to another. These organisms have not co-evolved with their new hosts and the hosts may have no defensive systems to counteract them nor are there natural biological controls in place. A classic example is provided by the effects of *Cryphonectria parasitica*, the cause of chestnut blight on *Castanea* sp. It causes virtually no damage in the far east where it is native but it has been extremely destructive to the chestnuts of North America and Europe.

A special feature of the UK is its very small number of native tree species. This has led to a series of introductions of trees, first from mainland Europe and then from further afield. Some associated pests have followed at intervals (e.g. the larch bark beetle (*Ips cembrae*) from Europe), whereas others are still absent (e.g. the weevil (*Pissodes strobi*) an important pest of Sitka spruce (*Picea sitchensis*) in western North America).

Damage caused by pests that have undergone genetic change

Both indigenous and introduced pests are subject to natural genetic change – and there is the possibility that this will increase their potential for damage. These changes involve mutation and recombination of genetic material during sexual reproduction. Much depends on the nature of the host/pest relationship and on the ‘selection pressure’ that is placed on the pest, e.g. new races of poplar rust (*Melamspora* spp.) have arisen recently following widespread planting of new cultivars resistant to the races present at the time.

When related indigenous and introduced pests encounter each other, there is the possibility of hybridisation and the consequent emergence of new forms. An example causing current concern is the fungus that causes the phytophthora disease of alder.

Responses to a pest outbreak

Identifying the problem

Understanding the reasons for pest outbreaks

The shifts in natural balances between pest organisms and their host plants provide valuable lessons on the reasons for pest outbreaks. Much can be learnt from the natural interactions of invertebrates, diseases and trees so that, when pest status is reached, it may be possible to restore the natural balance without resorting to measures such as use of chemical pesticides that may only provide short-term answers to the problem. In this respect, it is important to understand the ecological reasons for increases in the pest populations, and also to be able to predict the effects of direct intervention on both the target and non-target components of the ecosystem. General principles of ecological theory can help to interpret the underlying processes, but there is no substitute for direct observations and use of monitoring regimes to aid decision-making. Monitoring and interpretation should take account of combinations of tree species, site type and local environmental and climatic conditions at both stand and landscape scales, and aid early prediction of expanding pest populations.

Identifying the cause
Woodland managers and advisers are not expected to be expert in pest diagnosis. Forest Research has a team of entomologists and pathologists whose services are on call and expertise may also be available elsewhere. In addition there are a number of manuals designed for use by forest staff. FC Field Book 16: *Diseases and disorders of forest trees* provides a good account of current problems (including some caused by insects) and has a helpful section on diagnostic procedures; FC Handbook 1: *Forest insects* and FC Field Book 17: *Christmas tree pests* may also be useful. The interactive CD ROM *Tree Doctor* can also assist in identification and diagnosis.

Even if the cause of the damage seems fairly obvious, it is recommended that contact is made with Forest Research or a similar centre of expertise. This brings two beneficial consequences: firstly, it should ensure that the most up-to-date advice is received; secondly, the experts may recognise some unusual feature of the outbreak which warrants investigation in the national or international interest.

Evaluating the consequences

Assessing the scale of the problem
Various techniques are available for quantifying pest damage. Some will give information on distribution, some on severity, and some on both. Because of the requirement for maximum objectivity, most surveys are best carried out by specialist staff. However, some procedures for use by forest staff have been devised, e.g. *Bupalus* and *Panolis* pupal surveys. FC Practice Note 1: *Nearest neighbour method for quantifying wildlife damage to trees in woodland* describes a method for quantifying mammal damage that can be adapted to other kinds of damage assessment. In essence it provides for an unbiased method of selecting the trees on which damage data are collected.

Aerial surveys can be used to obtain a general idea of the distribution of damage due to pests (and abiotic diseases). Sometimes, in uniform forest blocks, photographs can provide quantitative information and here there is the possibility of links with Geographical Information Systems (GIS). The resolution obtained with satellite imagery is increasing all the time, but as yet has not reached a point where it is of practical value in forest pest assessment.

Developing a prognosis
The next step is for information on pest distribution and severity to be combined with available information on pest biology to produce a prognosis for the course of events. Expert help is likely to be crucial here. Sometimes there will be useful 'case histories' to be considered. In others a 'worst case scenario' may need to be taken into account.

Deciding on action or inaction

Economic considerations
The process of making a prognosis for the pest problem may enable an estimate of the likely financial and environmental cost of the problem to be calculated. Costs of control measures can also be calculated; these include the cost of application of any treatment, the value of any wood salvaged and the costs of any necessary environmental monitoring.

Consideration of environmental issues
If a pest problem is allowed to run its course there can be a wide range of environmental consequences. A forest pest may change the landscape or it may remove or seriously reduce the availability of food for other important organisms in the ecosystem. Equally it should be recognised that there can be benefits from attack by organisms generally perceived to be pests, e.g. through the provision of dead wood for rare invertebrates or the creation of glades and other openings in a stand for biodiversity. Control measures, whether chemical or biological, will have positive and negative environmental implications.

Consideration of health and safety issues
Health and safety issues are vitally important. The initiation of a control measure may result in the need to control public access for recreation, for example.

Approaches to control – avoiding the problem

Maintenance of a healthy and vigorous stand

The concept of preventing infestations arising, rather than attempting to treat the problem after it arises, is an attractive one and, as discussed earlier, can often involve gaining an improved knowledge of the ecological reasons for shifts in the average population levels of pests. Thus, good silvicultural practices such as maintaining high tree vigour, matching trees to sites, understanding the influences of climate and other non-biotic factors can be taken into account in preventing infestation development. At the same time, interactions at other trophic levels such as influences of natural enemies need to be taken into consideration.

Some pest problems occur more commonly in trees that are growing poorly than in those that are growing well. This is particularly true for mass attack bark beetles such as *Ips typographus*. Selective thinning to remove vulnerable trees may reduce pest impact to an acceptable level.

Control through the use of resistant trees

It may be that the best option is to change the species in the next rotation. Relevant information may well be available. For example many broadleaved species are very resistant to Fomes root and butt rot and use of these may be an option on sites badly infested with this pathogen.

Mixtures can be used to provide an insurance when the risk of disease is not clear, e.g. it is recommended that wild cherry (*Prunus avium*) forms no more than 10% of any new or restocked woodland because of the risk of it succumbing to bacterial canker (*Pseudomonas syringae* pv. *Morsprunorum*). In some situations mixtures can effectively delay or reduce the build-up of a pest within a plantation, for example the use of a mixed beech/conifer plantation can reduce the impact of beech bark disease. However, it must be recognised that there are some disadvantages to mixtures in terms of ease of management and productivity.

For some pests, programmes aimed at selecting or breeding for resistance have been conducted. Experience shows that resistance based on many genes acting together is much more 'durable' than that based on single genes. When it comes to the use of mixtures of genotypes, planting strategies need to be considered. For example to limit rust infection in poplar or willow grown as short rotation coppice, the recommendation is to plant mixtures of five or six varieties not susceptible to the same race of rust. As with mixtures of species there are likely to be implications in terms of complexity of management and loss of productivity. It is also important to assess whether introducing resistance to one pest species may be at the expense of resistance to another.

Approaches to control – remedial action

Control through sanitation

In the past considerable emphasis was placed on the removal and destruction of visibly diseased or infested trees. While this is sometimes an important process, for example clearing snow-broken and windblown pine to prevent damaging attacks on surrounding trees by the pine shoot beetle (*Tomicus piniperda*), it is often an ineffectual one. This is due to the fact that sanitation cannot always be conducted with the necessary degree of completeness to achieve results. In other cases there may be features of the pest or its biology that preclude successful sanitation. An example is provided by a number of tree-killing pathogens which are present in many healthy trees but only develop to cause symptoms when the host is put under stress, for example by drought. However, sanitation felling may be the only option to tackle outbreaks of newly introduced pests and can be successful in eradication if the problem is recognised early enough.

Control through the use of biological agents

The adoption by the Forestry Commission in the 1960s of the non-pathogenic wood-rotting fungus *Phlebiopsis* (previously *Peniophora*) *gigantea*, now used under the name 'PG Suspension', for the treatment of pine stumps to prevent colonisation by *Heterobasidion annosum,* was a pioneering move that has been followed by other countries (further information can be found in the specific section on Fomes root and butt rot, see page 19). Another successful example of biological control has been the rearing and release of the imported predatory beetle *Rhizophagus grandis* to control the great spruce bark beetle, *Dendroctonus micans*.

Control through the use of microbial pesticides

Use of pathogenic organisms, such as bacteria, fungi and viruses, both directly within spray programmes and indirectly by manipulating populations of the pathogen, can result in regulation of pest populations with little or no impact on non-target organisms. There are few examples of microbial pesticides currently approved for use in British forestry. However, the bacterial agent *Bacillus thuringiensis* has been used successfully against many of the most serious lepidopteran defoliators globally. Particular success has been achieved against spruce budworm in North America and against gypsy moth (*Lymantria dispar*) and nun moth (*Lymantria monacha*) in western and central Europe. Viral agents offer the highest levels of specificity and are often instrumental in the natural decline of populations of forest insects, many of which are pests. The potential use of baculoviruses against pine beauty moth (*Panolis flammea*) is described under the specific examples section (page 31). Successful control of European pine sawfly (*Neodiprion sertifer*) in young pine plantations was achieved with its specific baculovirus, registered as Virox, but this effective and selective control agent is no longer available since the registration has lapsed, due to the demise of the company distributing the virus.

Control through the use of natural and synthetic chemical pesticides

Use of chemical fungicides

The only chemical pesticides used in British forestry for the control of fungal diseases are those used for the prevention of stump colonisation by *Heterobasidion annosum*, the cause of Fomes root and butt rot, and are covered in the specific section devoted to this disease (page 19).

Use of chemical insecticides

There has been interest in invertebrate pest management for thousands of years. Records of various natural plant extracts and microbial agents being used to control pests date back to ancient Chinese times. Forms of biological and cultural control have been practised in many countries, but during the 20th century there was a move away from 'traditional' methods towards direct intervention for rapid pest suppression.

Reliance on natural plant extracts is still a current option in some countries but the advent of more refined extraction techniques, improved chemical analysis technology and the ability to synthesise active molecules has resulted in the development of a wide range of highly active compounds from the 1940s onwards. The current approvals for forestry use (not including nursery and Christmas tree treatments) are very restricted and the active ingredients themselves tend to be used selectively. These are shown in Table 1.1.

Table 1.1 Insecticides approved for use in forestry (correct at time of publication, April 2004).

Active ingredient	Products	Type of use
Carbosulfan (carbamate) (specific off label approval)	Marshal SuSCon	Weevil control in restocking.
Chlorpyrifos (organophosphate)	Alpha Chlorpyrifos 48EC Barclay Clinch II Choir Dursban 4 Greencrop Pontoon Lorsban T	Weevil and beetle control in cut logs (and transplant lines).
Diflubenzuron (insect growth regulator)	Dimilin Flo	Control of defoliating caterpillars on forest trees.
Alpha-cypermethrin	Alpha C 6ED Alphaguard 100EC	Weevil control in restocking.

Insecticides are generally applied as liquid formulations through a spray nozzle. The volume of application fluid and the type of spray nozzle can have profound effects on the distribution of spray droplets on both the target and non-target areas. The cubic relationship between spray droplet diameter and droplet volume emphasises the importance of spray machinery and nozzle selection in determining distribution of active ingredient into the target area. This is illustrated in Figure 1.1, where it can be seen how the losses of spray volume and, hence, of active ingredient can be exacerbated by use of spray machinery delivering droplets with a wide range of diameters.

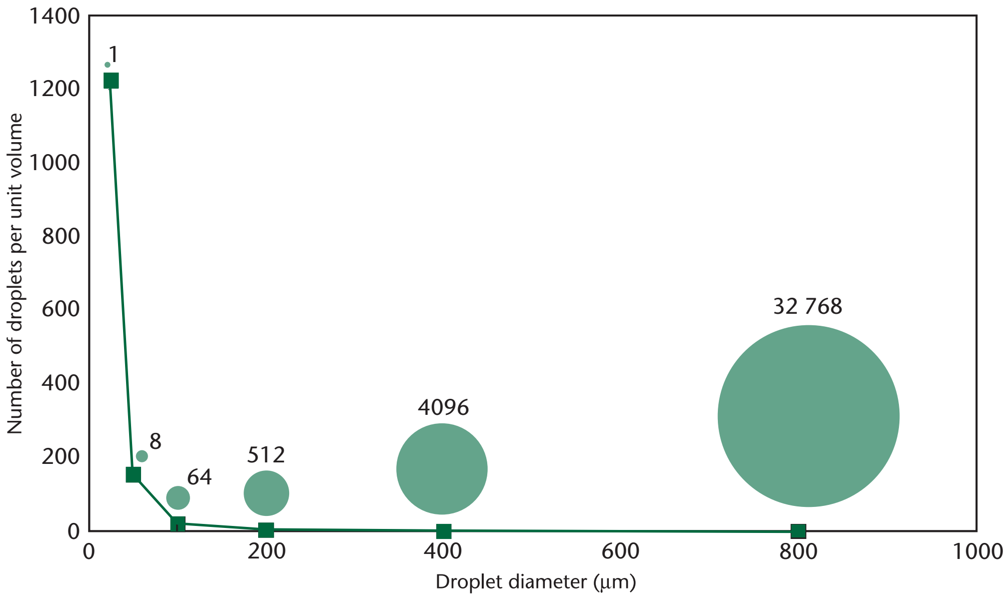

Figure 1.1 The relationships between droplet volume, droplet diameter and droplet numbers per unit volume. Droplets are drawn to diameter scale; numbers are relative volumes.

The importance of understanding droplet production and variability

The range of droplet sizes should be known for each combination of spray machine and spray carrier, the most important characteristics being the droplet median diameter and the span (a measure of the range of droplet sizes emitted) delivered. Clearly, if the sprayer produces droplets with a wide span of diameters, the relative volumes in each category will be extremely large. The most serious effects are losses of larger volume droplets to non-target areas, usually the ground, and the drifting of smaller diameter droplets outside the designated spray area. The latter is of less consequence in relative terms because of the much smaller volume within each droplet. It is also important to realise that droplet generation can change considerably with wear and tear during regular use and, thus, it is essential to clean and replace nozzles at regular intervals. Further details are given under Application technology in Section 2.4.

Minimising insecticide use

If a decision has been made to apply insecticide, it is necessary to consider what must be done technically to apply the minimum amount of pesticide needed for the required pest reduction. Control of droplet size and careful consideration of the target plant species as well as the position and behaviour of the pest are important factors in optimising efficiency while reducing total usage. However, it is more important to consider whether there are other options that could be pursued before resorting to active usage of chemical pesticides.

Behaviour-modifying chemicals

Behaviour-modifying chemicals – particularly sex attractant pheromones, bark beetle attractants and host tree volatiles – can be used both to monitor pest populations and to prevent or divert attacks. Bark beetles, especially in the genus *Ips*, produce attractant chemicals, derived partially from the host tree itself, to alert other beetles to the presence of suitable host material. These chemicals have been identified and synthesised and many are available commercially. *Ips typographus*, the European eight-toothed spruce bark beetle, is potentially one of the most dangerous pests of spruce in Europe and is not yet present in Britain. Pheromone traps, baited with the *I. typographus* attractant, have been deployed at ports and wood processing yards for a number of years and have allowed plant health inspectors to respond to infringements of import regulations. Other possible uses of pheromones are to disrupt successful mating through saturation of the atmosphere so that males are unable to locate females within the general pheromone atmosphere. Alternative techniques, such as target technology, can be used to attract pests to a source impregnated with insecticides or microbial agents so that the pests can be killed without broadcast sprays of insecticide.

Integrated Forest Management

Combinations of the techniques described above can be brought together to develop Integrated Pest Management (IPM) or, with other factors such as silvicultural management, to develop Integrated Forest Management (IFM). These concepts rely on understanding ecological processes and manipulating the key factors to reduce the likelihood of infestations or, if pests are already at damaging levels, to reduce population levels below an acceptable threshold. A key attribute of IPM/IFM strategies is the emphasis on ecologically sustainable methods based mainly around preventative measures and biological control, although selective use of chemical insecticides can also be considered. However, the overall aims are to develop sustainable methods that cause minimal ecological disturbance. Fundamentally, a recognition of the multiple interactions that determine whether or not an organism reaches pest status requires that all facets of the pest problem should be considered in long-term management. The concept of IFM provides a framework for this approach and will increasingly be used in the future as research develops. The management of *D. micans* can be regarded as an example of IFM, where facets of silvicultural management, internal quarantine controls and the use of a biological control agent all work together to keep the pest below the economic damage threshold.

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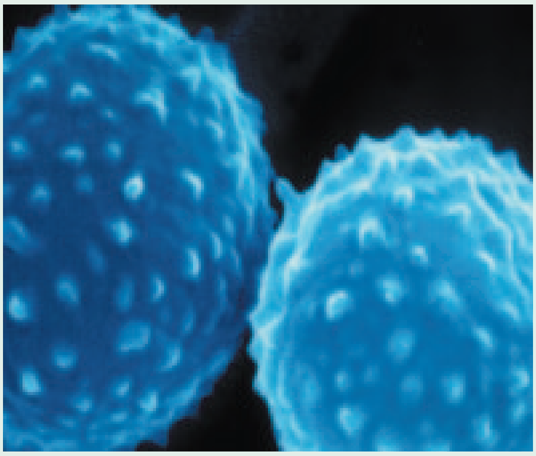
Fomes root and butt rot of conifers



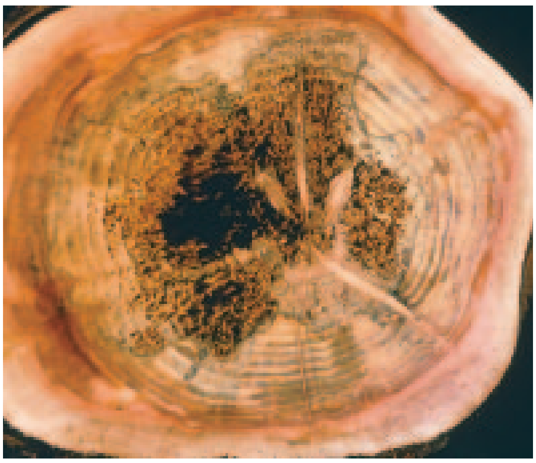
Airborne spores of Heterobasidion annosum.

Fomes root and butt rot is the most serious disease of conifers in the Northern Hemisphere. It is caused by the native wood-rotting basidiomycete fungus *Heterobasidion annosum*. This fungus is a natural component of conifer forests and can survive for many decades in old stumps, which can act as an infection source. Infection can develop in young trees at points where the root systems come into contact with this source. The disease is initially absent from first rotation plantations but can enter them when airborne spores of the fungus arrive from a distance and colonise the stumps created during routine forest operations. The fungus develops within the root system of these stumps and can spread to adjacent trees via root contacts. The pattern of attack on the standing tree varies with the tree species concerned. Most conifers are subject to butt rot which develops progressively upward from the base. Pines (*Pinus* spp.) are generally resistant to butt rot but they can suffer quite serious mortality on certain sites, most notably alkaline sands. See 'avoid the problem' for more detail on species' susceptibility. Treatments to prevent the infection of stumps have been applied routinely in the Forestry Commission and parts of the private sector since the 1960s.

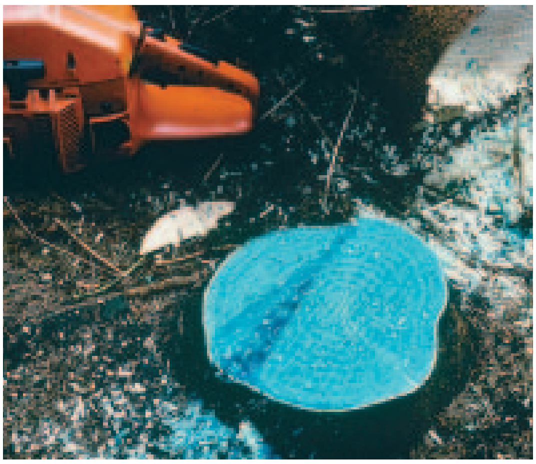
Consequences

Losses through the disease can be very considerable, and tend to increase from one rotation to the next. In the worst cases, up to 70% of pines planted in the second rotation on alkaline sands can be killed before they are 10 years old. Species that are susceptible to butt rot, such as Sitka spruce (*Picea sitchensis*) and larches (*Larix* spp.), can be severely attacked on mineral soils – 80% of trees may be decayed by the time of second thinning in a second rotation crop, with loses averaging 30% of volume or 40% of value for each infested tree. By contrast, on peat soils in high rainfall areas, disease losses can be negligible.

Research conducted over a number of years by the Forestry Commission has confirmed that the main threat of this fungus comes on sites with well-drained soils and relatively mild climates. The risks are lowest on upland sites dominated by wet peats. These findings have been used to devise a disease risk assessment system, in which the hazard of a site (defined by its soil and climate) is modified by the risks associated with the options chosen for the management of the crop (Pratt, 2002).



Fomes decay in Norway spruce heartwood.



Treatment of stumps with urea to protect against Fomes.

Options for control

▷ TAKE NO ACTION

Risks of damaging infections are negligible on peaty soils exceeding 15 cm in depth and are low on other soils in high rainfall areas (>1600 mm). Risks of economic loss are low in pines on some soils, but are very high on alkaline sands. However, pine stumps harbour the disease, and in subsequent rotations other species that follow pine can suffer severe infection.

Taking no action is therefore an option worth considering for:

- All conifers on peaty soils with a peat depth (surface horizon containing more than 25% organic matter) of at least 15 cm from the surface.
- Other low hazard sites, determined by climate and soil type, where options for management carry a low risk from the disease (see Table 1.2 and Figure 1.2).
- Pines which are **not** on alkaline sands, where no other conifer species will be used for replanting (e.g. stands of 'Caledonian' pine (*Pinus sylvestris*) on acid soils).

On high risk sites where the disease is already established and where de-stumping is not practicable, there may be little benefit in stump treatment in the present rotation. However, action may be taken to replant the site with resistant trees in future rotations.

Figure 1.2

Climate zones of Great Britain: based on accumulated temperature (day-degrees above 5°C) and annual soil moisture deficit (mm).

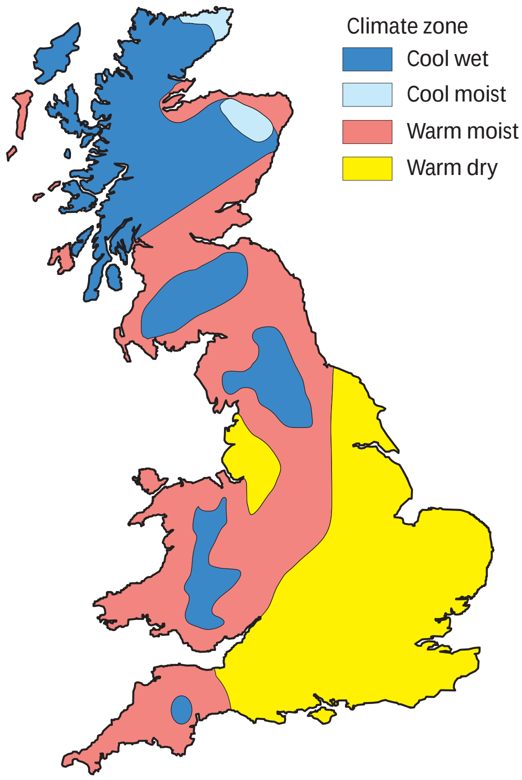


Table 1.2 Hazard from Fomes root and butt rot determined by climate and soil.

Fomes hazard	Climate type			
	Cool, wet	Cool, moist	Warm, moist	Warm, dry
High	Nil	Nil	Brown earth, Podzol	Brown earth, Podzol, Ironpan, Surface water gley, Ground water gley
Medium	Nil	Brown earth, Podzol, Surface water gley	Ironpan, Ground water gley, Surface water gley	Peaty gley (shallow)
Low	Brown earth, Podzol, Ironpan, Ground water gley, Surface water gley, Peat (>15 cm depth)	Ironpan, Ground water gley, Peaty gley, Peat (>15 cm depth)	Peaty gley, Peat (>15 cm depth)	Peat (>15 cm depth), Peaty gley

AVOID THE PROBLEM

No thinning

This will prevent entry of the disease into healthy crops, and may delay its progress in already diseased crops. However, treating clearfelled stumps at the end of each rotation will still be required on all but low hazard sites. In addition, abandoning thinning may not fit in with other management objectives.

Species selection

H. annosum has a very wide host range and there are slight differences between conifer tree species in terms of susceptibility. Experiments on high risk sites have produced the following ranking in decreasing order of susceptibility to butt rot:

- European larch (*Larix decidua*), Japanese larch (*Larix kaempferi*), hybrid larch (*Larix decidua* x *eurolepis*)
- Sitka spruce (*Picea sitchensis*)
- Douglas fir (*Pseudotsuga menziesii*)
- Norway spruce (*Picea abies*)
- Grand fir (*Abies grandis*)
- Noble fir (*Abies procera*)
- Pines (*Pinus* spp.)
- Broadleaves such as beech (*Fagus sylvatica*) and oak (*Quercus robur, Q. petraea*) are very resistant.

TAKE REMEDIAL ACTION

Stump removal

This is a practical option on certain badly affected sites where, in its absence, very high losses can be expected in the next rotation. The removal of pine stumps is a routine operation in some parts of Thetford Forest, East Anglia where there is a high incidence of disease in the current crop at the time of felling and where alkaline soil conditions are very favourable for further disease development in the next rotation. On these sites, the level ground and the lightness of the soil keep destumping costs low. Stumps are left piled to the side of the cleared area (windrowed).

Stump treatment

Stumps resulting from thinning and clearfelling can be treated to prevent their colonisation by spores of *H. annosum*. As this is a protective rather than a curative measure, it will bring only limited benefit on sites where the disease is already well-established in the root systems. There are two main treatments.

Treatment with urea
Urea, best known as a nitrogenous fertiliser, has been the standard treatment since 1971 when it replaced sodium nitrite. Following manual felling, urea is applied to stumps as a 20% aqueous solution (i.e. 1 kg of urea per 5 l of water). In harvesting machines it is applied as a more concentrated solution (37%), to reduce the chance that the delivery equipment will freeze up. Experiments on pine have demonstrated good control. Effectiveness on certain other species, notably Sitka spruce, is lower.

Urea's mode of operation has never been fully elucidated but it seems to be linked to the hydrolysis of the compound, resulting in the release of ammonia and a rapid increase in pH. The advantages of urea are that it is a non-toxic (to mammals), cheap, readily available, stable material. Disadvantages are that there is a small risk of increased nitrification of the soil, and at the concentrations used for stump treatment it is mildly phytotoxic to herbaceous plants. A significant disadvantage for machine harvesting is that urea can corrode mild steel and thus reduce the life of the delivery systems that are attached to the harvester heads. Also it can crystallise out of solution, causing blockages and a breakdown in the application systems.

Treatment with *Phlebiopsis gigantea*
Phlebiopsis gigantea is a native, non-pathogenic wood-rotting basidiomycete fungus that is used for the treatment of pine stumps under the name of 'PG Suspension'. It has full approval from the Pesticide Safety Directorate for use on pine in the UK. Experiments are in progress

involving another form of the same fungus, already marketed in Scandinavia under the name 'Rotstop', which is registered for use both on pine and spruce. *P. gigantea* operates by competing with *H. annosum* for the food reserves in the fresh stump and thereby denying the pathogen the chance to establish itself. Its advantages are that it is a natural material of native origin with no residues and no known unwanted environmental impacts. The product has very small bulk compared to chemical equivalents and is non-corrosive and non-toxic.

The disadvantage is that, as a living agent, the viability of the product has to be maintained by careful handling and good hygiene. For example, the spores are inactivated by exposure to high temperatures (above about 35ºC). The product has a finite shelf life and fresh suspensions have to be made up each day. *P. gigantea* is capable of causing decay in accidentally sprayed forest produce but this has not proved to be a problem in practice.

Table 1.3 details possible remedial control measures for Fomes root and butt rot.

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Table 1.3 Remedial control measures for Fomes root and butt rot of conifers.

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks	Comments
Non-chemical methods					
Stump removal	Very variable, but can be in the region of £450–550	£450–550	The removal of the stumps of a badly affected pine crop can reduce mortality in the next rotation from *c.* 70% at year 10 to less than 10%.	Soil and habitat disturbance. On steep sites, potential soil erosion and water sediment-ation. Possible atmospheric pollution from machine use, especially if poorly maintained. Removal of stumps from site will result in some loss of nutrients and increased risk of soil acidification.	Removal of stumps only worth con-sidering on certain site types – typically where pine is grown on high risk calcareous sands, and where sites are flat and relatively easy to de-stump. If stumps are windrowed there will be some loss of plantable ground. De-stumped ground is ideal for machine-planting the next rotation of trees.
Stump[3] treatment with PG suspension (harvester and manual application)	£44 (harvester) £84 (manual)	£44 £84	In the UK, efficacy has only been proven on pine.	*Phlebiopsis gigantea* is a native fungus and its use will be very unlikely to have any damaging effects on the ecosystem. Stumps are the habitat for a number of rare cryptogams (plants that reproduce by spores) that might be affected by stump treatment.	A living organism requiring careful handling; inactivated by high temperatures and pressures. Experiments are in progress to evaluate other strains of *P. gigantea* which may be effective on Sitka spruce. This form of the fungus is already marketed as Rotstop in Scandinavia where it is mainly used on Norway spruce.
Chemical methods					
Stump[3] treatment with urea at 37% via harvester	£45	£45	Good on pine, moderate on spruce (large-scale trials show 60% reduction in stump colonisation).	At 37% urea is mildly phytotoxic to woodland herbs. Some nitrification of soil but this is negligible over a rotation. Not hazardous to mammals. Stumps are the habitat for a number of rare cryptogams that might be affected by stump treatment.	Urea can corrode mild steel leading to damage to the delivery systems. At low temperatures it can crystallise causing blockages and breakdowns.
Stump[3] treatment with urea at 20% following manual felling	£85	£85	See above.	See above.	Special hand-held dispensers have been devised.

[1] Cost for individual fungicides includes chemical plus application cost.
[2] Each stump is only treated once, but there is a further requirement for treatment as fresh stumps are created. This cost is based on a clearfell, assuming 40 m^2 ha^{-1}. For thinned crops over a full rotation cumulative treated basal area could be double this figure.
[3] These are preventative treatments only. They will have no effect on disease already present on site.

Pine weevil *(Hylobius abietis)*

Hylobius abietis *adult feeding on Sitka spruce showing damage to stem.*

The pine weevil (*Hylobius abietis*) is a serious pest of newly established trees, both conifer and broadleaf. It occurs in virtually all reforestation sites throughout northern Europe, where conifers formed the preceding tree cover. In the absence of protective measures, losses of seedlings average around 50% but in the worst affected sites they can reach 100%. In Britain costs of either protection or replacement of lost trees are expected to rise as restocking becomes the dominant form of commercial tree planting.

Adult pine weevils are large (up to 12 mm long) and can live for up to 4 years, although the average life will be shorter than this. Total life cycle from egg to adult takes 1–2 years, depending on seasonal timing of egg laying and on average temperatures. The eggs are laid below ground level in the bark of stumps of recently felled conifers or in fallen/felled conifer stems and branches in direct contact with the ground. Larvae feed in the cambial layer of the bark and pass through several moults before finally pupating in a distinctive pupal chamber. Adults usually emerge in the autumn.

Consequences

Pine weevils are classified as serious forest pests because adult beetles feed on the bark of exposed lower stems of transplanted or naturally regenerated conifer seedlings and the upper part of the stem of broadleaves. Girdling of the stem results in plant death. Feeding is non-specific in the sense that adult weevils are known to browse on many available plant food sources including the branches of standing trees, seedlings and weeds on site. Adult *H. abietis* may attack at any time of year when it is warm enough for insect activity. Most feeding occurs between early March and November, but there is a tendency for two peaks of damage to occur, one in spring before egg laying and the other in late summer before the adults hibernate underground. The timing of these feeding periods depends on both the physiological condition of the insects and the ambient temperature. The relative magnitude of these peaks will vary from forest to forest and from year to year. When sites are clearfelled the availability of food sources for adult beetles is restricted and, hence, forest transplants tend to be favoured by the weevils, giving rise to extensive browsing and plant mortality.

Larva of Hylobius abietis *feeding in cambial layer bark.*

Risk factors

Adult weevils migrate onto felling sites, either in low numbers if the felling is entirely new within a given forest, or in high numbers if it is in close proximity to an existing clearfell. Recent research on population dynamics indicates that colonisation of stumps and, therefore, risks to transplanted seedlings in the immediate area are closely linked to the ages of the conifer stumps close by (Heritage and Moore, 2000). Availability of oviposition sites, such as recently cut stumps, dying trees and larger tree debris, is the main risk factor at a given site. However, timing of felling, average temperatures and availability of alternative food sources all contribute to determining whether transplants on site are actually damaged by the feeding of adult weevils.

Options for control

▷ TAKE NO ACTION

With no action, losses of transplanted seedlings will average around 50% for the years when they are likely to remain at risk (particularly the first two after planting), with a range from no damage to 100% loss. It is currently not possible to predict the likely level of damage at a given clearfell site. However, where a sustained felling programme is carried out over several years in a forest block, it can be assumed that there will be substantial damage during the subsequent restocking operation. Delayed success in restocking may lead to an increased need to weed, and hence an increased use of herbicides. Increased losses and beat ups will result in an uneven age of established crop. Sub-lethal damage may result in poor plant form and multi-leadering. Consequently, the 'take no action' option is a high risk strategy and most forest operations will need to include some form of active management against restocking pests.

▶ AVOID THE PROBLEM

Once established, large or isolated broadleaved forests are unlikely to be vulnerable when restocking. For sites previously planted with conifers, there is currently very little that can be done to avoid the problem. However, a number of mitigating factors will help to reduce the scale of the problem.

Allow the clearfell area to lie fallow for at least 5 years

Depending on species, stumps remain suitable for weevil reproduction for approximately 5 years after felling. During this time about two generations of *H. abietis* will emerge on site and, in the absence of suitable further conifer breeding resources, will tend to migrate to other sites. A fallow period *may* provide protection at a given site when replanting eventually takes place. However, on more fertile sites, leaving areas fallow can result in substantial weed growth and can dramatically increase the amount of herbicide which may need to be used. Open areas within the block may increase the risk of windthrow and delayed restocking may result in unacceptable delay of felling licence for adjacent crops.

Leaving sites fallow (for at least 5 years) may be worth considering on less fertile clearfell sites that are spatially separated from the nearest 0- to 4-year-old felling. However, even then it is a high risk strategy.

Manipulate weedy and weed-free areas to divert attack from transplants

Adult *H. abietis* move around clearfell sites mainly by walking. There is some indication that they avoid areas of open, weed-free ground with exposed mineral soil. In addition, areas with quite high weed cover of other woody plants, such as bramble (*Rubus fruticosus* agg.), can act as alternative food sources, thus diverting attacks away from tree seedlings. Hence the retention of cover from woody weeds, while maintaining open areas of mineral soil immediately surrounding tree seedlings by good weed control, may reduce the level of attack on site.

However, if large populations of weevils emerge, they can overwhelm such defensive strategies and lead to high transplant losses. In addition, leaving potentially very invasive weeds such as bramble on site can result in their dominating the area, and contributing to substantially increased tree mortality. A small amount of non-invasive woody vegetation between weed-free bands is desirable.

Use robust, good quality planting stock

Seedlings that are vigorous with good root systems and high quantities of resin are able to withstand attack better than small plants with poor defensive systems. Seedlings should have a good balance between root and shoot and should conform to British Standard 3936 (BSI, 1984). The thicker the bark and the more resin that a tree seedling produces, the more likely it is to be able to survive low to moderate browsing by *H. abietis*. However, initial attacks can actually attract other adult weevils to the damaged plants and, if populations of the pest are high, the plant will quickly succumb to attack. Vigorous well-balanced planting stock should be used at all times as this also helps to reduce the establishment period and weeding inputs.

TAKE REMEDIAL ACTION

Broadleaves or conifers protected by full tree-shelters (1.2–1.8 m tall with no holes or porous mesh) usually suffer far less damage than unprotected trees. The use of tall treeshelters purely for protection against *H. abietis* would be extremely expensive, but if they are needed to protect against browsing mammals, then any protection against *H. abietis* may be a bonus. Custom made plastic weevil guards have been found to be effective in Scandinavia and there is increasing interest in them in the UK. Research is taking place to examine their efficacy.

Currently the only effective remedial action for unguarded trees is to treat the young plants with insecticide, either before planting, during or immediately after planting. This strategy provides protection only and has little effect on total populations of weevils on site. The pyrethroid insecticide permethrin has been very effective in preventing damage, but was withdrawn from use at the end of December 2003 as a result of the European Union review of pesticides. Research carried out by Forest Research over the past 3–4 years has led to registration of alpha-cypermethrin, another pyrethroid insecticide with high activity against *H. abietis*.

Pre-plant treatment with alpha-cypermethrin (Alpha 6ED) applied through an electrodyn spray booth

This is a specialised application system that generates electrostatically charged spray droplets that are attracted to the earthed transplant on a conveyor belt, giving consistent positioning of the band of insecticide and rapid drying. The major advantage is the high level of operator protection and ability to transport the plants soon after treatment without a prolonged period of drying.

Pre-plant treatment of container grown plants with alpha-cypermethrin in the nursery

The treatment is applied using a knapsack sprayer or purpose built spray booth in the nursery, using 0.4% concentration of alpha-cypermethrin active ingredient (i.e. 1 l of Alphaguard 100EC (100 gl^{-1} alpha-cypermethrin) per 25 l of water). The spray booth provides controlled treatment and the plants are left under cover to dry before despatch.

Post-plant spraying with alpha-cypermethrin

This operation must be carried out as soon as stock is planted in order to avoid the high risk that the unprotected plants will be damaged or killed. Both conifers and broadleaves must be treated. Two applications of 0.1% alpha-cypermethrin active ingredient (i.e. 1 l of Alphaguard 100EC per 100 l of water) may be required. Details of the new registration of this insecticide can be found on www.forestry.gov.uk/weevils, which includes information on applications and the label for Alphaguard 100EC. This technique is also the only treatment that can be applied in the second year after planting.

Use of carbosulfan at the time of planting

A slow release granular formulation of carbosulfan (Marshal SuSCon) can be applied around the roots of plants during planting. The granules are either applied loose (10 g) to the planting hole or within a sachet containing the pre-measured dose of 10 g. The treatment is effective for at least 2 years, but has the disadvantage of taking 2–3 weeks for the active ingredient to be taken up systemically by the plant. It is usually necessary to apply alpha-cypermethrin to the plants to provide protection during this vulnerable period, unless container stock treated in the nursery is used. See Heritage *et al.* (1997) for general methods, but substitute alpha-cypermethrin at 0.1% for permethrin. See also www.forestry.gov.uk/weevils

Integrated Forest Management

All the factors described above in ‘avoid the problem’ and ‘take remedial action’ are being brought together under an Integrated Forest Management (IFM) system for future management of restocking pests. This management support system will use a combination of improved monitoring and population prediction, combined with use of biological control of weevil populations in the stumps, to suppress populations of the pest and, thence, to reduce or eliminate the need for chemical insecticides. Successful field scale trials of insect parasitic nematodes to selectively manage populations of *H. abietis* in conifer stumps have been carried out and indicate that significant population reduction can be achieved. The full management support system is currently under trial by the Forestry Commission and involves assessment of risk factors on a site by site basis, combined with direct monitoring of *H. abietis* adults using conifer billets to determine population size locally. This will indicate current and future risks and, by interpretation of the data gathered, will lead to a number of options for forest managers. Assessment, refinement and fuller roll-out of the management support system will take place from 2003 to 2006.

Table 1.4 details possible remedial control measures for *H. abietis*.

References and useful sources of information

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HERITAGE, S. G. AND MOORE, R. (2000).
The assessment of site characteristics as part of a management strategy to reduce damage by Hylobius.
Forestry Commission Information Note 38.
Forestry Commission, Edinburgh.

Table 1.4 Remedial control measures for pine weevil.

Method	Cost per treated ha per operation[1]	Total cost per ha for satisfactory restocking[1,2]	Efficacy	Environmental risks	Comments
Non-chemical methods					
Cultivation to expose mineral soil	£202[3]	£200–800	Unlikely to reduce damage to an acceptable level.	Soil erosion, water sedimentation, nutrient leaching, destruction of soil fauna, disruption of ground nesting birds and archaeology, and possible atmospheric pollution (especially if machinery is poorly maintained) can all result from inappropriate cultivation if guidelines are not followed.	Mounding or scraping of the soil at the planting position is necessary. This technique will result in the greatest reduction in weevil damage when used on sites with a high density of woody weeds. Planting should be in the centre of the cleared area of mineral soil.
Treeshelters	£4250 (£1.70 per 1.2 m tall shelter) £5500 (£2.20 per 1.8 m tall shelter)	£4250 £5500	Potentially 100% effective, but only if shelters are properly fitted, regularly inspected and maintained.	Unless fully biodegradable or removed, they form a source of chemical pollution.	Damage may be reduced but not eliminated. Not economic for protection from *Hylobius* alone. Need to be removed after trees are established.
Proprietary weevil guards (e.g. 'Stoppers' or 'Snapguards')	Limited trials suggest a cost (materials; fitting and extra planting cost) of £1100 ha^{-1}. This does not include maintenance costs which could be considerable (see Comments).		Very few controlled trials have been carried out in the UK but high levels of protection may be possible.	Unless fully biodegradable or removed, they form a source of chemical pollution.	The barriers require careful positioning to ensure that they are effective; the ground surrounding the barrier should be level and free from weed and felling debris. The site should be regularly inspected and the barriers maintained to ensure they are pushed into the ground and that no bridging has occurred. Most designs of barrier are designed to split after the main risk from damage is over and in theory may not need to be removed to allow continued tree growth.
Chemical methods					
Insecticides, general			Can be very effective.	If misused, all insecticides present a risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation and insects. Risks are reduced by spot treatment under controlled conditions. No long-term harmful effects have been detected at planting sites.	
Spraying with 0.4% alpha-cypermethrin before planting	£60–120	£60–£280	Provides good protection for 1st season, but dependent on weather and pest population.	Broad spectrum: many non-target insects could be killed. Toxic if swallowed, harmful and irritating in contact with skin, irritating to respiratory system and damaging to eyes. Dangerous for the environment and very toxic to aquatic life.	Only suitable for container-grown stock treated before planting. The plants may require additional treatment(s) in the second year after planting especially if small plant sizes are used.
Pre-plant treatment with alpha-cypermethrin 6ED applied via electrodyn spray booth	£80	£80–£240	Provides good protection for 1st season.	Broad spectrum: many non-target insects could be killed. Harmful if swallowed or by inhalation, and a skin sensitiser. Dangerous for the environment and very toxic to aquatic life.	Only suitable for bare-rooted stock treated before planting. The plants may require additional treatment(s) in the second year after planting particularly when insect populations are high.
Use of granular formulation of carbosulfan (Marshal SuSCon)	£415	£415	Provides good protection for two seasons.	Carbosulfan is an anticholinesterase compound and is harmful if swallowed, dangerous to insects and potentially dangerous to aquatic life. Risks are minimised by ensuring granules are safely buried beneath plant roots.	It is necessary to protect plants (using other insecticide treatments) during first few weeks after planting until an adequate concentration has been translocated to the stem, unless container-grown stock has been treated in the nursery.
Post-plant spraying with 0.1% alpha-cypermethrin	£60	£240–£320	Provides protection for 10 weeks only.	Broad spectrum: many non-target insects could be killed. Toxic if swallowed, harmful and irritating in contact with skin, irritating to respiratory system and damaging to eyes. Dangerous for the environment and very toxic to aquatic life.	Treatment must take place during dry weather. The deposit becomes rain-fast once dry. It is not possible to respond to insect activity and prophylactic sprays must be applied to ensure protection. Dyes may be added to the solution to check coverage.

[1] Cost for individual insecticides includes chemical plus application cost, assuming 2500 trees ha^{-1}.
[2] Cost given for all additional operations to establish an acceptable level of restocking.
[3] This operation may be undertaken for silvicultural benefits.

Pine beauty moth *(Panolis flammea)*

Adult P. flammea *and larvae feeding on lodgepole pine.*

Pine beauty moth (*Panolis flammea*) is a native moth that is found on, but does not cause damage to, Scots pine (*Pinus sylvestris*), throughout most of Britain. During the 1970s the moth was recorded for the first time in Caithness and Sutherland where it caused extensive damage and tree mortality to lodgepole pine (*Pinus contorta*).

Pine beauty moth produces one generation per year in Britain. It overwinters as a pupa in the litter layer below the trees and emerges as an adult between March and May. Females lay eggs in rows along the old needles, usually in the top third of the canopy. Eggs hatch in late May or early June and the young larvae feed initially only in the newly expanding needles of the current year's growth. As the larvae grow (they pass through five feeding stages on the trees), they migrate to feed on the older needles and can consume 100% of the foliage. Larvae drop to the forest floor towards the end of July and pupate at the interface between litter and soil.

Consequences

Trees can be completely defoliated and killed when moth populations are high. In Britain, damaging populations are found only on lodgepole pine in the north of Scotland.

Risk factors

The highest populations of the moth tend to be found on particular provenances of lodgepole pine on deep peat sites. However, although such sites favour the early build up of moth populations, insects in these 'hot spots' will spill over to surrounding areas and whole blocks may therefore be vulnerable. Alternatively the hot spots may represent early signs of a generally increasing population in the forest.

If the moth is left unchecked, trees will die, leading to reductions of moth populations in the following year, even in areas where some trees still survive. There are exceptions to this: for example, during a major outbreak on the Isle of Lewis, the remaining trees had to be sprayed in the second year.

Overall, there appears to a trend towards cycles of moth outbreaks with peaks occurring every 6–7 years. Similar cycles have been observed on continental Europe where, unlike Britain, the moth is often a problem on Scots pine.

Defoliation of lodgepole pine.

Options for control

TAKE NO ACTION

Without intervention, the moth can kill considerable numbers of mature trees in high-risk forest blocks. This has the obvious consequence of loss of timber as well as subsequent effects on the flora and fauna associated with pine plantations. A further consequence is that potential improvements to the impoverished, poorly drained soils arising from a rotation of lodgepole pine may be lost, thus preventing the growing of higher value crops such as Sitka spruce in later rotations. In high-risk blocks, monitoring should be in place at the very least. Since the only form of successful remedial action known is spraying with pesticide, this is only likely to be undertaken when monitoring indicates a risk of high mortality. Hence taking no action is the normal procedure.

AVOID THE PROBLEM

The problem can be completely avoided by not growing lodgepole pine and this is probably the most sensible future course of action on high-risk sites and sites where damage has already occurred. However, Forestry Commission research suggests that it may be possible to reduce risks by avoiding susceptible provenances of lodgepole pine (south coastal, southern and central interior), planting in mixtures with different species (e.g. mixtures of lodgepole pine and Sitka spruce, *Picea sitchensis*), and by retaining open spaces to encourage natural enemies (parasites and predators). This does not provide a guarantee that no problems will be encountered. Scots pine is equally palatable to *Panolis flammea*, but attacks are fewer because more natural enemies of the moth are present, especially when there is a more open understorey.

TAKE REMEDIAL ACTION

Specialist advice should be sought before any remedial action is undertaken. Remedial action is based on monitoring of moth populations, using a combination of pheromone traps to attract male moths, and pupal surveys to determine whether populations have exceeded the threshold of 15 pupae m^{-2} ground area, above which trees are likely to die. Further egg counts after the moths have flown are used to determine the precise areas for application of insecticides. There are three options that have been used routinely or experimentally for population suppression. In all cases, the active ingredients are applied from the air using a helicopter-mounted, ultra low volume application system designed and built by the Forestry Commission. This unique system allows very precise control over droplet generation and targeting, thereby reducing drift to non-target areas and keeping volumes and concentrations of active ingredients to the absolute minimum necessary for effective control.

Application of the insect growth regulator, diflubenzuron

Diflubenzuron acts by inhibiting the synthesis of chitin that is essential to develop the external skeleton of arthropods. It is therefore a relatively specific insecticide that has a good safety record worldwide. Nevertheless, great care is needed to ensure that contamination of non-target plants and watercourses is kept to a minimum. Use of precise controlled droplet application technology and electronic track guidance systems on the helicopters enables the pilot to target the spray area very accurately. Application of the chemical is timed to coincide with emergence of around 95% of the young larvae from the eggs, thus minimising damage by killing the insects before they consume large quantities of foliage (Heritage, 1997).

Experimental treatments

Two other treatments, the microbial agent *Bacillus thuringiensis* and a naturally occurring baculovirus disease of *P. flammea*, are being investigated but currently have no approval for general use.

Integrated Forest Management

Combining the use of more resistant provenances of lodgepole pine with encouragement of natural enemies by provision of mixed plantings and greater open spaces, offers the prospect of longer-term management of this pest. In addition, there is some evidence that, at least during certain years, high populations of the moth are killed by a naturally occurring fungal agent that reaches epidemic proportions and reduces successful pupation to very low levels. Unfortunately the effect of the fungus is often not certain until after the main damage period. Further work on this agent is required before its mode of action and longer term potential can be fully evaluated. Many of the areas at greatest risk are now being prematurely felled and restocked with other tree species.

Table 1.5 details possible remedial control measures for *Panolis flammea*.

References and useful sources of information

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HERITAGE, S.G. (1997). *Pine beauty moth: its biology, monitoring and control.* Forestry Commission Research Information Note 290. Forestry Commission, Edinburgh.

Table 1.5 Remedial control measures for pine beauty moth.

Method	Cost per treated ha per operation	Efficacy	Environmental risks	Comments
Non-chemical methods				
Only pheromone and pupal monitoring.		Not strictly a control method.	Not all sites will generate high populations and this practice will reduce the risk of unnecessary environmental disturbance to unsusceptible crops.	Remedial action may be essential in areas with a high population. There is usually no visible sub-lethal defoliation before a fatal outbreak.
Chemical methods				
Insect growth regulator, diflubenzuron	No recent data. The specialist nature of the operation requires a case by case approach to include costs of helicopter hire, the use of specialised ULV equipment, track guidance, active ingredient costs etc.	The risk of damage should be low if accompanied by adequate monitoring and adequate spray technology.	If misused, all insecticides present a risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation and insects. This is minimised by application of a relatively specific insecticide using precise, controlled droplet application technology and electronic track guidance systems to target the spray area very accurately. Diflubenzuron is not hazardous to mammals, not toxic to adult insects and not harmful to aquatic life.	Diflubenzuron acts by inhibiting the synthesis of chitin that is essential to develop the external skeleton of arthropods and will not kill adult insects. The spray system prevents drift into non-target areas and contamination of watercourses.

Great spruce bark beetle *(Dendroctonus micans)*

Adult and larvae of Dendroctonus micans.

Great spruce bark beetle (*Dendroctonus micans*) is a Eurasian bark beetle that was discovered in Britain in 1982. It is likely to have been brought into this country on poorly debarked logs or packaging material during the early 1970s and remained undiscovered for at least 10 years. Although pesticides are not usually recommended for use on *D. micans*, information is included here as it is one of the few damaging insects which warrants control measures; it also provides a good example of the development of a successful non-chemical control strategy.

Adult beetles burrow through the bark of spruce trees to develop a gallery system in the cambium. Each female beetle can successfully attack a tree (unlike some bark beetles, such as *Ips typographus*, that require mass attack to overcome tree defences) and thus the potential for tree colonisation and damage is very high. Observations of the life cycle in Britain indicates that larval development may take between 12 and 24 months depending on when the eggs are laid. The entire development takes place underneath the bark, beginning with egg laying and development through 5–6 larval stages, pre-pupation and adult development. Mating also tends to take place within the gallery system, so that, unlike many bark beetles that employ attractant pheromones, the females do not have to find mates once they leave the initial host tree. This means they are able to attack fresh trees and lay eggs immediately.

Consequences

All species of spruce are vulnerable to attack by *Dendroctonus micans*, although Norway spruce (*Picea abies*) is the natural host in Western Europe. Repeated attacks on the same tree can result in tree mortality, even on mature trees. This may take several years during the initial build-up after the beetle colonises a stand. Significantly, Sitka spruce (*Picea sitchensis*) is more likely to be killed than Norway spruce for a given number of attacks per tree. In Britain, some forest areas have been very heavily attacked, but tree mortality has been relatively low due to the management strategy that has been in place since 1982.

Symptoms of attack include the presence of resin tubes arising from the production of resin as a response to attack, and the maintenance of a passage to the outside by the adult beetle. Unusually for bark beetles, *D. micans* adults are able to cope with copious resin flow and are not killed by the normally toxic chemicals within the resin. Later, the larval feeding within the cambium can result in girdling of branches and the entire stem resulting in branch death, top death and, ultimately, death of the entire tree. Adults usually move only short distances between trees and so tree deaths are usually found in small groups, even when *D. micans* populations are high.

Damage to Norway spruce.

Risk factors

Virtually all spruce trees are vulnerable to attack but there are some factors that encourage greater levels of colonisation and successful breeding. Sites prone to moisture deficit where some damaged trees are already present (for example resulting from wind blow or damage from thinning operations) tend to be more vulnerable than vigorously growing trees.

Options for control

TAKE NO ACTION

The period from approximately 1970 to 1982 indicates that, without any form of intervention, *D. micans* was able to colonise most of the forests in Wales and the bordering counties of England and in some forests caused significant tree mortality and high levels of tree attack. A pattern of slow initial build-up and then a rapid increase in population size to reach damaging proportions is typical of this bark beetle in newly colonised areas of its natural range in Europe. Some mortality of trees can be expected and, if the forest is predominantly Sitka spruce and there has been a prolonged period of drought, considerable numbers of trees could die. There is also the potential risk of rapid transport of *D. micans* to previously uninfested parts of the country. Currently, taking no action is not a viable option as indicated by the financial appraisal of existing options – see O'Neill and Evans (1999).

AVOID THE PROBLEM

The only reliable options for avoiding the problem are not to grow conifers or to prevent arrival of the beetle in the first instance. Once the beetle has colonised a forest, there is very little further action that can be taken apart from planting non-susceptible host tree species; the only other conifer that is occasionally attacked successfully is Scots pine, therefore use of other conifer species could be considered.

TAKE REMEDIAL ACTION

During the initial phases of colonisation in Europe, action has often involved sanitation felling and insecticide treatment of the bark of felled trees to kill the beetles. This strategy was also used in Britain during the period from 1982 to 1984 when a 'seek and destroy' tactic was used to try to reduce or eliminate *D. micans* populations in the known infested area to the west of the country. Since that time, an Integrated Forest Management (IFM) strategy has been adopted (Evans and Fielding, 1996; Forestry Commission, 2002).

IFM strategy

The elements of the current IFM strategy are:

- **Controlling timber movement to prevent the pest being moved to areas of the country still free from *D. micans*.**
  The area of Britain infested by *D. micans* has been designated by the European Union as a *Dendroctonus Micans* Control Area. The uninfested area has been designated as a *D. Micans* Protected Zone. It is illegal to move infested timber from the Control Area to the Protected Zone. This strategy is designed to reduce or prevent movement of the beetle with timber to the major spruce forests of northern England and Scotland. Specifically, plants over 3 m in height (including tops) must have a plant passport to signify that the place of production has been officially inspected and found to be free of *D. micans*. Wood that is square sawn or stripped of bark can be moved freely without a plant passport but if the wood has been kiln dried and still retains some bark, it must have a plant passport to confirm that kiln drying has taken place. Isolated bark has to receive an approved treatment (composting, pulverising or fumigation) before it can be moved outside the control area.

- **Survey and felling of infested trees on a peripheral zone around the infested area.**
  It is known that *D. micans* spreads at an annual rate of between 2 and 5 km. A survey zone 10 km wide has been established around the known infested area. All stands of spruce within this zone are sampled each year and

any infested trees are felled and the specific predator *Rhizophagus grandis* released on site (see below). This strategy is designed to further reduce the potential for spread by the pest.

- **Rearing and release of the specific predatory beetle, *Rhizophagus grandis.***
In its natural range in Eurasia, *D. micans* populations are regulated mainly by the action of a predatory beetle, *R. grandis*, which is known to be entirely specific to the bark beetle. *R. grandis* was imported to Britain in 1983 and, following the granting of permission under the Wildlife and Countryside Act 1981, releases of the predator started in 1984. Release programmes concentrated initially on the main infested area and in recent years have been carried out only in the periphery of the Control Area and in newly discovered infestations in Kent, North Devon, and in the northwest of England up to Penrith. The predator has well-developed host finding capability and is now the main regulatory factor in keeping populations of *D. micans* below economic levels in the infested area. It has provided sufficient control to be able to drop sanitation felling and insecticide treatment completely from the *Dendroctonus Micans* Control Area. The predator is also moving with the bark beetle as it spreads slowly from the central area, indicating that it is reacting to changes in distribution and abundance of its specific host, *D. micans*.

Table 1.6 details possible remedial control measures for *D. micans*.

References and useful sources of information

EVANS, H.F. AND FIELDING, N.J. (1996). Restoring the natural balance: biological control of *Dendroctonus micans* in Great Britain. In: *Biological control introductions: opportunities for improved crop production*, ed. J.K. Waage. BCPC, Farnham, 45–57.

FORESTRY COMMISSION (2002). *Dendroctonus micans – a guide for forest managers on control techniques.* Forestry Commission Plant Health Leaflet 9. Forestry Commission, Edinburgh.

O'NEILL, M. AND EVANS, H.F. (1999). Cost-effectiveness analysis of options within an Integrated Crop Management regime against great spruce bark beetle, *Dendroctonus micans* (Kug.) (Coleoptera: Scolytidae). *Agricultural and Forest Entomology* **1**, 151–156.

Table 1.6 Remedial control measures for great spruce bark beetle.

Method	Cost per ha per operation	Total cost	Efficacy	Environmental risks	Comments
Non-chemical methods					
Timber movement controls within PZ[1] system	Nil cost for movement within the DMCA[2].	Cost of surveys, debarking and/or kiln drying or fumigation for movement to the PZ. Total varies from year to year, but minimum cost is around £55 000 per annum.	Apart from a new infestation in Kent that might be a completely new introduction to Britain, there have been limited isolated infestations discovered outside the DMCA[2].	There are no environmental risks for the majority of actions under movement control. However, if fumigation is used to render timber safe, then some pollution of the atmosphere by methyl bromide, for example, could occur. However, this option does not appear to be used by forest owners/timber processors.	An effective strategy that is known to be financially sound and carries virtually no environmental consequences.
Maintenance of PZ[1] status	Survey costs are £20 for lures and costs of cutting, placement of billets and inspection of trees and billets. Estimate is £500 ha^{-1}.	Total cost of 45 survey sites on a national grid is approximately £22 500, i.e. £500 ha^{-1}.	Maintenance of the PZ is essential to be able to keep border controls for prevention of possible importation of *D. micans* and other bark beetles, especially *I. typographus*, from the rest of the EU.	There are no environmental risks. The strategy provides assurance that extremely damaging bark beetles are absent from our forests.	
Rearing and release of *Rhizophagus grandis*	Approximately 100 beetles ha^{-1} are released. Rearing system costs around £15 000 per annum. Approximate cost is up to £150 ha^{-1} treated but the price per ha drops if greater areas are treated.	Total cost per annum for up to 100 000 beetles is around £15 000, i.e. £150 ha^{-1}.	An extremely effective biological control agent which, since its introduction in 1994, has reduced *D. micans* populations in the DMCA[2] to sub-economic levels.	*R. grandis* is totally specific to *D. micans* and does not attack any other species. It is capable of finding very low populations of its host and spreads into new infestations of the bark beetle naturally. Once released, no further management is required.	*D. micans* arrived in Britain without its specific naturally occurring predator, *R. grandis*. The UK programme has restored the 'natural balance' that maintains *D. micans* at relatively innocuous levels through most of its range in Eurasia. This is an excellent example of successful biological control, integrated with other aspects of forest management that have stabilised populations of *D. micans* in the DMCA[2] and have prevented rapid movement of the pest to vulnerable spruce forests in the rest of Britain.
Chemical methods					
Sanitation felling and pesticide treatment	Depends on extent of felling. Some sites were clearfelled during the early phase of infestation in the UK.	Costs of felling are £10–15 m^{-3}. Not all felled timber can be extracted. Costs of stripping bark and insecticide treatment are approximately £10 m^{-3}. Possible cost £1800 ha^{-1}, plus considerable cost of lost income.	An effective strategy in that all beetles are killed.	The early strategy included some premature clearfelling of sites plus debarking on site with a portable debarker and burning of the detached bark. Potential reduction in biodiversity and pollution from burning were likely consequences of clear-felling/ debarking. Selective felling, local debarking and application of insecticide were also used. Although selective, the use of insecticide may have had local effects on non-target insects, and if misused offers potential risk of soil and water pollution and potential risk of poisoning of wildlife.	Not recommended in most cases due to reductions in net discounted revenue and potential environmental effects of premature clearfelling. Cheaper, environmentally friendly options (especially use of *R. grandis*) have been introduced as part of an Integrated Forest Management strategy.

[1]PZ = Protected Zone, that area of the country (outside the DMCA) known to be free of *D. micans*.
[2]DMCA = *Dendroctonus Micans* Control Area, defined as the area that is known to be infested by *D. micans*.

1.2 Vegetation management

The need to weed

Thousands of years ago, forests in the UK regenerated successfully without human involvement, although it might have taken tens or hundreds of years to replace what was lost through natural processes. However, people have interrupted these natural cycles. Wiping out predators and introducing domestic animals such as sheep and rabbits increased browsing pressure; the introduction of invasive and non-native vegetation increased competition; and utilisation of the forest for fuel and land for agriculture introduced much greater disturbance. All these factors meant natural regeneration of woodland was less likely to occur without human intervention. In past centuries, much regeneration was carried out by planting huge quantities of seeds in the soil, and intensively tending and weeding them by hand for many years with peasant labour. Such forms of artificial regeneration are rarely practicable in the modern developed world. Alternative methods must be used.

A weed is usually defined as a plant which, from a land manager's point of view, is growing in the wrong place. Weeds compete with trees primarily for moisture, nutrients and light. Competitive vegetation can cause physical damage, severe growth suppression and death, particularly when trees are very young. Different plant species will compete with trees in different ways depending on their physiology and location. As a rule of thumb for managers, it is fair to assume that the more vigorously growing (in terms of root and shoot biomass), and the more invasive a weed species is, the more intense the competition it is likely to offer to tree species on any given site.

On wet, infertile sites in the uplands, competition from weeds for nutrients or light are often the most important factors. On nutrient-rich lowland sites in the drier eastern and southern parts of the country, competition for moisture is often the most important factor. In all situations adequate weed control is important, but the actual weed species present, their relative growth rates and hence the amount and nature of weeding operations that may be necessary will vary considerably depending on location.

Site fertility has a major impact on the amount of weed growth that occurs. On infertile, upland gleys, podzols and peats, successful establishment can often be achieved with little weed control other than that resulting from pre-planting cultivation, although this will depend on tree species, type of cultivation and the weed species present. On fertile lowland brown earths, and to an even greater extent on agricultural land being converted back to woodland, weed growth is usually profuse and successful tree establishment is likely to require frequent weeding.

The amount of weed control required to achieve management objectives is influenced by a variety of factors. Some, like site fertility, are difficult to manipulate but others such as choice of silvicultural system are under the manager's control. Whatever method of weeding is employed, it is likely to be expensive, often intrusive and has the potential to cause environmental damage. So while adequate weed control is essential, it is equally prudent to attempt to minimise the need to weed in the first place.

Minimising the need for weed control

The ultimate in minimisation – establishing woodland without any weed control or other inputs at all through natural colonisation – may be an option if the impact of browsing mammals can be controlled through culling or exclusion, and no pernicious invasive weed species such as rhododendron (*Rhododendron ponticum*) or Japanese knotweed (*Fallopia japonica*) are growing nearby. However, it may take 50 to 100 years to form a woodland on abandoned land and, even then, it may not meet the owner's objectives.

The key elements in minimising the need for weed control are adoption of good silvicultural practice, choice of appropriate silvicultural system, and the targeting of control operations. For the purposes of this guide, silvicultural practice includes choice of species, spacing, and planting practice, and these apply equally to new planting and restocking. Choice of appropriate silvicultural systems is taken to apply primarily to the regeneration of existing woodland and has a considerable influence on the extent of weed control required.

Good silvicultural practice

New planting on lowland sites

Fertile lowland sites pose particular problems for weed control and several methods may need to be used in combination. On arable sites, high fertility and a weed seed bank of a wide variety of agricultural species can result in a rapid invasion of very vigorous vegetation once rotational cropping ceases. Ground preparation often exacerbates the problem. On improved grassland sites the same potential problem exists if the grass cover is removed.

A good technique for reducing herbicide use in this situation is to utilise alternative ground covers. If they are not already present, low-growing, less competitive grasses, or grass and wild flower mixes, can be sown to occupy the ground between weed-free bands or spots and so reduce the invasion of noxious weeds. The sown areas may also act as a reservoir to colonise the site once weeding ceases.

Species choice

Careful matching of tree species to the site can reduce the need for herbicides and other forms of weeding. Species that are not suited to poor quality sites will require repeated weeding to help them establish, and this should be avoided. Slow growing, stress tolerating species may be more appropriate. In some situations, such as poorly restored industrial sites, it may be better not to attempt to plant any tree species at all. On good sites for tree growth, fast growing species will establish quickly and hence reduce the amount of weeding that might be required. The Forestry Commission Ecological Site Classification provides useful guidance on species suitability for different site types.

Planting practice

Appropriate ground preparation, careful plant handling and high quality planting stock are crucial to good establishment and hence in minimising the need to weed. Plant handling methods should avoid physical damage and exposure of roots to drying both in the planting process itself and in storage. Planting stock should have a good balance between root and shoot and ideally should conform to British Standard 3936 (Morgan, 1999; British Standards Institution, 1984). Large planting stock will tend to establish more quickly and hence require less weeding. However, on exposed sites larger transplants are not appropriate as they may suffer more from desiccation. Whips and standards are likely to require more intensive weeding than well-balanced smaller stock, because their root system is poorly developed in relation to their transpiring foliage area.

The timing of planting is also important. Planting at the correct time of year for each species will maximise survival and early growth (see Morgan, 1999). Often, weed-free conditions exist on the forest floor beneath even-aged stands of many coniferous and some broadleaved tree canopies. Rather than allowing land to lie fallow for one or more seasons, planting (at the correct time of year) as soon as possible after felling allows young trees to take advantage of these weed-free conditions.

Spacing

Planting trees at closer spacings can dramatically reduce the amount of weeding that is required. This is because, in general, the closer trees are planted together, the more rapidly they will start to out-compete and shade out weed species.

In addition, a woodland environment is created more rapidly with close spaced trees. This may be important if introductions of woodland ground flora species are being considered. If the objective is to provide a woodland environment for recreation or conservation, the quickest way of achieving this is to plant trees at close spacings (with areas of planned open space if necessary), then manipulate tree stocking once the woodland is established. Closer grown trees also usually produce higher quality timber.

To minimise weeding and speed the development of a woodland environment, most tree species should be planted no wider than 2 m x 2 m (2500 stems ha^{-1}). If timber production is an objective, oak and beech should be planted no wider than 1.8 m x 1.8 m, and poplars 8 m x 8 m.

Planting trees at even closer spacings (50 cm x 50 cm spacing – 40 000 stems ha^{-1} – and to a lesser extent – 1 m x 1 m spacing – 10 000 stems ha^{-1}) can reduce weeding and establishment periods significantly. Unfortunately, such an approach is rarely economically viable. However, where natural regeneration is successful, it may sometimes be possible to establish dense stands of seedlings as cheaply as conventional planting. In the case of new woodland establishment with some broadleaved species on certain site types, experiments have shown that the technique of direct seeding can achieve 10 000–50 000 established stems ha^{-1} at around two-thirds of the cost of conventional establishment at 2500 stems ha^{-1}. However, direct seeding requires more research before it can be widely recommended in Britain.

Protection

Where necessary, trees should be protected from damaging mammals (as well as insects and fungal pathogens). Individual tree protection through the use of tree shelters can also help to increase the early growth of most broadleaves including beech (*Fagus sylvatica*) as long as beech woolly aphid (*Phyllaphis fagi*) is adequately controlled in the nursery. Shelters are not normally suitable for conifers. They have a particularly dramatic beneficial effect on beech and oak (*Quercus* spp.), increasing their apical dominance and early growth until they clear the top of the shelter, and reducing the establishment period. **However, weeding is still essential to ensure survival and early growth**. In addition, tree shelters are expensive and, except on small areas (usually less than 1 ha), it is often best to fence and invest any extra resources on closer tree spacing.

Choice of silvicultural system: regeneration of existing woodland

Natural regeneration

Given an adequate seed source, trees will probably regenerate naturally in most parts of Britain. However, the presence of browsing mammals and invasive weeds may make this a very long process, or even impossible in some cases. In addition, it is often less reliable and more expensive

The use of natural regeneration may allow a reduction in herbicide inputs but young trees may still require remedial weeding once the overstorey canopy is opened up.

to achieve than planting. Trees naturally regenerated from seed face the same problems from weed competition as planted trees. Nevertheless, on sites where dense regeneration occurs, trees are likely to establish quickly as they shade out competing vegetation sooner. As with densely planted trees, successful natural regeneration may reduce the need for weeding inputs.

Coppice systems

Coppicing, as traditionally practiced, rarely requires weed control. Regrowth from healthy, correctly cut, unbrowsed stumps is usually sufficiently vigorous to out-compete other vegetation. Exceptions to this may arise when trying to control invasive tree or shrub species, or when planting new trees within neglected coppice to form future coppice stools. Poplar (*Populus* spp.) and willow (*Salix* spp.) grown as short rotation coppice on agricultural land usually require intensive, complete weed control after planting and cutting.

Continuous cover forestry

Continuous cover forestry describes a range of silvicultural systems where there is a presumption for maintaining some form of canopy cover throughout the regeneration phase. The key process in continuous cover forestry is to manage the balance between the existing tree canopy, the regeneration of trees and the growth of competing vegetation. This requires an understanding of the site and the species being regenerated. Continuous cover forestry offers the potential for reducing weeding inputs as the tree canopy can be used to control light levels and hence vegetation growth on the forest floor. However, even where this technique is used successfully, some supplemental weeding may be required to control invasive weeds such as bracken and bramble. Additional inputs may also be required if the manager loses control of the canopy–regeneration–vegetation balance, or if attempts to regenerate the desired tree species fail. While some form of continuous cover forestry could in theory be practised on a broad range of site types, the greatest potential for reducing weeding inputs exists on wind-firm, less fertile sites using shade tolerant tree species.

Large group/clearfell systems

Large group or clearfell systems are often used in woodlands that are composed of light demanding species, or are established on unstable soils with a high risk of windthrow. Vegetation cannot be controlled through manipulating canopy cover, and high inputs of other forms of weeding may be required.

Targeting and the intensity of weed control

Trees can benefit from weed control throughout their life. However, it is usually only desirable to control vegetation sufficiently to allow trees to establish, that is, up to the point when they start to dominate the competing weeds, no further significant losses from competing vegetation are likely and they are no longer vulnerable to losses from browsing mammals. Typically, the establishment period lasts 3–5 years, but it could be much longer on poor quality sites or if a wide initial tree spacing (>2 m x 2 m) is used, or if there is high mortality of regenerating trees.

Although trees derive maximum benefit from complete removal of all other competing vegetation, the usual method of targeting weed control is to practise spot or band weeding. A 1 m wide weed-free band or 1 m diameter weed-free spot is the minimum for good establishment. However, as this is seldom achieved in practice, it is more prudent to aim for a 1.2–1.5 m wide weed-free band or spot depending on tree spacing. The use of 1 m wide weed-free bands on 2 m x 2 m spaced trees results in only 50% of the crop area actually being weeded; for 1 m circular spots, only 20% of the site is treated.

There are some situations in which complete removal of all other vegetation within planted areas on a site may be appropriate, though it is important to assess the possible environmental impact in such cases. The most common examples are:

- in the first 1–3 years of growth to achieve rapid establishment and reduce the length of time for which weeding is necessary;
- when trees are planted close together;
- before planting on sites dominated by highly invasive weeds.

Methods of weed control

Often a combination of techniques, involving both non-chemical and chemical approaches, may be the most practical way of reducing overall herbicide inputs, for example, cultivation with other forms of weeding or pre-plant herbicides with mulches.

Mowing

For grass dominated sites, mowing is an ineffective form of weed control. In fact, cutting grassy swards is more likely to harm than help the tree. Grasses can compete vigorously for soil moisture due to an abundance of fine roots. In addition, their vegetative growth involves very little stem elongation, aerial growth being mainly leaf, with stem and buds very close to ground level. This means that when grasses are cut, stems and buds are usually undamaged, allowing them to immediately regrow. With other weed types cutting may be more effective in reducing above ground regrowth, and may reduce root interference, but it never eliminates it. Mechanical flailing (sometimes referred to as mulching) is usually more effective than cutting at damaging or killing roots, but the deeper and more intensively a site is flailed, the more risk there is of damage to the soil structure or erosion. To avoid site damage from intensive flailing requires considerations similar to those needed for cultivation (see below).

Cutting before flowering can stop annual weeds from setting seed. In addition, repeated cutting may weaken some non-creeping herbaceous species. However, repeated mowing also tends to change the balance between the various species in a mixed weed flora in favour of grasses, which are resistant to cutting. In this way mowing can create a grassy weed flora that is very harmful to trees. However, when used in conjunction with other methods, mowing can be helpful, for example, in maintaining a grass sward between weed-free bands on new planting sites.

Cutting can also be useful for controlling unwanted woody species sufficiently to allow trees, once past their early establishment phase (3–10 years old), to dominate the site and shade out competing vegetation. It can also allow access to a site that is otherwise impossible to weed, and allow herbicides to be more effectively and safely targeted on to woody vegetation.

Although single mechanised mowing operations are usually fairly cheap, they can be expensive when attempting to control woody species such as *R. ponticum*. Mowing usually needs to be repeated several times a year and often for many years to achieve any degree of weed suppression. They can involve repeated trafficking and disturbance of the site. Hand (non-mechanised) cutting is labour intensive and therefore usually very expensive.

Trees are often accidentally damaged when adjacent vegetation is being cut. In addition, repeated mowing, particularly from mechanised cutters, can result in soil compaction. The use of mechanised and hand-held machinery, especially if machinery is poorly maintained, can also result in a degree of pollution from exhaust gases, which may contain significant amounts of unburned oil, and introduces the risk of further soil and water pollution from spillage of fuels and lubricants.

Tillage

Hoeing, ploughing and other cultivation techniques aim to cut weeds below ground level, and either uproot, leaving them to desiccate, or bury them. However, some weeds, such as couch grass, can regenerate speedily from cut rhizomes. In addition, fertile soils may contain a seed bank of tens of thousands of weed seeds per square metre, some of which are brought to the surface and germinate when a soil is cultivated. Cultivation is most effective in countries with a Mediterranean climate (little or no summer rainfall) where seed brought to the surface in summer cannot germinate successfully, and uprooted weeds and rhizomes soon wither.

However, mechanised cultivation is fairly cheap, and is often practised to relieve soil compaction and so assist in tree establishment. Almost all sites require a degree of cultivation to improve aeration, increase temperature and nutrient availability, and improve rootability. The only soils that usually do not require cultivation to improve planting conditions are freely draining brown earths. On these site types, cultivation is not always necessary for tree establishment and often actually encourages weed growth.

The effectiveness of cultivation for weed control depends on the site type. By itself, on infertile soils such as upland gleys, podzols and peats, pre-planting cultivation can offer sufficient weed control to allow tree establishment, often with no further herbicide or other weeding operations being required. However, on more lowland, fertile sites, such as brown earths, and in particular on new planting sites in the lowlands, cultivation can actually make the weeding problem worse. Tillage by hoe or mattock post-planting, with care taken to minimise damage to tree roots, can be very effective but it is expensive and only appropriate at very small scales. In damp seasons, fertile sites may require seven or more hoeings a year to keep them reasonably weed-free.

Cultivation, especially mechanised cultivation, can lead to soil erosion, and washout of soil material into watercourses. The turbidity and siltation from the latter can be extremely damaging to aquatic wildlife and can have implications for treatment of drinking water. These problems can only be avoided by strict adherence to guidelines for site preparation. Other potentially negative effects of intensive cultivation are nitrification, acidification, oxidisation of organic material, disruption of complex ecosystems and destruction of archaeological remains. The worst effects are likely to be associated with complete plough cultivation while less intensive techniques such as scarification and mounding pose fewer risks.

Complete cultivation can also be achieved through penning pigs onto a site. In theory at least, this can be achieved at nil cost, with the sales of meat offsetting the costs of husbandry. However, in practice, this technique requires specialist pig farmers, is limited to a small number of readily accessible sheltered sites and is only likely to give temporary pre-planting weed control.

Mulches

Most soil moisture is lost by transpiration, so the primary way in which mulching conserves moisture for the tree is by suppressing weeds. Mulches can also reduce the smaller losses which occur by evaporation from bare soil. In addition, by keeping the surface soil moist mulching helps maintain nutrient availability. On readily leached sandy soils, impermeable sheet mulches reduce nutrient loss in wet weather. Sheet mulches also raise soil temperatures and thus stimulate root growth.

Many materials can be used as mulches. Traditionally, organic materials such as bark, peat, straw, and leaves were used. Unless they are killed before mulch is applied, vigorous weeds are able to grow through even a 100 mm organic mulch, although new weeds germinating in the mulch are easier to control, as they are readily uprooted. Fresh bark contains volatile oils which are toxic to plants so bark for horticultural use is composted first, which reduces the concentration of these oils to sub-phytotoxic levels. Materials with a high carbon : nitrogen ratio, such as bark, wood chips and straw, can induce nitrogen deficiency in mulched plants and nitrogenous fertiliser may be needed. Alkaline materials, such as spent mushroom compost, can induce iron and manganese deficiency.

Many opaque, inorganic sheet materials such as polythene, old carpets and roofing felt can be used as a mulch. If available locally as a waste material, the latter two can be quite cost effective on a small scale. Old carpets and roofing felt are often heavy enough to require no further anchorage, but polythene sheets must be secured by stakes or by burying at the edges. Black polythene can form a good mulch. Thicker polythene films are easier to handle and less likely to be torn by stones or animals such as foxes and cats which sometimes scratch at voles nesting beneath sheet mulches. On rough sites, 125 µm (0.125 mm) thickness is usually needed. A covering of organic mulch or dead vegetation on top of a polythene mulch will make it less unsightly, and also help to anchor and protect it from ultra-violet light.

Mulches can, however, cause problems. On poorly drained sites, the reduced evaporation may exacerbate any waterlogging, causing anaerobic soil conditions which can kill trees. Such sites should be drained before planting or mulching. Voles sometimes nest under sheet mulches and gnaw trees below the sheet, even felling small trees; this damage can be reduced by placing clods of earth or other weights on the sheet, close to the tree.

Mulches can be expensive and their durability is often a problem. Wood chips are very expensive and need to be repeatedly applied to give any degree of control. Although cheaper than organic mulches, inorganic mulches such as plastics are still expensive, and may not last for the 3–5 years needed for trees to establish. Weedy sites may require other forms of weed control before mulches can be laid down. Harvesting residues and stumps may also need to be chipped or removed – these are all costly, and not always practical or desirable operations.

It is particularly important in the case of mulches to ensure a weed-free spot at least 1.2 m wide, as weeds tend to root underneath the margins of the mulch and hence reduce the effective weed-free area.

Inorganic mulches can form a source of solid chemical waste in the environment. Unless fully biodegradable, they will need to be collected at the end of their useful life. Unless inert, waste materials used as mulches may also emit pollutants onto a site.

Other non-chemical methods

Other non-chemical methods of weed control exist, some of which are routinely and successfully used by gardeners. Generally, due to very high labour requirements, such methods are only practical on a very small scale around individual amenity trees. However, the availability of volunteer labour may make them feasible for some owners and managers.

Burning will kill certain weed species, although others are adapted to survive or re-invade rapidly following fire. Burning is a traditional method of management for heather moorland. For tree establishment, large-scale burning of a site is unlikely to be acceptable due to the habitat destruction and atmospheric pollution it may cause.

Small scale hand-held flame or steam generator units are commercially available. These will kill above ground weed growth, but not necessarily the roots of weeds. Both will create some atmospheric pollution. Such units are only likely to be practical on an extremely small scale, perhaps around individual amenity trees. Larger mechanised systems have been used on flat, man-made, hard surfaces but access and cost restrict their practicability for woodland use.

Physical pulling of vegetation can control some weed species, but will be ineffective on deeply rooting or rhizomatous species. Unless volunteer labour exists, pulling by hand is only practical on a very small scale. Mechanised pullers exist that can remove tall growing noxious weeds such as ragwort (*Senecio jacobaea*) from lower growing grasses.

Herbicides

In strictly financial terms, the use of herbicides is usually the most cost-effective means of controlling weeds currently available in the UK. If used correctly, they also have the advantage, in many cases, of causing less physical site disturbance than other methods. However, their disadvantages include the risk of environmental pollution, and harm to operators, non-target vegetation and wildlife. If misused, their potential for harm is probably greater than for non-chemical methods of weed control.

Minimising herbicide inputs

For both environmental and economic reasons, the aim should always be to use the minimum quantity of herbicide required to give the desired degree of control. This is a particularly important consideration where herbicides are used on sensitive sites. Activity should be confined as far as possible to the target plants and this may involve using selective rather than broad-spectrum products. Residual soil acting herbicides may offer a way to reduce the need to revisit a site compared with repeated applications of foliar acting products that may drift and damage non-target vegetation. However, soil acting residual products may prevent desirable vegetation from re-invading a site, and may be more susceptible to leaching, or run-off if soil particles bound with herbicide erode, depending on site conditions.

Herbicides that have a low toxicity should be favoured. On the other hand, it is counterproductive to use a marginally less toxic, less active, or less persistent herbicide, if it fails to control the target vegetation, or requires high application rates or repeated applications to be made.

If use of a herbicide cannot be avoided, it is important to choose the right one for the job, target the application and apply it properly.

Herbicide selection

Careful assessment of the weed problem and selection of the most appropriate herbicide are vital. This publication aims to guide managers through the chemical/non-chemical selection process and does not repeat comprehensive guidance available elsewhere on the choice of specific chemicals for efficacy. **Reference to Forestry Commission Field Book 8: *The use of herbicides in the forest* (Willoughby and Dewar, 1995) on the selection of herbicides for specific weeding situations is essential.**

Adjuvants may be necessary to maintain or increase activity in some situations. A wide variety of adjuvants that may be effective and useful are available, but only three are referred to in this guide: Partna, which must be used with the herbicide Fusilade (fluazifop-p-butyl); Actipron which must be used with the herbicide Laser (cycloxydim); and Mixture B, which can be particularly useful in increasing the efficacy of herbicides used to control *Rhododendron ponticum*.

Tank mixes of herbicides are very commonly used in agriculture and may have a place in some woodland weed control situations, particularly for new planting on fertile ex-agricultural land. The use of tank mixes can help to achieve more effective weed control, and reduce the need for repeat visits.

Timing

The use of pre-emptive weed control is often more effective than dealing with greater problems later. For example, in new planting situations on better quality sites, where profuse weed growth is guaranteed, the use of soil-acting herbicides is less damaging to trees, and more effective than the repeated later use of foliar-acting herbicides.

‘Revenge’ applications – the application of herbicides to weeds late in the season after they have caused their damage – should be avoided. For example, controlling weeds around trees in August with glyphosate is unlikely to offer much benefit during that season, and can easily result in tree damage. However, on less fertile sites, applications in August may be a good means of achieving weed control for the following season.

Activity

High efficacy in a herbicide does not necessarily equate with a high potential for harm to the environment. A single application of a highly effective herbicide (especially if it is also very selective) may lead to less chemical loading than if using less active products. Repeated visits to a site to apply a less active herbicide may offer more potential for herbicide contamination, as well as more disturbance and greater petrochemical usage.

Targeting/application technology

Herbicide use can be minimised through carefully targeting treatments, avoiding contamination of crop trees with herbicide, and whenever possible using herbicides offering the greatest crop tolerance. The correct applicator and volume rate should be used. Rates and droplet size should be large enough to avoid drift, but low enough to avoid run-off (see Section 2.4 for more details). The use of dye markers can be particularly helpful in enabling operators to spot, and so reduce, drift and damage to non-target vegetation, and improving the effectiveness of applications; see Willoughby (2001) for further guidance.

Dye markers can be used to reduce the non-target impacts of herbicides.

The correct choice of method of application and most appropriate choice of applicator ensures precise targeting of herbicides. This also helps to improve efficacy, thus reducing the total amount of herbicide required. Follow-up applications are less likely to be required, hence reducing the risk of adverse environmental impacts.

Intensity

Pre-plant sprays will often need to be made across the entire planting site, except for buffer zones around desirable features or watercourses where strips 10 m wide (20 m for water bodies and 50 m for boreholes) should be left untreated. In general, spots or bands should be favoured unless there is a specific justification for carrying out an overall spray, such as the presence of very invasive weeds, or when combined with close spaced trees to achieve rapid establishment and an overall reduction in herbicide use. After planting, depending on species, site and weed vegetation, bands (1–1.5 m) or spots (1–1.5 m diameter) can often be used.

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Grass and herbaceous weeds: new planting and restocking

A clearfell site planted with Corsican pine, subject to competition particularly from grasses and rushes.

A wide variety of grass and herbaceous species become weeds when they are found among young trees. After clearfelling, or to a lesser extent selection felling, increased light levels on the forest floor stimulate rapid growth of naturally occurring vegetation. In new planting situations, there is usually an existing vegetation cover, often dominated by grasses, that can slow or prevent tree regeneration. Grass and herbaceous vegetation compete with trees throughout their life but usually only warrant intervention during a tree's establishment period. Once trees form a continuous canopy cover, the growth of highly competitive invasive species diminishes. Given the right conditions, the ground flora tends to become dominated by woodland species forming an important and desirable component of a woodland ecosystem. However, these desirable species are often themselves out-competed by other vegetation in the higher light levels present during the tree regeneration phase.

Correct identification of the competing vegetation is important to allow selection of the most appropriate weed control method, but all grass and herbaceous vegetation competes to a greater or lesser degree with newly planted trees. The more vigorous and invasive the species, the more intense the competition for resources is likely to be. Grasses can be particularly problematic.

Consequences

Grass and herbaceous weeds compete strongly with trees for moisture, light and nutrients. This competition leads to severe growth suppression and often death of planted or naturally regenerated trees. Growth suppression lengthens the establishment period, and so extends the time during which trees are vulnerable to attack from pests, diseases, browsing animals, fire and adverse climatic conditions. Well-timed vegetation management, in the first year in particular, can substantially reduce the subsequent management inputs required, including the use of pesticides and fertilisers.

Nitrogen deficiency induced by heather (*Calluna vulgaris*) in older, pre-canopy closure Sitka spruce (*Picea sitchensis*) may require fertilisation, weed control or both, depending on site type – see pages 71–76 for a summary of the options. Full details are given in Forestry Commission Bulletin 89: *Nitrogen deficiency in Sitka spruce plantations* (Taylor and Tabbush, 1990).

Natural regeneration site invaded by mixed herbaceous weeds when the overstorey canopy was thinned.

Measuring naturally regenerating trees that are being suppressed by the invasion of grass and mixed herbaceous weeds.

Options for control

TAKE NO ACTION

Generally, taking no action is not an acceptable option: many trees could die, particularly in the first season after planting, and growth of the remainder could be severely suppressed. Once trees are established – at the point of canopy closure or sufficiently tall and vigorously growing to reach this point without further loss – it is seldom worth investing resources in controlling grass and herbaceous weeds.

AVOID THE PROBLEM

In woodland situations, it is sometimes possible to avoid the need for weeding by maintaining a sufficient overstorey canopy cover. Some tree species are shade tolerant in their early years, and it may be possible to plant or encourage natural regeneration while maintaining low light levels to prevent growth of competitive grass and herbaceous species.

However, this approach is not practical for clearfell situations or with very light-demanding species, or on sites where it is impractical to maintain a continuous canopy cover due to problems of stability. With light canopied species, and for any species when the canopy is opened up to encourage growth of established young seedlings, some additional weeding may be required.

Good silvicultural practice, as described earlier, can reduce the need for weeding. Appropriate choice of species, stock type, planting time, ground preparation, spacing and protection can dramatically reduce the amount of weeding required.

TAKE REMEDIAL ACTION

Remedial action is usually required. In most cases it is prudent to act pre-emptively to anticipate the problem based upon local experience, as it is far easier to prevent weed invasions than deal with a more substantial problem once vegetation has become established. For example, mulches are easier to fix on bare sites before weed invasion. Similarly, on more fertile sites, the use of soil acting residual herbicides is often more effective, safer to crop trees and requires less chemical to be used than repeatedly spraying foliar acting herbicides later in the year. Some non-chemical methods of controlling grass and herbaceous weeds exist, and they should always be considered before resorting to herbicides.

Cutting by hand or mechanised means is not generally an effective form of control. Although it may weaken some species, cutting fails to kill most herbaceous vegetation and it tends to favour the development of a vigorous grass sward, which is even more detrimental to tree growth. However, there are four situations when cutting may assist in weed management:

- If grass and herbaceous weeds are overtopping planted trees, cutting reduces light (but not moisture) competition.
- Cutting at or just before flowering can reduce the spread of annual weeds, but it will not always kill them, and weed seed will in any case already be present in the soil.
- Regular mowing of an existing grass sward between weed-free bands around trees helps to reduce infestations of noxious weeds on fertile sites.
- Cutting dense or tall vegetation can make it easier to apply herbicides.

Burning and steam treatment can control grass and herbaceous weeds but they are not operationally practical for most situations. Pulling is only suitable on a very small scale. This leaves mulching, cultivation, pigs and the use of herbicides as potential alternative remedial treatments.

Table 1.7 details possible remedial control measures.

The costs given for different treatments reflect a range of situations from infertile to potentially problematic fertile sites. When comparing methods, compare like with like (i.e. low end of cost range of treatment *x* with lower range of costs for treatment *y*). For herbicides, it is rarely possible to use only one product to achieve sufficient weed control for tree establishment. Usually, several different products may need to be used, perhaps in the same year, to achieve control, as different weed species invade a site after others are removed. However, the figures for total cost over the 5-year period give an estimate of cost if only one herbicide was repeatedly used; although this is seldom practical, except occasionally for broad spectrum or residual products, it is included to give a feel for the general differences in prices between the treatments.

The estimate of costs given are indicative, for comparison purposes only and do not include VAT. They refer to the cost to treat one hectare of ground, and an estimated cost of achieving 5 years of weed control using this method, which may often require several treatments to achieve control of subsequently invading vegetation. Note that if spot or band weeding is practised, the costs reduce accordingly. For example, for trees at a spacing of 2500 stems ha^{-1}, a 1.2 m diameter wide band requires 60% and a 1.2 m diameter spot 28% of the cost of weeding an entire hectare of ground. Given good initial weed control, weeding may only be necessary for 2–3 years.

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Table 1.7 Remedial control measures for grass and herbaceous weed control: new planting and restocking.

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Non-chemical methods					
Mulches	£3800–23 500	£3800–117 500	Can be highly effective if placed on clear ground. Less effective at controlling some very vigorous species or when large established weeds are already present.	Unless fully biodegradable, or collected and disposed of, mulching can form a source of solid chemical pollution and can exacerbate anaerobic conditions and nutrient deficiency.	Also benefits tree growth on some sites through increases in temperature and moisture retention. Inorganic mulches may rip and need to be replaced. Organic mulches may need topping up at least once a year and are much more expensive. Not effective on very exposed sites. Should be at least 1.2 m in diameter. Local sources of waste material such as old carpet may be very cheap. Existing vegetation may need to be removed before mulches can be fixed. Restock sites may need to be brash raked and destumped at an additional cost of £500–1000 per hectare to allow mulches to be used. Unlike other forms of weed control, it will not prevent vole damage.
Mechanised cultivation	£100–400	£100–400 but rarely possible	Gives effective suppression of many perennial weeds. Suppression may last up to 4 years on infertile sites or less than 1 month on very fertile sites.	Soil erosion, water sedimentation, nutrient leaching, destruction of soil fauna, disruption of ground nesting birds and archaeology, and possible atmospheric pollution (particularly if machinery is poorly maintained) can all result from inappropriate cultivation if guidelines are not followed.	Repeated cultivation would lessen density of annual weeds, but is impractical amongst planted trees. A single pre-plant cultivation can suppress many perennial and annual weed species depending on site type. Cultivation also gives great benefits for tree establishment. Cultivation is not possible on slopes >65% (up to 70% for walking excavators), and there is a risk of soil erosion on all slopes. However, on fertile brown earth soils subject to moisture deficits, cultivation can worsen a weed problem, and some weed species are spread by ploughing on any site type. Operations should be timed to avoid sensitive periods for wildlife.
Hoeing/ screefing	£1500–7000	£3000–245 000	Gives effective suppression of many perennial weeds. Suppression may last up to 4 years on infertile sites, or less than 1 month on very fertile sites.	As cultivation but much smaller risk. No atmospheric pollution other than transport to site.	Essentially a non-mechanised version of cultivation: only suitable for very small areas. Can be practised post-planting with care. Up to 7 hoeings a year may be needed to control weeds on very fertile sites.
Pulling	£1500–7000	£3000–245 000	May control some species. Impractical, and not effective for many deep rooted and rhizomatous species.	Small risk of soil erosion. Disturbance to ground nesting birds.	Only practical on a very small scale, for shallow rooting non-rhizomatous species. Up to 7 visits a year might be required to control weeds on very fertile sites. Mechanised pullers exist that can selectively remove ragwort from grass swards. These are currently only suitable for new planting or rides, and cost around £150 per operation. Operations should be timed to avoid sensitive periods for wildlife.
Pigs	Potentially zero, but increased management costs.	Potentially zero, but rarely possible.	Can be very effective – total vegetation control and cultivation in enclosed areas.	Damage to trees. Soil compaction and destruction. Damage to non-target flora and fauna. On a large scale, air pollution from ammonia could damage trees and pollute water.	Not practical post-planting – trees will be killed. Will give similar level of control as complete cultivation. Only suitable for small areas; requires sheltered site preferably below tree canopy. Supplementary feeding and regular visits make this a specialist operation only suitable for experienced pig farmers. Not suitable for sensitive sites – produces total vegetation control and severe site disturbance. Subsequent use of machinery may be difficult. Produces ideal weed seedbed, possibly site enrichment, and subsequent weed regrowth may be even more vigorous.

Table 1.7 Remedial control measures for grass and herbaceous weed control: new planting and restocking (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Chemical methods					
Herbicides, general	£40 mechanised application only £70 manual application only		Can be very effective. Contact acting herbicides may need to be applied 1–3 times a year for up to 5 years.	If misused, all herbicides present a risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	If used correctly, can be effective, cheap and of low environmental impact. Trees may be damaged unless tolerant of the herbicide. A pre-plant spray, used before cultivation may be all that is required on less fertile sites. On very fertile sites, spraying may be needed before and immediately after cultivation. Band spraying (1–1.5 m wide) is usually preferable to overall spraying, post-planting.
Atrazine	£67–111	£67–555	Effective control of most established or germinating grass weeds. Residual control for up to one season.	Broad spectrum – most treated vegetation could be damaged. Can be mobile in soil – risk of damage to trees on light textured soils. Potentially harmful to aquatic life. Atrazine not hazardous to mammals. Low toxicity to insects.	Effective herbicide for the control of established and germinating grass weeds. Favour band applications and ensure 10–20 m aquatic buffer zone is rigidly adhered to. Treat sites subject to severe run-off or erosion with care. Of particular use at lower rates in mixture with cyanazine. Atrazine will be withdrawn during 2007.
Atrazine + cyanazine	£115–156	£115–780	Mixtures of these two herbicides can be very effective. Controls a wide range of grass and herbaceous vegetation and gives residual control for up to one season.	Broad spectrum – most treated vegetation could be damaged. Can be mobile in soil – risk of damage to trees on light textured soils. Potentially harmful to aquatic life. Atrazine is not hazardous, cyanazine is harmful to mammals. Low toxicity to insects.	Effective herbicide mix, controlling established and newly germinating weeds on fertile sites. Favour band applications ensuring the usual 10–20 m buffer zone. Treat sites subject to severe run-off or erosion with care. Atrazine and cyanazine will be withdrawn during 2007.
Clopyralid	£75–141	£75–1410	Effective on a limited range of herbaceous weeds. May give one season's control but repeat treatment may be required.	Highly selective – only limited herbaceous species affected. Not hazardous to mammals or insects.	Particularly effective as a selective control of thistles. With repeat use, species not affected would come to dominate the site.
Cycloxydim	£74–147	£74–1470	Effective on many grass species. May give one season's control – newly germinating grasses may require a repeat treatment.	Highly selective – only grasses will be affected. Not hazardous to insects. Low toxicity to mammals. Potentially irritating to eyes and skin. Potentially toxic to aquatic life and dangerous for the environment.	Selective herbicide, grasses controlled with practically no risk to non-target trees or vegetation. With repeat use, herbaceous species not affected would come to dominate the site. Must be used with adjuvant Actipron.
2,4-D	£80–135	£80–1350	Effective on most herbaceous and many woody species. Grasses unaffected. May give one season's control but repeat treatments may be required.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Moderately toxic to mammals – harmful if swallowed or in contact with skin. Potentially harmful to aquatic life. With ester formulations, risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather. Not hazardous to insects.	Particularly effective against problem herbaceous weeds such as nettle, dock, ragwort, buttercup and also against heather. Potential for volatilisation and taint means care must be taken in water catchments. Will taint edible fruit. Avoid spraying in areas with high public pressure if alternatives are available.

[1] Cost for individual herbicides includes chemical plus application cost.
[2] For 5 years, weed control may require several re-treatments of subsequently invading vegetation. In reality, it is likely that a combination of herbicides rather than one single product will be needed.
[3] Selectivity refers to effects on vegetation, not on other biological kingdoms such as insects.

Table 1.7 Remedial control measures for grass and herbaceous weed control: new planting and restocking (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
2,4-D + Dicamba + Triclopyr	£84–180	£84–1800	Effective control of most herbaceous and many woody species. Grasses unaffected. May give one season's control but repeat treatments may be required.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Moderately toxic to mammals – harmful if swallowed and irritating to eyes and skin. Potentially dangerous to aquatic life. Risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather. Not hazardous to insects.	Particularly effective against problem herbaceous weeds such as nettle, dock, ragwort, buttercup and also against heather. Potential for volatilisation and taint means care must be taken in water catchments. Will taint edible fruit. Avoid spraying in areas with high public pressure if alternatives are available. More effective woody weedkiller than 2,4-D.
Dichlobenil	£376–820	£376–4100	Effective control of most germinating and many established weeds for up to one season or longer.	Most vegetation will be damaged; 2-yr-old trees of certain tree species are tolerant. Not hazardous to insects. Low toxicity to mammals. Potentially harmful to aquatic life.	Effective total herbicide. Expense limits its use to spot treatments on very weedy sites.
Glufosinate ammonium	£79–135	£158–2025	Gives effective control of most annual weeds. Perennial species require repeat applications to be effective.	All green vegetation will be damaged if sprayed. Harmful if swallowed or in contact with skin. Potential irritant. Not toxic to insects. Potentially harmful to aquatic life.	Total herbicide. Applications must be made between 1 March and 30 September of a given year.
Glyphosate	£48–95	£48–950	Gives effective control of most weeds. Repeat applications are required for control of subsequent germination.	Broad spectrum – all vegetation, including most tree species, damaged if oversprayed in active growth. Not hazardous to mammals, insects or aquatic life.	Particularly effective, cheap treatment for mixed weed spectra.
Isoxaben	£150–180	£150–900	Effective control of some germinating herbaceous species. Will not control established weeds.	Selective – trees, grasses and established vegetation unaffected. Not hazardous to mammals or insects, but exclude livestock.	Mainly of use in mixture with propyzamide to extend range of herbaceous weeds controlled.
Paraquat	£64–114	£128–1140	Gives effective control of most annual weeds. Not translocated, so large and perennial species require repeat applications.	All green vegetation will be damaged if sprayed. Not toxic to insects. Poisonous to mammals – can kill if swallowed. Irritating to eyes. Harmful to skin.	Subject to Poisons Rules 1982. Safe once absorbed by soil or plants, but poisonous as liquid – exclude livestock and public until absorbed. Useful as a dormant season spray over broadleaved trees: can help to release natural regeneration. Diquat + paraquat has very similar characteristics.
Propyzamide	£127–298	£127–1490	Very effective grass weedkiller. Controls established grass, and gives residual control.	Selective – few established herbaceous or woody species affected. Not hazardous to mammals or insects.	Effective winter weed treatment: offers long-term control, with good tree tolerance.
Triclopyr	£96–126	£96–1260	Effective control of many established herbaceous weeds.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed or in contact with skin; an irritant. Not hazardous to insects. Potentially dangerous to aquatic life. Risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather.	Similar control to 2,4-D on herbaceous species.

Footnotes as previous page.

Grass and herbaceous weeds: new planting on lowland arable or improved grassland sites

Profuse invasion of annual weeds swamping newly planted trees on an ex-arable site.

When converting intensively managed farmland to woodland, there is often an acute need to control grass/herbaceous vegetation. On arable sites, high fertility and a seed bank of agricultural weeds can result in a very rapid and extensive invasion of very vigorous weeds once rotational cropping ceases. When compared with the preceding agricultural crop, invading vegetation can provide valuable additional food sources for bird, mammal and insect species. However, this potential benefit needs to be balanced against the fact that these weeds compete strongly for resources, particularly moisture. Ground preparation often exacerbates the problem. On improved grassland sites the same potential problem exists once the grass cover is removed.

Correct identification of competing species is important to allow selection of the most appropriate control method.

Consequences

Grass and herbaceous weeds compete strongly with trees for moisture, light and nutrients. This competition leads to severe growth suppression and often death of planted or naturally regenerated trees. Growth suppression lengthens the establishment period, and so extends the time during which trees are vulnerable to attack from pests, disease, browsing mammals, fire and adverse climatic conditions. Well-timed vegetation management, in the first year in particular, can substantially reduce the subsequent management inputs required, including the use of chemical pesticides and fertilisers. Annual weeds are often succeeded by perennial varieties after 2–3 years. These can be very persistent and prevent the colonisation of true woodland species until canopy closure occurs and low light levels are produced. Even then, some weed control may be necessary to allow woodland species to establish.

Good silvicultural practice: maintaining weed-free bands around trees and utilising a grass cover crop on the remainder of the site.

A wildflower meadow, sown to act as an inter-row cover crop.

Options for control

TAKE NO ACTION

Once trees are established – at the point of canopy closure, or sufficiently tall and vigorously growing to reach that point without further loss – it is seldom worth investing resources in controlling grass and herbaceous weeds.

In most other cases, taking no action is not an acceptable option: many trees will die, particularly in the first season after planting, and growth of the remainder will be severely suppressed or even non-existent.

Left undisturbed, certain noxious weeds can also seed to adjacent agricultural land, and there may be a legal obligation to control them.

Naturally colonising trees of certain species may eventually establish on ex-agricultural sites, but this may take many years, and the woodland formed may be undesirable in structure or composition.

AVOID THE PROBLEM

Given that we are dealing with new planting, it is not possible to avoid the problem entirely. Good weed control in preceding agricultural crops can reduce subsequent problems, but the main way to reduce the intensity of weeding operations on arable sites is to sow a low productivity grass sward or wildflower meadow across the entire site prior to tree planting (Williamson, 1992). A sown or existing grass sward means that subsequent weed control can be confined to 1.2 m wide bands around the trees if desired. As long as weed-free areas are maintained, the grass occupying the unweeded part of the site reduces the infestation of other weed species and acts as a reservoir to colonise the site after weed control operations cease. Ideally, the grass should be regularly mown to maintain its vigour. Creating and mowing a grass sward without maintaining adequate weed-free areas around young trees is not effective and will lead to tree death. If close tree spacing (1 m x 1 m or less) is used, or maximising early tree growth through the use of complete weed control is an objective, the use of grass swards may not be appropriate.

On freely drained soils in the lowlands that are subject to moisture deficits and have been regularly cultivated in the past, there is little value to be gained from cultivation (other than disrupting a plough pan). Cultivation can make the weed problem worse as it breaks up existing grass cover and brings weed seed to the surface.

Closer tree spacing (1 m x 1 m or less) can substantially reduce the need for weeding. Direct seeding may offer a cheap means of achieving this for some broadleaved species. Other elements of good silvicultural practice, as described earlier (pages 40–41), will help to reduce the amount of weeding inputs required.

TAKE REMEDIAL ACTION

As in 'New planting and restocking' (pages 51–56) remedial action is usually required. In most cases it is prudent to act pre-emptively and anticipate the problem based upon local experience, as it is far easier to prevent a weed invasion than deal with a more substantial problem once vegetation has become established. For example, mulches are easier to fix on bare sites before weed invasion. Similarly, on more fertile sites, the use of soil-acting residual herbicides is often more effective, safer to crop trees and requires less chemical to be used than repeatedly spraying foliar-acting herbicides later in the year. Some non-chemical methods of controlling grass and herbaceous weeds exist, and they should always be considered before resorting to herbicides.

Cutting by hand or mechanised means is not in general an effective form of control. Cutting fails to kill most herbaceous vegetation, and favours the development of a vigorous grass sward, which is even more detrimental to tree growth. There are however four situations when cutting may assist in weed management:

- If grass and herbaceous weeds are overtopping planted trees, cutting reduces light (but not moisture) competition.

- Cutting at or just before flowering can reduce the spread of annual weeds, but it will not always kill them, and weed seed will already be present in the soil.

- Regular mowing of an existing grass sward between weed-free bands around trees helps to reduce infestations of noxious weeds on fertile sites.

- Cutting dense or tall vegetation can make it easier to apply herbicides.

Burning and steam treatment can control grass and herbaceous weeds but they are not operationally practical for most situations. Burning can give 1–3 seasons of suppression of heather, but other weeds may invade the site.

Pulling is only a practical option on a small scale. In some circumstances mechanised pullers may be appropriate for the selective removal of tall weeds such as ragwort but potentially competitive low growing weeds such as grasses will be left untouched. This leaves mulching, cultivation, pigs and the use of herbicides as potential alternative remedial treatments.

Table 1.8 details possible remedial control measures.

The costs given for different treatments reflect a range of situations from fertile to very fertile problematic sites. When comparing between methods, compare like with like (i.e. low end of cost range of treatment *x* with lower range of costs for treatment *y*). For herbicides, it is rarely possible to use only one product to achieve sufficient weed control for tree establishment. Usually, several different products may need to be used, perhaps in the same year and in mixture, to achieve control, as different weed species invade a site after others have been controlled. However, the figures for total cost over the 5-year period give an estimate of cost if only one herbicide was repeatedly used. Although this is seldom practical except occasionally for broad spectrum or residual products, it is included to give a feel for the general differences in prices between the treatments.

The estimate of costs given are indicative and for comparison purposes only, and do not include VAT. They refer to the cost to treat one hectare of ground, and an estimated cost of achieving 5 years of weed control using the method, which may often require several re-treatments to achieve control of subsequently invading vegetation. Note that if spot or band weeding is practised, the costs reduce accordingly. For example, for trees at a spacing of 2500 stems ha^{-1}, a 1.2 m diameter wide band costs 60%, and a 1.2 m diameter spot 28%, of the cost for treating an entire hectare of ground.

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Table 1.8 Remedial control measures for grass and herbaceous weed control: new planting on lowland arable or improved grassland sites.

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Non-chemical methods					
Mulches	£3800–23 500	£3800–117 500	Can be highly effective if placed on clear ground. Less effective at controlling some very vigorous species or when large established weeds are already present.	Unless fully biodegradable, or collected and disposed of, mulching can form a source of solid chemical pollution and can exacerbate anaerobic conditions and nutrient deficiency.	Also benefits tree growth on some sites through increases in temperature and moisture retention. Inorganic mulches may rip and need to be replaced. Organic mulches may need topping up at least once a year and are much more expensive. Not effective on very exposed sites. Should be at least 1.2 m in diameter. Local sources of waste material such as old carpet may be very cheap. Existing vegetation may need to be killed with herbicides or by cultivation before mulches can be fixed. Restock sites may need to be brash raked and destumped at an additional cost of £500–1000 per hectare to allow mulches to be used. Unlike other forms of weed control, it will not prevent vole damage.
Mechanised cultivation	£100–400	£100–400 but rarely possible	Gives effective suppression of many perennial weeds. Suppression may last up to 4 years on infertile sites or less than 1 month on very fertile sites.	Soil erosion, water sedimentation, nutrient leaching, destruction of soil fauna, disruption of ground nesting birds and archaeology, and possible atmospheric pollution (particularly if machinery is poorly maintained) can all result from inappropriate cultivation if guidelines are not followed.	Repeated cultivation would lessen density of annual weeds, but is impractical amongst planted trees. A single pre-plant cultivation can suppress many perennial and annual weed species depending on site type. Cultivation also gives great benefits for tree establishment. Cultivation is not possible on slopes >65% (up to 70% for walking excavators), and poses a risk of soil erosion on all slopes. However, on fertile brown earth soils subject to moisture deficits, cultivation can worsen a weed problem, and some weed species are spread by ploughing on any site type. Operations should be timed to avoid sensitive periods for wildlife.
Hoeing/ screefing	£1500–7000	£3000–245 000	Gives effective suppression of many perennial weeds. Suppression may last up to 4 years on infertile sites, or less than 1 month on very fertile sites.	As cultivation but much smaller risk. No atmospheric pollution other than transport to site.	Essentially a non-mechanised version of cultivation: only suitable for very small areas. Can be practised post-planting with care. Up to 7 hoeings a year may be needed to control weeds on very fertile sites.
Pulling	£1500–7000	£3000–245 000	May control some species. Impractical, and not effective for many deep rooted and rhizomatous species.	Small risk of soil erosion. Disturbance to ground nesting birds.	Only practical on a very small scale, for shallow rooting non-rhizomatous species. Up to 7 visits a year might be required to control weeds on very fertile sites. Mechanised pullers exist that can selectively remove ragwort from grass swards. These are currently only suitable for new planting with wide inter-rows or rides, and cost around £150 per operation. Operations should be timed to avoid sensitive periods for wildlife.
Pigs	Potentially zero, but increased management costs.	Potentially zero, but rarely possible.	Can be very effective – total vegetation control and cultivation in enclosed areas.	Damage to trees. Soil compaction and destruction. Damage to non-target flora and fauna. On a large-scale, air pollution from ammonia could damage trees and pollute water.	Not practical post-planting as trees will be killed. Will give similar level of control as complete cultivation. Only suitable for small areas, requires sheltered site preferably below tree canopy. Supplementary feeding and regular visits make this a specialist operation only suitable for experienced pig farmers. Not suitable for sensitive sites – produces total vegetation control and severe site disturbance. Subsequent use of machinery may be difficult. Produces ideal weed seedbed, possibly site enrichment, and subsequent weed regrowth may be even more vigorous.

Table 1.8 Remedial control measures for grass and herbaceous weed control: new planting on lowland arable or improved grassland sites (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Chemical methods					
Herbicides, general	£40 mechanised application only £70 manual application only		Can be very effective. Contact acting herbicides may need to be applied 1–3 times a year for up to 5 years.	If misused, all herbicides present a risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	If used correctly, can be effective, cheap and of low environmental impact. Trees may be damaged unless tolerant of the herbicide. On very fertile sites, spraying may be needed before and immediately after cultivation. Band spraying (1–1.5 m wide) is usually preferable to overall spraying, post-planting.
Atrazine	£67–111	£67–555	Effective control of most established or germinating grass weeds. Residual control for up to one season.	Broad spectrum – most treated vegetation could be damaged. Can be mobile in soil – risk of damage to trees on light textured soils. Potentially harmful to aquatic life. Not hazardous to mammals. Low toxicity to insects.	Effective herbicide for the control of established and germinating grass weeds. Favour band applications and ensure 10–20 m aquatic buffer zone is rigidly adhered to. Treat sites subject to severe run-off or erosion with care. Of particular use at lower rates in mixture with cyanazine. Atrazine will be withdrawn during 2007.
Atrazine + cyanazine	£115–156	£115–780	Mixtures of these two herbicides can be very effective. Controls a wide range of grasses and herbaceous vegetation and gives residual control for up to one season.	Broad spectrum – most treated vegetation could be damaged. Can be mobile in soil – risk of damage to trees on light textured soils. Potentially harmful to aquatic life. Atrazine is not hazardous, cyanazine is harmful to mammals. Low toxicity to insects.	Effective herbicide mix for controlling established and newly germinating weeds on fertile sites. Favour band applications ensuring the usual 10–20 m buffer zone. Treat sites subject to severe run-off or erosion with care. Atrazine and cyanazine will be withdrawn during 2007.
Clopyralid	£75–141	£75–1410	Effective on a limited range of herbaceous weeds. May give one season's control but repeat treatment may be required.	Highly selective – only limited herbaceous species affected. Not hazardous to mammals or insects.	Particularly effective as a selective control of thistles. With repeat use, species not affected would come to dominate the site.
Cyanazine	£100–130	£100–650	Effective control of many germinating grass, herbaceous species and some established weeds.	Moderately selective. Harmful if swallowed or in contact with skin. Harmful to aquatic life. Not hazardous to insects.	Effective in mixture with other soil acting products, and particularly atrazine. Cyanazine will be withdrawn during 2007.
Cycloxydim	£74–147	£74–1470	Effective on many grass species. May give one season's control – newly germinating grasses may require a repeat treatment.	Highly selective – only grasses will be affected. Not hazardous to insects. Low toxicity to mammals. Potentially irritating to eyes and skin. Potentially toxic to aquatic life and dangerous for the environment.	Selective herbicide, grasses controlled with practically no risk to non-target trees or vegetation. With repeat use, herbaceous species not affected would come to dominate the site. Must be used with adjuvant Actipron.
2,4-D	£80–135	£80–1350	Effective on most herbaceous and many woody species. Grasses unaffected. May give one season's control but repeat treatments may be required.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed or in contact with skin. Potentially harmful to aquatic life. Potential irritant. With ester formulations, risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather. Not hazardous to insects.	Particularly effective against problem herbaceous weeds such as nettle, dock, ragwort, buttercup and also against heather. Potential for volatilisation and taint means care must be taken in water catchments. Will taint edible fruit. Avoid spraying in areas with high public pressure if alternatives are available.

[1] Cost for individual herbicides includes chemical plus application cost.
[2] For 5 years, weed control may require several re-treatments of subsequently invading vegetation. In reality, it is likely that a combination of herbicides rather than one single product will be needed.
[3] Selectivity refers to effects on vegetation, not on other biological kingdoms such as insects.

Table 1.8 Remedial control measures for grass and herbaceous weed control: new planting on lowland arable or improved grassland sites (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
2,4-D + dicamba + triclopyr	£84–180	£84–1800	Effective control of most herbaceous and many woody species. Grasses unaffected. May give one season's control but repeat treatments may be required.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed, irritating to eyes and skin. Potentially dangerous to aquatic life. Risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather. Not hazardous to insects.	Particularly effective against problem herbaceous weeds such as nettle, dock, ragwort, buttercup and also against heather. Potential for volatilisation and taint means care must be taken in water catchments. Will taint edible fruit. Avoid spraying in areas with high public pressure if alternatives are available. More effective woody weedkiller than 2,4-D.
Dichlobenil	£376–820	£376–4100	Effective control of most germinating and many established weeds for up to one season or longer.	Most vegetation will be damaged; 2-yr-old trees of certain tree species are tolerant. Not hazardous to insects. Low toxicity to mammals. Potentially harmful to aquatic life.	Effective total herbicide. Expense limits its use to spot treatments on very weedy sites.
Fluazifop-p-butyl	£76–178	£76–1780	Effective on many grass species. May give one season's control; newly germinating grasses may require a repeat treatment.	Highly selective – only grasses will be affected. Low toxicity to mammals and insects. Irritating to skin. Potentially toxic to aquatic life and dangerous for the environment.	Selective herbicide, grasses controlled with practically no risk to non-target trees or vegetation. With repeat use, herbaceous species not affected would come to dominate the site. Must be used with the adjuvant Partna.
Glufosinate ammonium	£79–135	£158–2025	Gives effective control of most annual weeds. Perennial species require repeat applications to be effective.	All green vegetation will be damaged if sprayed. Harmful if swallowed or in contact with skin. Potential irritant. Not toxic to insects. Potentially toxic to aquatic life.	Total herbicide. Applications must be made between 1 March and 30 September of a given year.
Glyphosate	£48–95	£48–950	Gives effective control of most weeds. Repeat applications are required for control of subsequent germination.	Broad spectrum – all vegetation, including most tree species, damaged if oversprayed in active growth. Not hazardous to mammals, insects or aquatic life.	Particularly effective, cheap treatment for mixed weed spectrums.
Isoxaben	£150–180	£150–900	Effective control of some germinating herbaceous species. Will not control established weeds.	Selective – trees, grasses and established vegetation unaffected. Not hazardous to mammals or insects, but exclude livestock.	Mainly of use in mixture with propyzamide to extend range of herbaceous weeds controlled.
Lenacil	£176–206	£176–1030	Effective control of many germinating grass and herbaceous species. Established vegetation not affected.	Established vegetation usually tolerant. Low toxicity to mammals and insects. Irritating to skin. Potentially harmful to aquatic life.	Often used in tank mixes with other soil acting products.
Metamitron	£153–183	£153–915	Effective control of many germinating grass and herbaceous species. Established vegetation not affected unless at seedling stage.	Large established vegetation usually tolerant. Harmful if swallowed. Not hazardous to insects or aquatic life.	Often used in tank mixes with other soil acting products.
Metazachlor	£95–125	£95–625	Effective control of many germinating grass and herbaceous species. Established vegetation not affected unless at seedling stage. Some established vegetation controlled when young.	Trees and most large established vegetation unaffected. Potentially very toxic to aquatic life and dangerous for the environment. Harmful if swallowed. Irritating to skin.	Often used in tank mixes with other soil acting products.

Table 1.8 Remedial control measures for grass and herbaceous weed control: new planting on lowland arable or improved grassland sites (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Napropamide	£84–250	£84–1250	Effective control of many germinating grass and herbaceous species. Particularly useful for direct seeding systems.	Most trees and established vegetation unaffected. Not hazardous to mammals or insects. Potentially harmful to aquatic life.	Often used in tank mixes with other soil acting products.
Oxadiazon	£320–350	£320–1750	Effective control of some germinating and established grass and herbaceous vegetation.	Most trees tolerant when dormant. Low toxicity to mammals; low toxicity to insects. Irritant. Potentially dangerous to aquatic life.	Often used in tank mixes with other soil acting products.
Paraquat	£64–114	£128–1140	Gives effective control of most annual weeds. Not translocated, so large and perennial species require repeat applications.	All green vegetation will be damaged if sprayed. Not toxic to insects. Poisonous to mammals – can kill if swallowed. Irritating to eyes. Harmful to skin.	Subject to Poisons Rules 1982. Safe once absorbed by soil or plants, but poisonous as liquid – exclude livestock and public until absorbed. Useful as a dormant season spray over broadleaved trees to help to release natural regeneration. Diquat + paraquat has very similar characteristics.
Pendimethalin	£75–105	£75–525	Effective control of many germinating grass and herbaceous species. Established vegetation not affected. Particularly useful for direct seeding systems.	Most established vegetation unaffected. Not hazardous to mammals or insects. Potentially very toxic to aquatic life and dangerous for the environment.	Often used in tank mixes with other soil acting products.
Propaquizafop	£74–121	£74–1210	Very effective on some grass species. May give one season's control; newly germinating grasses may require a repeat treatment.	Highly selective – only grasses will be affected. Low toxicity to mammals and insects. Irritating to eyes and skin. Potentially harmful to aquatic life.	Very selective herbicide, grasses controlled with practically no risk to non-target trees or vegetation. With repeat use, herbaceous species not affected would come to dominate the site.
Propyzamide	£127–298	£127–1490	Very effective grass weedkiller. Controls established grass, and gives residual control.	Selective – few established herbaceous or woody species affected. Not hazardous to mammals or insects.	Effective winter weed treatment, offers long-term control, with good tree tolerance.
Simazine	£47–77	£47–385	Effective control of many germinating grass and herbaceous species. Established vegetation not affected.	Established vegetation usually tolerant. Not hazardous to mammals. Can be mobile in soil – risk of damage to trees in light textured soil. Potentially dangerous to aquatic life. Not toxic to insects.	Often used in tank mixes with other soil acting products.
Triclopyr	£96–126	£96–1260	Effective control of many established herbaceous weeds.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed or in contact with skin. Not hazardous to insects. Potentially dangerous to aquatic life. Irritating to eyes and skin. Risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather.	Similar control to 2,4-D on herbaceous species.

Footnotes as page 61.

Bracken *(Pteridium aquilinum)*

Mature bracken fronds.

Bracken (*Pteridium aquilinum)* prefers a warm, high rainfall environment and well-drained, fertile, slightly acid soils. Bracken can be present, but is usually less vigorous, on cold exposed sites, shallow or waterlogged soil, podzols and alkaline soils. It spreads primarily through underground rhizomes.

Consequences

Bracken competes strongly with young trees for light during the latter part of the growing season. At the end of the year it dies back and can collapse, smother and kill small trees, particularly when growing densely or after snowfall. In addition, bracken competes for moisture and nutrients through its extensive system of below ground rhizomes. There is some evidence to suggest it can be allelopathic, i.e. it can release plant chemicals into the soil that may inhibit the growth of other vegetation. Although a desirable natural component of many mature woodland types, bracken is highly competitive and will quickly dominate restock sites after felling, as existing bracken stands benefit from increased light levels. It can also rapidly invade non-forest open ground, particularly if there is under- or over-grazing. Burning tends to encourage the spread of bracken. Bracken can be carcinogenic to humans and wildlife if eaten, or if sap or spores come into contact with sensitive tissue such as eyes. It also harbours ticks which can spread Lyme disease.

Bracken can over-top and swamp young trees.

Treeshelters will stop bracken swamping trees but will not alleviate moisture competition.

Options for control

TAKE NO ACTION

If bracken is present at or shortly after felling it will probably spread rapidly and dominate the site. Taking no action is rarely an option, although local experience may indicate where re-invasion is likely to be sufficiently slow to allow delay in remedial action. However, in mature woodlands, as long as it is not preventing regeneration or dominating the site to the exclusion of other species, bracken forms a desirable natural component of the ground flora.

AVOID THE PROBLEM

In woodland situations the only practical way to avoid the problem is to maintain a sufficiently continuous cover of heavy canopied species to shade out bracken while allowing planting or regeneration. However, in most cases, the light levels required to allow growth of regenerating seedlings will also allow bracken to grow and eventually dominate. In clearfell or new planting situations, very dense natural regeneration, very close spacing of planted trees (1 m x 1 m or less) or use of a very fast growing species might help to reduce the risk of tree death from smothering if bracken growth is initially sparse.

In open ground managed as agricultural pasture, encroachment of bracken can be limited by maintaining correct livestock densities. Contact a local Defra or ADAS office for further advice (www.defra.gov.uk or www.adas.co.uk, or refer to the local Yellow Pages).

TAKE REMEDIAL ACTION

If the objective is to maintain open space free of bracken, then the aim should be to totally eradicate the species and actively replace it with an alternative vegetation type. For woodland situations, the aim should be to suppress the bracken sufficiently to allow tree establishment – total eradication of rhizomes to prevent any subsequent regrowth is rarely worthwhile.

Once controlled, other vegetation will rapidly take the place of bracken. As yet there is insufficient evidence to justify using mechanical control alone to prevent tree swamping. For woodlands, the aim should be to kill sufficient above and below ground bracken growth to allow tree establishment; in practice complete eradication of all rhizomes is rarely possible or desirable. Total control of bracken within the planted area is more appropriate than spot or band weeding, as the latter allows rapid recolonisation of the site.

Repeated cutting, pulling, whipping of individual fronds and crushing can all weaken bracken if they are repeated over a long period of time (5–10 years) (Brown and Robinson, 1997). They may be most appropriate in some open space management situations. However, they are unlikely to be practical treatments on a large scale, or once trees are planted. Deep cultivation through ploughing or the use of pigs can be partially effective, but may cause soil erosion and will require follow up spraying. Burning is likely to make the problem worse. Organic mulches are ineffective, and inorganic mulches are probably impracticable since it is very difficult to fix the mulch sufficiently strongly in the ground. The use of tall treeshelters may prevent swamping of the tree, but will do nothing to alleviate moisture competition. The use of herbicides is often the only practical option for control on a large scale for woodland establishment.

Table 1.9 details possible remedial control measures for bracken.

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Table 1.9 Remedial control measures for bracken.

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Non-chemical methods					
Hand cutting	Clearing saw: £150–250 Hook/scythe: £50–100	£1500–5000 £500–2000	Tends to weaken and suppress rather than kill. Cutting twice a year for 5–10 years prior to tree planting may be required for any useful degree of control.	Cutting in June–July can disrupt ground nesting birds. Sap and spores can cause health risk to operators if hand cutting. Potential atmospheric pollution from power tools, particularly if poorly maintained.	Cutting should take place twice a year, in late June and August. May be useful as a careful hand cut over planted trees to prevent swamping by dead bracken, but cutting will not address the problem of severe moisture competition. Cutting can be useful as a follow-up treatment after spraying in open ground. Cut bracken could be sold and used for composting, which may reduce costs. Operations should be timed to avoid sensitive periods for wildlife.
Mechanical cutting	£40–70	£400–1400	Tends to weaken and suppress rather than kill. Cutting twice a year for 5–10 years prior to tree planting may be required for any degree of control.	Cutting in June–July can disrupt ground nesting birds. Sap and spores can cause health risk to operators. Potential atmospheric pollution from machine use, especially if poorly maintained. Risk of soil compaction and damage from repeated trafficking.	As hand cutting. Mechanical cutting not possible on slopes >45%. Not practical on non-destumped restock sites. Operations should be timed to avoid sensitive periods for wildlife.
Rolling/ crushing	£40–70	£400–1400	Tends to weaken and suppress rather than kill. Rolling twice a year for 5–10 years prior to tree planting may be required for any degree of control.	As mechanised cutting. Lower risk to operators. Greater risk of soil compaction and erosion.	Requires heavy mechanical rollers, so not suitable post-planting. As for cutting, rolling would be required twice a year for 5–10 years prior to planting to get a useful degree of suppression. Operations should be timed to avoid sensitive periods for wildlife.
Pulling	£250	£5000	Similar effect to cutting. Not suitable on a large-scale. May be effective in controlling very sparse regrowth after spraying, or new encroachment.	Disruption of ground nesting birds. Sap and spores can cause health risk to operators.	Similar to cutting. Only suitable as a follow-up to spraying, on a very small scale. Mechanical weed pullers exist, and may cost £150 ha^{-1} per operation (£1500 total ha^{-1}), but these have not been adequately tested for bracken control. Operations should be timed to avoid sensitive periods for wildlife.
Whipping	£50–100	£500–2000	As hand cutting.	As hand cutting.	Can be ergonomically better than hand cutting, but with similar costs and effect. Only suitable for small areas – labour requirement too great for large areas. Useful to allow easier spraying of lower regrowth in August.
Pigs	Potentially zero, but increased management costs.	Potentially zero, but rarely possible.	Can be effective at rooting out rhizomes in enclosed areas.	Damage to trees. Soil compaction and erosion. Damage to non-target flora and fauna. On a large scale, air pollution from ammonia could damage trees and pollute water.	Probably only suitable for small areas. Requires sheltered site, preferably below tree canopy. Supplementary feeding and regular visits make this a specialist operation only suitable for experienced pig farmers. Not suitable for sensitive sites as will produce total vegetation control and soil cultivation. Severe site disturbance can result, making subsequent machinery use difficult. Much higher management input is required, so headline costs increase. Produces ideal weed seedbed, possibly site enrichment, and subsequent weed regrowth may be even more vigorous.
Ploughing	£150–250	£300–500 or much more; complete control is not always possible.	Deep ploughing can be effective if all rhizomes are brought to the surface. Re-buried rhizomes will regrow. At least two seasons of ploughing are required for sustained control.	Potential for soil erosion, water sedimentation, nutrient leaching, destruction of soil fauna and archaeology, disruption of ground nesting birds, and atmospheric pollution, (particularly if machinery is poorly maintained) can all result from inappropriate ploughing.	The deep cultivation techniques needed to control bracken are more likely to cause environmental disturbance. Ploughing is unlikely to offer complete control by itself and should be used in addition to other treatments. However, ploughing is cheap, may offer several months control from a single cultivation, and is likely to be required for good tree establishment. Not possible on slopes >65% (up to 70% for walking excavators), and poses a risk of soil erosion on all slopes. Post-planting deep cultivation may be difficult on non-destumped sites. Operations should be timed to avoid sensitive periods for wildlife.

Table 1.9 Remedial control measures for bracken (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Chemical methods					
Herbicides, general	£40 mechanised £70 manual application only		A single treatment usually gives sufficient control for tree establishment.	If misused, all herbicides present a risk to operator health, risks of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	Pre-plant overall sprays are generally the cheapest and most effective method of dealing with bracken. Aerial sprays are permitted within stringent controls, but they present greater environmental risks than ground-based sprays. If used correctly ground applied herbicides can be highly effective, cheap and of lower environmental impact than other methods of control. Trees may be damaged unless tolerant to the herbicide. Once bracken is controlled, other vegetation will invade and may need to be controlled with herbicides. For open space management, total eradication and replacement by a desirable vegetation type will require follow-up treatments.
Asulam	£85–300	£85–300	Effective – one application will give two or more seasons of control.	Selective – very few other species controlled. Not hazardous to mammals, insects or aquatic life. Most tree species are tolerant. Some fern and grass species may be susceptible.	Tall bracken may necessitate low volume CDA (Controlled Droplet Applicator) drift sprays giving increased risk of non-target contamination. If a pure bracken problem, asulam is often the best herbicide choice pre- or post-planting.
Dichlobenil	£820	£820	Can be effective in controlling bracken. Also controls a wide range of other weed species for one or more seasons.	Broad spectrum total herbicide. Only 2-yr-old trees of certain species are tolerant. Potentially harmful to aquatic life. Not hazardous to mammals and insects.	Effective total herbicide, but expense limits its use to spot applications post-planting on very weedy sites. Gives one season or more of residual weed control. Sites subject to run-off or erosion should be treated with care – contamination of nearby watercourses may result without sufficient buffer zones (10–20 m). Dichlobenil is formulated as a granular product and applied in winter, the risk of drift being substantially reduced.
Glyphosate	£55–85	£55–170	Can be very effective: one application may give two or more seasons of control, but often a second application may be required.	Broad spectrum – most vegetation, including planted trees, can be killed if oversprayed. Not hazardous to mammals, insects or aquatic life.	Less effective than asulam, but controls a wide range of other weeds. An effective treatment when a mixed weed spectrum exists pre-planting.

[1] Cost for individual herbicides includes chemical plus application cost.

[2] Total cost per hectare is for complete clearance of bracken sufficient to allow tree establishment; subsequently other vegetation may re-invade.

[3] Selectivity refers to effects on vegetation, not on other biological kingdoms such as insects.

Heather *(Calluna vulgaris)*

Heather growing successfully as a dense shrub.

Heather is an attractive, native evergreen shrub. On acid soils, it can dominate extensive tracts of moorland, lowland heath and open woods. Heather is a perennial and spreads by seed. Lowland heaths are an internationally important and threatened habitat.

Consequences

On drier sites, as with any vegetation species, heather can be a significant competitor for moisture and nutrients with all young trees in the establishment phase (usually 1–5 years after planting).

However, the most significant impact of heather is through the inducement of longer term nitrogen deficiency particularly in Sitka spruce (*Picea sitchensis*). Heather can check (significantly reduce) the growth of trees through the release of allelopathic compounds which inhibit mycorrhizal development in spruce roots. The subsequent nitrogen deficiency in Sitka spruce is recognisable by a yellowing of foliage, shortening of needles and reduced leader growth. The risk of check is usually reduced when full canopy closure occurs, which may take 12–16 years after planting or longer depending on spacing and yield class.

Heather can also induce check through nitrogen deficiency with other species of conifers – Norway spruce (*Picea abies*) western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*) and silver firs (*Abies* spp.). Pines (*Pinus* spp.) and larches (*Larix* spp.) can occasionally be affected, but usually less severely (Taylor, 1991).

As with any weed, heather can compete with young trees for moisture.

Heather can also induce nitrogen deficiency on some sites.

Site categorisation – heather with Sitka spruce up to pole stage

To aid decisions on treatment prescription, Taylor and Tabbush (1990) suggested a categorisation of heather-dominated nitrogen-deficient sites planted with Sitka spruce up to pole stage. Taylor (1991) implies that this categorisation can also be applied to other spruces and firs if necessary.

Step 1
Find the appropriate soil type in Table 1.10 and start from the left-hand side of the categories listed against that soil type. If only one category is listed there is no need to continue to steps 2 and 3.

Step 2
Identify the appropriate lithology group in Table 1.11.

Table 1.10 Main soil types of upland Britain categorised by nitrogen availability.

Soil group	Code	Soil type	Category			
Brown earths	1	Typical brown earth	A			
	1d	Basic brown earth	A			
	1u	Upland brown earth	A	B		
	1z	Podzolic brown earth	A	B		
	1e	Ericaceous brown earth	A	B	C	
Podzols	3	Typical podzol		B	C	D
	3p	Peaty podzol		B	C	
Ironpan soils	4	Ironpan soil	A	B	C	D
	4b	Intergrade ironpan soil	A	B	C	
	4z	Podzolic ironpan soil		B	C	D
	4p	Peaty ironpan soil	A	B	C	
Peaty gleys	6	Peaty gley	A	B	C	D
	6z	Podzolic peaty gley		B	C	
Surface-water gleys	7	Surface-water gley	A	B	C	
	7b	Brown surface-water gley	A			
	7z	Podzolic surface-water gley	A	B	C	
Basin bogs	8a	Phragmites bog	A			
	8b	*Juncus articulatus* or *acutiflorus* bog	A			
	8c	*Juncus effusus* bog	A			
	8d	Carex bog	A			
Flushed blanket bogs	9a	*Molinia, Myrica, Salix* bog	A			
	9b	Tussocky *Molinia* bog; *Molinia, Calluna* bog	A	B		
	9c	Tussocky *Molinia, Eriophorum vaginatum* bog		B	C	
	9d	Non-tussocky *Molinia, Eriophorum vaginatum, Trichophorum* bog		B	C	
	9e	*Trichophorum, Calluna, Eriophorum, Molinia* bog (weakly flushed)		B	C	D
Sphagnum bogs	10a	Lowland *Sphagnum* bog				D
	10b	Upland *Sphagnum* bog				D
Unflushed blanket bogs	11a	Calluna blanket bog			C	D
	11b	*Calluna, Eriophorum vaginatum* blanket bog			C	D
	11c	*Trichophorum, Calluna* blanket bog				D
	11d	*Eriophorum vaginatum* blanket bog				D

If this lies within:

- group I, move two categories to the right;
- group II, move one category to the right;
- group III, stay in the same category.

Step 3

If the soil type is mineral or organo-mineral (soil group codes 1, 3, 4, 6 or 7) and the site is dominated by *C. vulgaris* (more than 50% ground cover – equivalent to the 'ericaceous phase' mapped in FC soil surveys) move one category to the right. If not, then stay in the same category. Note that this third step should not be applied if the soil is classified as deep peat (i.e. soil group codes 8, 9, 10 or 11).

Table 1.11 Ranking of the main lithologies according to the likely availability of nitrogen in overlying soils.

Group I: Low nitrogen availability	Geological map[1] reference numbers
Torridonian sandstone	61
Moine quartz-feldspar-granulite, quartzite and granitic gneiss	8, 9, 10, 12
Cambrian quartzite	62
Dalradian quartzites	17
Lewisian gneiss	1
Quartzose granites and granulites	34 (part only)
Middle/Upper Old Red Sandstone (Scotland)	77, 78
Upper Jurassic sandstones and grits	97, 98, 99
Carboniferous grits and sandstones	81 (part only)
Group II: Moderate nitrogen availability	**Geological map[1] reference numbers**
Moine mica-schists and semi-pelitic schists	11
Dalradian quartzose and mica schists, slates and phyllites	18, 19, 20, 21, 23
Granites (high feldspar, low quartz content)	34 (part only)
Tertiary basalts	57
Old Red Sandstone basalts, andesite and tuff	44, 46, 47, 48, 50
Silurian/Ordovician greywackes, mudstones (Scotland)	70, 71, 72, 73, 74
Lower and Middle Jurassic sediments	91, 94, 95
Group III: High nitrogen availability	**Geological map[1] reference numbers**
Gabbros, dolerite, epidiorite and hornblende schist	14, 15, 26, 27, 32, 33, 35
Lower Old Red Sandstone	75
New Red Sandstone	85, 89, 90
Carboniferous shales and basalts	53, 54, 80[2], 81 (part only), 82, 83, 84
Silurian/Ordovician/Devonian Shales	68, 69, 70, 71, 72, 73, 74
(Wales and southwest England)	75, 76, 77, 78
Limestones	24, 67, 80[3], 86
Cambrian/Precambrian	60, 64, 65, 66

[1]Reference: *Institute of Geological Sciences Geological Map of the United Kingdom*, 3rd edition, 1979, published by the OS.
[2]Refers to Scotland only.
[3]Refers to England and Wales only.

Notes:
- Geological Map index no. 34 has been subdivided into: (a) quartzose granites and granulites (group I), and (b) granites with a high feldspar and low quartz content (group II).
- Geological Map index no. 81 has been subdivided into: (a) grits and sandstones (group I) and (b) shales (group III).
- Where soils occur over drift material, then their characteristics (in terms of nitrogen availability) will be similar to that of the solid parent material from which the drift was derived.

Treatment prescriptions

Depending on the final categorisation the following treatments are appropriate.

Category A
Heather dominated sites with sufficient nitrogen available for acceptable tree growth, despite the presence of heather. No herbicide or fertiliser required to alleviate nutrient competition (*take no action*).

Category B
Sites where heather is the principle cause of nitrogen deficiency and where heather control alone would result in adequate availability of nitrogen for Sitka spruce (*take remedial action*).

Category C
Heather is the dominant vegetation type, but not the sole cause of nitrogen deficiency. Heather control will bring some benefit, but by itself will not result in permanent relief from nitrogen deficiency. A series of applications of nitrogen fertiliser will also be necessary, if nurse species are not used (*avoid the problem, or take remedial action*).

Category D
The principle cause of nitrogen deficiency is a low mineralisation rate. Heather control by itself is insufficient. A series of applications of nitrogen will be necessary if nurse species are not used (*avoid the problem, or take remedial action*).

Options for control

TAKE NO ACTION

Lowland heaths are an internationally important and threatened habitat. New planting on lowland heaths is not generally appropriate. After clearfelling or thinning, opportunities to restore heathland, or to expand and link existing areas of heathland habitat within woodlands, should be examined (Currie, 1994).

In some upland situations where Sitka spruce is planted, depending on soil type and nutrient status, taking no action up to the point of full canopy closure will result in significantly reduced growth. Where timber production is a major objective, taking no action is not normally an acceptable option.

For other situations and tree species other than spruces and firs, long-term check can still occur but is less likely to be a problem. In these situations it may be sufficient to treat heather in the same way as other competing herbaceous weed species. A spot or band should be kept weed free around the tree for 3–5 years after planting until trees are established (see earlier section on grass and herbaceous weed control, pages 51–56, for further guidance on initial weed control in these situations). Trees should be monitored for signs of check, as longer-term weed control or fertilisation may still be necessary.

AVOID THE PROBLEM

On all site categories, the use of nurse species can help to avoid nitrogen deficiency in Sitka spruce when heather is present. Scots pine (*Pinus sylvestris*), lodgepole pine (*Pinus contorta*) or larch planted in 50:50 mixture can help to suppress heather and increase nitrogen availability through root and microbial activity. Adequate levels of foliar phosphorus and potassium will still need to be maintained. Such a high proportion of nurse species may reduce overall timber revenue. However, even if timber production is the primary objective, the use of nursing mixtures should be considered as an alternative to any remedial treatments on category C and D sites.

TAKE REMEDIAL ACTION

Before planting, burning can delay re-invasion of heather. Mowing may encourage other vegetation types such as grasses which themselves may need to be controlled to prevent moisture and nutrient competition with trees. Complete cultivation can delay re-establishment of heather.

Herbicides are often the most practical method of control should remedial action be required post-planting to aid tree establishment.

Fertiliser applications are not discussed in this guide but they should be considered alongside herbicide applications in some situations for heather control. Fertilisation application is likely to be required and may give better tree growth than heather control for Sitka spruce up to pole stage suffering from nitrogen deficiency on category C and D sites. Where both herbicide weed control and the use of fertilisers may be an alternative option (some category C sites), managers must make a judgement as to the likely environmental impacts and quantities of the chemical inputs required in both cases.

Table 1.12 details possible remedial control measures for heather.

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Forestry Commission Field Book 8.
HMSO, London.

Table 1.12 Remedial control measures for heather.

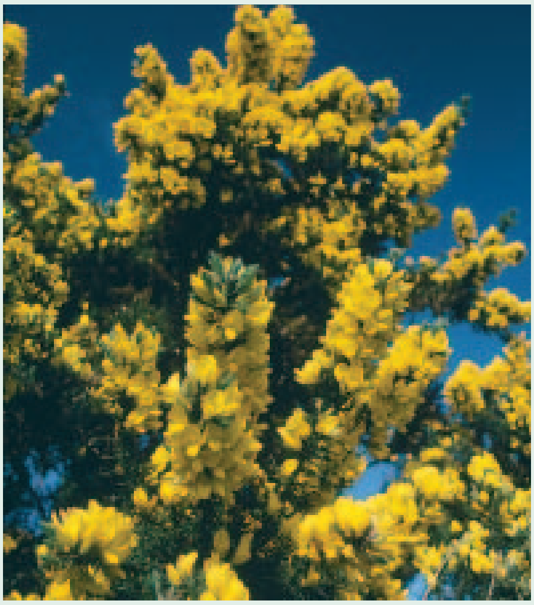
Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Non-chemical methods					
Mechanised cultivation	£100–400	£100–400 but complete control rarely possible	Gives effective suppression of many perennial weeds. Suppression may last up to 4 years on infertile sites, or less than a month on very fertile sites.	Soil erosion, water sedimentation, nitrification, destruction of soil fauna, disruption of ground nesting birds and archaeology, and atmospheric pollution (particularly if machinery is poorly maintained) can all result from inappropriate cultivation if guidelines are not followed.	A single pre-plant cultivation can delay heather re-invasion. Cultivation also gives great benefits for tree establishment. Cultivation is not possible on slopes >65% (up to 70% for walking excavators), and poses a risk of soil erosion on all slopes. Operations should be timed to avoid sensitive periods for wildlife.
Fertilisers	£75 (aerial application) £105 (hand application)		Can give relief from heather-induced nitrogen deficiency for 3–4 years after application.	Fertilisation can cause vegetation change. If guidelines are not followed, it can cause pollution and eutrophication of water.	Not strictly a remedial control measure, but may give relief from nitrogen deficiency for 3–4 years after application for spruce prior to canopy closure. May need to be repeated 3–4 times up to the point of canopy closure, or perhaps for the duration of the crop. Only worth while on site categories C–D. Applications (330 kg ha^{-1} urea) should be made by the end of June, avoiding frosted or waterlogged ground.
Chemical methods					
Herbicides, general	£40 mechanised £70 manual application only		Can be very effective, giving complete control from a single application. However, in the worst case scenario, may need to be reapplied bi-annually until crops enter pole stage.	If misused, all herbicides present a risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	If used correctly, can be effective, cheap and of low environmental impact. Trees may be damaged unless tolerant of the herbicide. Often the most practical method of control post-planting for the initial establishment phase, 2–5 years after planting. However for pre-pole stage spruce crops (5–16 years), may only be worth while on certain limited site types in the categories B–C.
2,4-D	£80–135	£80–1080	Gives effective control. Grasses unaffected.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed or in contact with skin. Potential irritant. Potentially harmful to aquatic life. With ester formulations, risk of volatilisation and drift resulting in damage to non-target vegetation in hot weather. Not hazardous to insects.	Particularly effective against heather. Potential for volatilisation and taint means care must be taken in water catchments. Will taint edible fruit. Avoid spraying in areas with high public pressure if alternatives are available.
Glyphosate	£70–100	£70–800	Gives effective control of most weeds. Repeat applications are required for control of subsequent germination.	Broad spectrum: all vegetation, including most tree species, damaged if oversprayed in active growth. Not hazardous to mammals, insects or aquatic life.	Less effective than 2,4-D, but a cheap treatment for mixed weed species. Mixture B adjuvant may improve control.

[1] Cost for individual herbicides includes chemical plus application cost.

[2] For 5 years' weed control, several treatments of subsequently invading vegetation may be required. In reality, it is likely that a combination of herbicides rather than one single product will be needed.

[3] Selectivity refers to effects on vegetation, not on other biological kingdoms such as insects.

Woody weeds



A mature gorse bush in flower.

Woody weeds can include a wide range of species, for example bramble (*Rubus fruticosus* agg.), gorse (*Ulex europaeus*), broom (*Cytisus scoporius*), climbers such as *Clematis vitalba* or honeysuckle (*Lonicera periclymenum*), other shrubs and, depending on circumstances, all species of trees. Invasion of non-native tree species into ancient semi-natural woodland can also be problematic.

In most situations a minor component of species such as birch can add a highly desirable element of diversity in a pure conifer crop. Many other woodland species form a natural component of a mature woodland and are desirable invaders once the main crop has become established. However, regardless of management objectives for species diversity, several woody species can act as weeds, particularly when trees are young. In addition, high densities of crop species themselves can be problematic – stands resulting from natural regeneration may have such high densities that re-spacing to provide continued diameter growth is required prior to conventional thinning operations.

Consequences

Woody weeds compete for light, moisture and nutrients and cause physical damage to young trees. They can rapidly dominate a site, and shade and kill a crop species both during the conventional 3–5 year establishment period and in some cases beyond initial canopy closure. Regenerating tree species may also potentially colonise open ground, and in some cases may need to be controlled if this threatens a rare habitat type such as lowland heathland.

Among older pole stage trees, birch (*Betula* spp.), for example, can compete for light, space, moisture and nutrients, and physically damage species such as Douglas fir (*Pseudotsuga menziesii*). Climbing species such as clematis and honeysuckle can also damage pole stage trees.

Within more mature woodlands, high densities of crop species themselves will need to be re-spaced or thinned to allow continued crown and stem development, and hence produce large diameter trees for timber production and the enhancement of biodiversity.

Brambles swamping young oak seedlings.

Japanese knotweed: an invasive noxious weed.

Options for control

TAKE NO ACTION

In young trees, pre-canopy closure, strong growth of invasive weeds such as gorse, bramble, clematis, or heavy canopied tree species can easily dominate a site and kill crop trees. Managers must make a judgement based upon local expertise, but only rarely is it sensible to take no action.

Among older pole stage and mature trees it is often best to accept intrusions of other tree and shrub species as they add a welcome element of diversity. A 5% component of native broadleaves is a requirement for new restocking/planting under the UK Woodland Assurance Standard, and invasions of birch and rowan often offer a cheap way of achieving this. Occasionally however intrusions of broadleaves into conifer crops will be so great that production is severely affected and they must be controlled.

Invasive woody weeds such as *Rhododendron ponticum* (considered separately, see pages 83–86), Japanese knotweed (*Fallopia japonica*) and Himalayan balsam (*Impatiens glandulifera*) should be eradicated from the woodland whenever they appear. On mature trees, clematis and honeysuckle cause a few problems, but where tree regeneration is planned it may be prudent to carry out some control, as these species are likely to grow extremely rapidly in the higher light levels following felling. On mature trees, ivy (*Hedera helix*) rarely does any harm, although it may increase windthrow risk and compete for light if particularly dense. Ivy produces valuable food for birds and can prevent unwanted epicormic shoot growth on oak (*Quercus* spp.).

A dense, even-aged area of a single crop species is often the intended outcome of successful planting. Dense spacing also occurs naturally when trees regenerate, and indeed can help to reduce the amount of weeding required in the establishment phase. However, as close spaced trees mature, taking no action is rarely an option. All species will naturally self-thin, but some take considerably longer than others. In most species the net result of doing nothing is that trees become very tall and make little diameter growth, so no marketable timber is produced. In some cases the formation of large trees is severely delayed, hence reducing biodiversity. Ground flora may be prevented from developing on the forest floor due to dense shade. In addition, some species can stagnate, suffer nitrogen deficiency and die. In areas where windthrow is a risk, delay in re-spacing results in high risk of windblow after thinning, although unthinned trees themselves remain fairly stable.

AVOID THE PROBLEM

Good silvicultural practice ensuring rapid establishment and growth of the crop species reduces the problem of woody weeds. Most woody species are natural components of mature woodlands, so little can be done to prevent their colonisation in the next rotation. However, for problem weeds, such as Japanese knotweed and Himalayan balsam, future problems can be avoided by eradicating weeds when they first occur (Willoughby, 1996). Species such as bramble, gorse, clematis and honeysuckle may be easier to control before felling, as increased light levels after felling stimulate rapid growth. Dense initial establishment of trees has a great many silvicultural advantages, so the issue of thinning or re-spacing cannot be avoided. However, early intervention again is often better than delaying.

TAKE REMEDIAL ACTION

Some woody weeds can be cut to release young crop trees. However, in many species this simply stimulates more rapid regrowth which can soon reach canopy height again.

Stump removal or flailing or cutting are not particularly effective for invasive woody weeds such as gorse, bramble, Japanese knotweed and Himalayan balsam, and it is usually impractical for climbers. Cutting would be required twice a year for perhaps the entire rotation to suppress these types of woody weeds. In cases where it is difficult to find an alternative to herbicide use, the most common approach is to spray cut stumps, hence reducing the risk of drift to non-target plants.

Cut material for species such as Japanese knotweed may need to be burnt to prevent further spread.

For the re-spacing of young trees, most broadleaves except beech will regrow (coppice) when cut unless the stumps are treated with herbicide. Conifers cut below the lowest live whorl can be effectively killed. For broadleaved tree species, stumps can also be killed by stump removal or grinding *in situ*, but these operations are very expensive and not always practical. Mulching and flailing are more effective than cutting, but some regrowth is still likely. When selective re-spacing of dense regeneration is required, cutting, possibly with herbicide treatment, is likely to be the only practical option.

In more mature woodlands, physical thinning – cutting to waste or for profit – of dense crop species is usually the best solution. Only rarely will chemical thinning be justified, i.e. in situations where it is cheaper than thinning to waste and where it may help to maintain stability on exposed sites where conventional thinning is impossible.

Table 1.13 details possible remedial control measures for woody weeds.

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Table 1.13 Remedial control measures for woody weeds.

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Non-chemical methods					
Hand cutting (including chainsaws)	£500–6500	£500–13 000 (conifers) £500–520 000 (broadleaves) (highest figure is speculative based on cutting each year for up to 80 years)	Effective on conifers if cut below lowest live whorl. On most other woody weeds, repeated cutting required to weaken plant. Stimulates growth in plants such as bramble and Japanese knotweed.	Risk of pollution from petrochemicals if power tools are used. Disturbance to wildlife from repeated trafficking. Atmospheric pollution, damage to soil and overstorey stems if burning.	Small plants can be cut by scythes/saws, larger plants by power tools. Burning may be required for some species which may spread from cut material. By itself, only practical on conifers on a large-scale. However, cut stumps or young regrowth is more susceptible and considerably easier to treat with herbicides. Operations should be timed to avoid sensitive periods for wildlife.
Hand pulling	£1500–7000	£1500–14 000 or more	Pulling of very young seedlings effectively prevents regrowth.	Minor site disturbance. Atmospheric pollution, damage to soil and overstorey stems if burning.	Only effective on very young seedlings. Impractical on larger plants or bushes. Burning of pulled material may be required for some species which spread from cut material. Only practical for sparse invasions.
Mechanised cutting/ flailing	£350–2000	£350–4000	Flailing and mulching more effective than cutting for control of tree species, but some regrowth is still likely. Will not kill species such as bramble or Japanese knotweed.	Disruption of ground nesting birds. Non-target vegetation destroyed or damaged. Petrochemical pollution from cutting. Risk of atmospheric pollution, damage to soil and overstorey stems if burning.	Initially, will give total unselective vegetation control. Only practical amongst mature widely spaced trees, or pre-planting or open ground. Regrowth more susceptible and easier to treat with herbicides. Mechanical flails not suitable on slopes >45%. Walking excavators can be used on slopes up to 50%. Remains of species which can spread from cut material may need to be gathered and burnt if not adequately mulched. Large bushes which are otherwise difficult to spray can be cut and the regrowth treated. For early re-spacing, often useful to create access racks by mechanised cuts, with selective motor-manual clearance – total cost around £600 per hectare for 4000 stems ha^{-1}. Operations should be timed to avoid sensitive periods for wildlife.
De-stumping	£500–2000	£500–2000	Effective for most tree species if all of root and stem is removed. Not practical for invasive woody weeds and climbers.	On steep sites, potential soil erosion and water sedimentation. Possible atmospheric pollution from petrochemicals (particularly if machinery is poorly maintained). Risk of soil compaction. Removal of stumps from site will result in some loss of nutrients.	Difficult to get complete control with species that can grow from remaining stem or root fragments. Most practical for broadleaved tree species on a small scale. Operations should be timed to avoid sensitive periods for wildlife.
Stump grinding	£5000–10 000	£5000–10 000	Can be very effective on tree species.	Risk of compaction and soil and air pollution from machine use.	Expensive and time-consuming. Only practical on a very small scale. Trees need to be cut before grinding. Operations should be timed to avoid sensitive periods for wildlife.

Table 1.13 Remedial control measures for woody weeds (continued).

Method	Cost per treated ha per operation[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks[3]	Comments
Chemical methods					
Herbicides, general	£40 mechanised £70 manual application only		Can be effective: 1–2 treatments give complete control.	If misused, all herbicides present a potential risk to operator health, soil and water pollution, poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	Most newly planted trees are susceptible – sprays must be carefully directed. Pre-plant sprays are safest. Most overstorey trees are tolerant. For small bushes/trees (<1 m) foliage can be sprayed. For larger bushes/ trees, may need to cut or flail and treat cut stumps. Alternatively after cutting/flailing, treat very young regrowth. Stem injection or cutting and spraying stems is a possible alternative to cutting and treating stumps, but is often less effective. Only 10–50% of a gross area might be treated if spraying is limited to cut stumps or young regrowth, and costs will be reduced accordingly.
Ammonium sulphamate	£520–1750	£520–1750[4]	One application usually gives complete control.	Most vegetation will be damaged if oversprayed. Not hazardous to mammals. Very soluble: potential for run-off and leaching. Corrosive to metal. Potentially harmful to aquatic life.	Most effective as a cut stump spray or spray of young regrowth. Large amounts of active ingredient required. Breaks down to ammonium sulphate. Care should be taken when treating steep slopes or areas that may erode near to watercourses as the herbicide is very soluble and contamination could result if there are insufficient buffer zones (10–20 m is usually sufficient).
2,4-D + dicamba + triclopyr	£150–180	£150–180[4]	One application usually gives complete control.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed or in contact with skin. Irritating to eyes and skin. Potentially dangerous to aquatic life. Risk of volatilisation and drift and damage to non-target vegetation in hot weather. Not hazardous to insects.	Most effective as a cut stump spray, or spray of young regrowth.
Glyphosate	£50–125	£50–250[4]	Can be effective but may require a follow-up treatment.	Broad spectrum – all vegetation, including newly planted (not overstorey) trees damaged or killed if oversprayed. Not hazardous to mammals, insects or aquatic life.	Less effective than triclopyr as a cut stump spray. Gives good control as a foliar spray of seedlings and young regrowth. Most effective as cut stump spray or spray of young regrowth.
Triclopyr	£100–300	£100–300[4]	Very effective. Particularly effective against gorse. One application usually gives complete control.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Moderately toxic to mammals – harmful if swallowed or in contact with skin. Irritating to eyes and skin. Potentially dangerous to aquatic life. Risk of volatilisation and drift and damage to non-target vegetation in hot weather. Not hazardous to insects.	Effective as a cut stump spray, also of young regrowth.

[1] Cost for individual herbicides includes chemical plus application cost.
[2] Cost given for complete control of established woody weeds. Subsequent invasions will require repeat treatment.
[3] Selectivity refers to effects on vegetation, not on other biological kingdoms such as insects.
[4] For larger bushes/plants, the cost of cutting before treatment (£500–6500 ha^{-1}) needs to be added.

Rhododendron *(Rhododendron ponticum)*

Rhododendron ponticum*: an attractive woody ornamental but also a problematic invasive weed.*

Rhododendron is an introduced, evergreen, woody ornamental species. Its spring flowers can be extremely attractive, but bushes can form dense thickets up to 5 m in height. It will dominate on a wide variety of site types, but favours moist acid soils in the west of Britain. Growth is poor on exposed sites above 300 m in the UK, and on soils with a pH >5.0. Rhododendron spreads by seed and layering. The seed is wind-borne and can travel from 100 m to more than 1 km in open areas. Seedling establishment is more successful on disturbed or mossy sites. Established plants spread rapidly by layering and buried pieces of cut stem (not roots) will also regrow. It is a very shade tolerant species, has few natural pests or diseases and is unpalatable to browsing animals. Cut or burnt stumps will rapidly regrow. Exposed sites, alkaline soils, heavy wet soils (gleys and clays) and undisturbed sites with thick vegetation cover are at least risk from new seed-borne infestation (Tabbush and Williamson, 1987).

Consequences

Rhododendron can rapidly form tall dense thickets which effectively shade out all other vegetation. Native woodland flora is killed, and natural or artificial regeneration of the woodland becomes impossible. The eventual logical outcome of this process is a climax vegetation of rhododendron. Timber harvesting can be considerably more expensive among dense rhododendron and public access is limited. Younger or sparse rhododendron growth will compete for moisture and nutrients, and there is some evidence of allelopathic compounds – chemicals that may inhibit the growth of other vegetation – in the leaves. Rhododendron will also spread to open ground.

Rhododendron outgrowing and swamping young trees.

Using a flail to help eradicate rhododendron.

Options for control

TAKE NO ACTION

If established rhododendron is left uncontrolled, it will spread and cause an even greater problem. After clearfelling, increased light levels can encourage rhododendron to an extent that even relatively sparse growth can rapidly overwhelm a site. Taking no action is not a prudent approach.

AVOID THE PROBLEM

On sites where rhododendron is likely to establish (moderately sheltered areas with well-drained acid soils where the plant is already established nearby) new seedling invasions can be lessened by the following means.

Avoiding site disturbance

Unfortunately, to encourage natural regeneration or plant trees, the site may need to be disturbed.

Species choice

If established at sufficient densities, overstorey species casting dense shade, such as western hemlock (*Tsuga heterophylla*), and to a lesser extent spruces (*Picea* spp.), may shade out and kill established rhododendron, or prevent its re-establishment. However, after thinning, nearby rhododendron on rides or open space can rapidly re-invade. Rhododendron will still need to be controlled to allow trees to establish, but once at the point of canopy closure tree species casting dense shade will dominate the site. Belts of woodland casting dense shade can reduce the speed of spread of rhododendron, but their effect will be lessened by forest roads, rides, thinning, selection felling or clearfelling, ground disturbance and fire. Deciduous species will not shade out rhododendron.

TAKE REMEDIAL ACTION

Although rhododendron growth can be suppressed, or new invasions kept in check through non-chemical methods, realistically the use of herbicides, often in combination with cutting, pulling or bulldozing, offers the only effective means of control. There are currently no practical completely non-chemical methods for controlling established bushes. If cutting does take place, stems may need to be burnt to prevent rhododendron spreading.

The most prudent approach to rhododendron management is to eradicate young seedlings as soon as they establish, before they have a chance to grow large or spread. However, once large rhododendron bushes are established in or near the woodland, the only effective approach is to control them first in order to reduce seed source and further spread. This will result in a reduction of the total amount of herbicide required. It is far easier to control small seedlings than large bushes. It is also often easier to control rhododendron pre-felling. Post-planting treatments are difficult and expensive and should be avoided if possible.

The use of the adjuvants, for example Mixture B, may be helpful in increasing the efficacy and reducing the herbicide dose rates required to control rhododendron.

Table 1.14 details possible remedial control measures for rhododendron.

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Table 1.14 Remedial control measures for rhododendron.

Method	Cost per treated ha per operation[1,2]	Total cost per ha for complete control[3]	Efficacy	Environmental risks[4]	Comments
Non-chemical methods					
Hand cutting (including chainsaws)	£1750–6500	Not possible.	Not effective by itself. Cut stumps will rapidly regrow. Buried stems will regrow.	Risk of pollution from petro-chemicals, possible atmospheric pollution (particularly if machinery is poorly maintained), damage to soil and overstorey stems from burning.	Large bushes can be cut by chainsaw or flailed. The cut stumps or young regrowth are more susceptible and considerably easier to treat with herbicides. Buried stems will regrow. Remains of large bushes will need to be gathered and burnt to prevent spread. Operations should be timed to avoid sensitive periods for wildlife.
Hand pulling	£1500–7000	May not be possible.	Pulling of very young seedlings prevents regrowth.	Minor soil disturbance.	Only effective on very young seedlings. Impractical on larger bushes. Buried stem fragments will regrow. For light infestation levels, a single treatment may cost as little as £100 – the costs given are for an even coverage of seedlings across an entire hectare of ground, for comparison. Pulling creates a good seedbed for further infestation – unless on alternative vegetation types or heavy canopy shade is established, the operation may be self-defeating. Operations should be timed to avoid sensitive periods for wildlife.
Bulldozing/ winching	£2000	Not possible.	Large bushes can be effectively killed by uprooting. However, this is likely to bury stem fragments that will regrow.	Severe site disturbance. Destruction of soil fauna and archaeology. Soil erosion, sedimentation and nutrient enrichment of watercourses. Atmospheric pollution from petrochemicals (particularly if machinery is poorly maintained) and burning.	Can be effective, but causes severe site disruption. Buried stem fragments likely, which will regrow. Regrowth is easier to treat with herbicides. Remains of bushes will need to be gathered (raked) and burnt to prevent spread. Not practical on slopes >45%. Can create ideal conditions for seed germination and re-infestation. Operations should be timed to avoid sensitive periods for wildlife.
Mechanised cutting/ flailing	£500–2000	Not possible.	Flailing and mulching are more effective than cutting, but some regrowth is almost inevitable. Whole buried stems will regrow.	Disturbance of ground nesting birds. Non-target vegetation destroyed. Possible atmospheric pollution from machinery, particularly if poorly maintained. Atmospheric pollution from burning. Soil damage and compaction from trafficking.	Buried stems will regrow if not adequately mulched. Total vegetation control. Only practical amongst mature widely spaced trees or pre-planting or open ground. Regrowth more susceptible and easier to treat with herbicides. Mechanical flails not suitable on slopes >45%. Walking excavators can be used on slopes up to 50%. Remains will need to gathered and burnt if not adequately mulched. Large bushes which are otherwise difficult to spray can be cut and the regrowth treated. Operations should be timed to avoid sensitive periods for wildlife.
Chemical methods					
Herbicides, general	£40 mechanised £70 manual application cost only		Can be effective: 1–3 treatments can give complete control.	If misused, all herbicides present a potential risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	Only 10–50% of a complete hectare might be treated if spraying cut stumps or young regrowth, and costs will be reduced accordingly. Newly planted trees are susceptible. Most overstorey trees are tolerant therefore treat pre-felling or pre-planting. Herbicides do not translocate well: all foliage must be sprayed for good control. Small bushes (<1.3 m) and where all foliage can be reached, can be overall sprayed. Larger bushes and clumps will need to be cut or flailed, and the cut stumps sprayed. Alternatively, after cutting/flailing, treat very young regrowth and growth from buried stems. Closely monitor site for re-invasion.
Ammonium sulphamate	£520–1750	£520–5250[5]	Can be very effective, but up to 2 follow-up treatments may be required.	Most vegetation will be damaged if oversprayed. Not hazardous to mammals. Very soluble – potential for run-off and leaching. Corrosive to metal. Potentially harmful to aquatic life.	Most effective as a cut stump spray or spray of young regrowth. Large amounts of active ingredient required. Breaks down to ammonium sulphate. Care should be taken when treating steep slopes or areas that may erode near to watercourses – the herbicide is very soluble and contamination could result if there are insufficient buffer zones.

Table 1.14 Remedial control measures for rhododendron (continued).

Method	Cost per treated ha per operation[1,2]	Total cost per ha for complete control[3]	Efficacy	Environmental risks[4]	Comments
2,4-D + dicamba + triclopyr	£150–180	£150–540[5]	Can be very effective, but up to two follow-up treatments may be required.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Harmful if swallowed or in contact with skin. Irritating to eyes and skin. Not hazardous to insects. Potentially dangerous to aquatic life. Risk of volatilisation and drift and damage to non-target vegetation in hot weather. Can taint water.	Most effective as a cut stump spray, or spray of young regrowth.
Glyphosate	£85–125	£85–375[5]	Can be very effective, but up to two follow up treatments may be required	Broad spectrum – all vegetation including newly planted (not overstorey) trees damaged or killed if oversprayed. Not hazardous to mammals, insects or aquatic life.	Most effective as a cut stump spray, or spray of young regrowth. Best used with Mixture B adjuvant.
Triclopyr	£264–294	£264–882[5]	Can be very effective, but up to two follow-up treatments may be required.	Most herbaceous vegetation, but not grasses, will be damaged if oversprayed. Not hazardous to insects. Harmful if swallowed or in contact with skin. Irritating to eyes and skin. Potentially dangerous to aquatic life. Risk of volatilisation and drift and damage to non-target vegetation in hot weather.	Most effective as a cut stump spray, or spray of young regrowth. Often more effective than glyphosate as a cut stump spray.

[1] Higher figure is for larger denser bushes.

[2] Costs given are for comparison purposes between alternatives only. Unless otherwise stated, all costs assume a dense even spread of rhododendron across one full hectare of ground. Actual costs will of course vary depending on the nature of the target vegetation at each site type.

[3] Cost is for complete control of established bushes. Re-invasion will require repeat treatment.

[4] Selectivity refers to effects on vegetation, not on other biological kingdoms such as insects.

[5] For larger bushes the cost of mechanised clearing (£500–6500 ha^{-1}) needs to be added. Cost includes amounts for herbicide and application.

1.3 Wildlife management

Wild mammals damage trees and shrubs in woods, amenity areas and gardens by:

- Browsing: the removal of leaves, buds and shoots, or sometimes the entire stem.
- Bark stripping: the removal of the bark and underlying tissues from the main stem and branches with the incisor teeth.
- Fraying: the removal of bark and breaking of branches as a result of the action of male deer rubbing their antlers on young trees to clean them of velvet or mark territory as a prelude to the rut.
- Seed predation: the removal of seed, before germination, from nursery seedbeds, direct sowing on ex-agricultural sites, or from within woodlands in natural regeneration situations.

See FC Practice Note 3: *The prevention of mammal damage to trees in woodland* (Hodge and Pepper, 1998) for further details.

Damaging agents

Mammals most likely to cause damage to trees are rabbits, hares, squirrels, deer and voles. Table 1.15 lists the animals most likely to cause damage, the type of damage, and the time of year when damage occurs. This damage may prevent or delay establishment unless management is undertaken. The most common methods of management for some species are non-chemical, e.g. shooting deer or fencing, while for others chemical control offers an option and is occasionally the most cost effective available, e.g. poisoning squirrels or fumigating rabbits.

Damage identification

Because different animal species can cause similar damage symptoms but require different damage control strategies, it is important to identify the species responsible. To aid diagnosis the trees and their surroundings should be inspected for the following diagnostic features:

- Form of damage (browsing, bark stripping or fraying).
- Height of damage.
- Time of year when damage occurred.
- Presence and size of teeth marks.
- Signs of animal presence and abundance, e.g. droppings, footprints, runs, scrapes or burrows.

Tables 1.16 and 1.17 detail the diagnostic features of browsing and bark stripping respectively.

Damage assessment

The presence of damage or of damaging mammals does not automatically mean that protective measures should be taken. The decision should be objectively based on an evaluation of the economic and ecological costs and benefits, including the overall objective. This requires an assessment of current damage or potential for damage in the future.

In large, continuous woodlands, the current amount of damage to trees can be determined by sampling using the Nearest Neighbour Method (Pepper, 1998). In the absence of trees, prior to planting, damage risk can be inferred from intensity of animal signs and past experience of damage in adjacent areas or similar landscapes. Once the degree of risk has been estimated the options can be assessed and the least costly, most appropriate action taken. There may be some locations where it is inappropriate to plant trees because of the risk of damage and the associated costs of continuous mammal management.

Table 1.15 Mammal species damaging forest trees.

Mammal	Time and type of damage				Mammal distribution
	Browsing	Stripping	Fraying	Other	
Roe deer *Capreolus capreolus*	Autumn to spring		March to July		Southern England; northern Britain; moving into mid-Wales
Red deer *Cervus elaphus*	Autumn to spring	Any time	March to May		Scotland; some geographically distinct English populations
Sika deer *Cervus nippon*	Autumn to spring	Any time	March to May	Bole scoring	Spreading in west and north Scotland; some English populations
Fallow deer *Dama dama*	Autumn to spring	Occasional	March to May	Feeding on farm crops	Midlands and southern England; few Welsh and Scottish populations
Muntjac deer *Muntiacus reevesi*	Autumn to spring	Occasional	March to May	Damage to shrub and herb layers	Spreading through southern Britain
Chinese water deer *Hydropotes inermis*	Potentially autumn to spring, but damage very rare				Rare, in marshy areas in Eastern England
Feral goats *Capra hircus*	Autumn to spring	Occasional			Scotland and Wales. Scattered populations in the uplands of England
Sheep *Ovis* spp.	At any time				Main alternative land-use in upland Britain
Rabbit *Oryctolagus cuniculus*	Autumn to spring, occasionally summer	Winter, particularly during prolonged snow cover, spring		Cutting stems of recently planted trees. Grazing farm crops	Widespread, except upland Scotland
Brown hare *Lepus capensis*	Winter and spring			Cutting stems of recently planted trees. Grazing farm crops	Locally abundant. Widespread in lowlands
Blue hare *Lepus timidus*	Winter and spring			Cutting stems of recently planted trees. Grazing farm crops	Widespread in uplands
Field vole *Microtus agrestis*		Any time, particularly late winter			Widespread, often at high density
Bank vole *Clethrionomys glareolus*		Occasional, often high up in tree shelters			Widespread usually at low density
Grey squirrel *Sciurus carolinensis*		April–July		Feeding on seeds and cones	Southern Britain and lowland Scotland
Edible dormouse *Glis glis*		Late spring		Domestic property nuisance	Very restricted round Chilterns

Table 1.16 Identification of browsing damage to trees.

Mammal	Tree size	Time of year	Description of damage
Bank vole	Newly planted	Winter	Will remove buds, particularly of pine, usually on restock sites; often immediately after planting.
Rabbit	Up to 0.5 m	Winter, spring rarely summer	Sharp-angled, knife-like cut on ends of stems or branches, removed portion often eaten. Damage up to 0.5 m (higher in snow).
Hare	Up to 0.7 m	As rabbits	As rabbits but shoots often not consumed. Damage up to 0.7 m.
Deer	Up to 1.8 m	All year	Lack of teeth in front upper jaw produces ragged edge on damaged stems. Roe and muntjac browse up to 1.1 m, fallow, red and sika up to 1.8 m. Fallow pull newly planted trees out of ground. Chinese water deer are currently not reported as causing significant damage to trees.
Sheep and goats	Up to 1.5 m	All year	Coarse browsing of foliage to 1.5 m. Newly planted trees pulled out of ground. Sheep and deer browsing damage very similar.

Table 1.17 Identification of stripping, rubbing or fraying damage.

Mammal	Tree size	Time of year	Description of damage
Field vole	Young trees to 5 cm diameter	All year but greatest risk in winter	Bark is stripped on roots or lower stem up to height of surrounding vegetation. Very small trees can be girdled and felled. Bark removed in short, irregular strips 5 to 10 mm wide, with incisor marks 1 mm wide in pairs in the bark around the edge of the wound.
Bank vole	Up to early pole stage	Winter and spring	Bark removed in short, irregular strips 5 to 10 mm wide, with incisor marks 1 mm wide in pairs. Bank voles climb so damage can occur up to 4 m. Less common than damage by field voles.
Rabbit	All	Winter and spring	Bark stripping can occur to a height of 0.5 m (higher in snow). Incisor marks are 3 to 4 mm wide, in pairs, usually running diagonally across the stem. Beech particularly vulnerable. Bark usually consumed.
Squirrel	10–40 years old	April–July	Incisor marks 1.5 mm wide in pairs, usually running parallel with stem or branch. Stripping can be on bole, trunk or branches. Sycamore, beech, oak and pine most at risk. Bark shreds left on ground.
Deer	Up to pole stage	All year	Red, sika and fallow deer strip bark leaving vertical incisor marks. Muntjac often partly bite through tall thin shoots and then eat terminal foliage.
Edible dormouse	Young pole stage onwards	Late spring	Bark stripping; small patches from upper trunk, often just above branches. Larch, beech, spruce, pine most at risk. Similar to squirrel but smaller teeth marks. Restricted to Chilterns area.

Damage control

Where the requirement for damage control operations has been identified the following tree protection options should be considered:

- **Barriers**: treeguards or treeshelters, fencing, and chemical repellents.
- **Population management:** shooting, trapping, or poisoning.
- **Habitat management:** reducing favourable conditions locally to discourage a target pest, or to encourage them use specific areas where they can be controlled.

Barriers

Treeguards and treeshelters
Individual tree protection is available in a range of shapes and sizes, including plastic tubes, spiral guards and mesh guards. Each is designed for a specific application.

Fences
Fences can provide an effective barrier to rabbits and deer, provided they are constructed and maintained to the recommended specifications (Pepper, 1992, 1999). However, the costs of these fences can be high. It is therefore imperative that the objective of the fence is clear and that the chosen specification is correct.

Chemical repellents
Chemical repellents are the least-used damage prevention option. The repellents currently approved for use are either of limited efficacy in forestry situations, require repeated application, are phytotoxic to actively growing plants, or expensive to purchase and apply. Aaprotect (ziram) has, to date, proved to be the most consistently effective repellent. Repellents may also offer some protection from seed predation.

Population management

All control techniques are constrained by legislation for use on particular species in particular circumstances or at certain times of year.

Shooting

Shooting is the only permissible method of killing deer. It may also be used as an adjunct to other methods for rabbit control. However, it is not recommended for grey squirrel control as numbers cannot be reduced sufficiently by shooting alone over the main damage period of May to July.

Trapping

Live trapping (cage and box traps) or kill trapping (approved spring traps set in tunnels or burrows) can both be used to control grey squirrels and rabbits, though only live trapping is recommended for squirrels. Traps are easy to site and set but have a high capital cost and there is a legal requirement to visit them daily.

Poison (rodenticides)

At the time of writing, warfarin may be used to control grey squirrels in specified areas of England, Wales and Scotland. It is the most cost effective method of controlling grey squirrels but it does involve the use of a hazardous mammalian toxin in the environment. It also kills squirrels in a way that is considered, by some, to be inhumane.

Poison (fumigation)

The fumigation of burrow systems with aluminium phosphide is the most effective method of rabbit control. However, it is hazardous to operators if stringent safety precautions are not fully observed. It requires properly trained and equipped personnel.

Habitat management

Habitat management can be used as an aid to reducing the risk of damage by pest species. This may be through selecting a less vulnerable tree species or choosing a planting site that is not immediately adjacent to favourable habitat for a damaging animal. The woodland can be modified to make control easier by, for example, encouraging the establishment of areas of bare ground for squirrel traps, glades where deer can be safely shot or by making it less favourable to the pest species by discouraging the establishment of dense ground cover. However, it is difficult to make anything other than broad generalisations given the lack of research in this area.

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Rabbit (*Oryctolagus cuniculus*)

Rabbits are a widespread mammalian pest.

Introduced by the Normans in the 11th century, rabbits (*Oryctolagus cuniculus*) are found throughout the UK. Rabbit numbers have been increasing by approximately 2% per year. This is mainly the result of the lessening effect of myxomatosis which, in the 1950s, killed 99% of rabbits but now only accounts for around 20% of the population annually. Rabbit numbers are found at pre-myxomatosis levels in some woodlands, but are generally now only at about 30% of pre-myxomatosis levels.

Consequences

The potential for damage to young trees is now very high in some areas and increasing in others. The problem is exacerbated by a number of management factors:

- Many areas of new woodland are on ex-agricultural sites where a large rabbit population is already established.
- The presence of brash and wind-blown stumps on felled areas provides cover for rabbits and makes control difficult.
- Rabbit fencing is relatively costly for use in protecting small areas of newly planted or regenerating trees.
- There is often a lack of manpower at the time of year when control is most needed.
- Because myxomatosis eliminated the need for rabbit control for many years, the necessary skills and expertise available pre-myxomatosis have been lost.

Damage to trees, by either browsing or bark-stripping, is the result of feeding. Therefore, the more rabbits that are present, the greater will be the level of damage. Browsing and bark stripping are the most common form of damage on young trees of all species and can occur up to a height of 0.5 m in normal conditions, higher over lying snow. Bark stripping to the base of pole stage trees (up to 0.5 m) is much less common than browsing; ash and beech are most vulnerable to this form of damage.

Bark stripping by rabbits.

Rabbit browsing damage to Sitka spruce.

Options for control

The protection of trees can only be achieved by good planning, careful evaluation of existing methods and thorough implementation of the most suitable options for a given situation. Forest Commission Practice Note 2: *The prevention of rabbit damage to trees in woodland* (Pepper, 1998) gives further advice on evaluating the cost-effectiveness of methods of rabbit control.

Viral haemorrhagic disease (RVHD) has recently been diagnosed in wild rabbits but cannot be relied upon to reduce numbers, and therefore tree damage, in a similar way to myxomatosis. Although little is known about RVHD, experience in other countries suggests that rabbit damage may only be reduced in the short-term. Nevertheless, by more intensive use of appropriate control measures, low damage levels may be maintained for longer where rabbit populations are affected by the disease.

The complete eradication of rabbits in woodland is impractical. The aim should be to protect tree crops through planned management taking the following into account:

- use of barriers;
- the need for more fencing between forest edge and fields;
- sufficient time to enable rabbit clearance of fenced areas before planting;
- a reduction of rabbit harbourage – slash, windblown pockets and clumps of thick cover;
- use of the most effective control method – fumigation;
- the most effective control period is November–March;
- co-operative rabbit control;
- the conservation of other wildlife habitats;
- ranger/operator training;
- local markets for the sale of rabbits.

Rabbit populations are very resilient and can withstand high mortality. Therefore there are likely to be some woodland areas where the rabbit problem is so great that current techniques may not be capable of reducing damage to an acceptable level unless virtually unlimited time and manpower are expended.

TAKE NO ACTION

To take no action may contravene legislation through which owners or occupiers of land may be obliged to control pests damaging crops on adjoining land (the Pests Act 1954, the Agricultural Act 1947 and the Agricultural (Scotland) Act 1948). This is likely to apply where horticultural or agricultural crops require protection.

When rabbit populations exceed 40 per ha, browsing can completely destroy new planting but more generally results in the need for heavy beating-up over several years. Levels of bark stripping in mature trees are rarely sufficient to justify control. To do nothing may seriously restrict options for woodland regeneration.

AVOID THE PROBLEM

There is no known way of completely avoiding rabbit damage to palatable trees if the animals are present. The scale of the problem may be reduced by reducing the amount of harbourage such as bramble (*Rubus fruticosus* agg.) patches, gorse (*Ulex europaeus*), brash piles or wind-thrown stumps. However, clearance may conflict with other management objectives such as the conservation of wildlife. The unnecessary control of predators (e.g. foxes, *Vulpes vulpes*) should be avoided. Where compatible with other objectives, rabbit burrows can be ripped out.

TAKE REMEDIAL ACTION

Barriers

Treeguards and treeshelters

Mesh guards or shelters 0.6 m high, in a range of diameters, are sufficient for protecting newly planted trees and shrubs from browsing. Depending on tree spacing, treeshelters are usually more expensive than fencing on areas greater than 1 ha in size.

Fencing

Areas should be rabbit-fenced to a high specification prior to planting in sufficient time to allow the removal of rabbits from within the fenced area before planting. Some internal sub-dividing fencing may be necessary to aid the removal of rabbits from heavily infested areas.

Chemical repellents

Aaprotect (ziram) has proved to be the most consistently effective repellent when applied by spraying to the whole tree to protect against browsing or by painting or spraying onto vulnerable areas of bark. Only the parts of the tree actually treated with repellent are protected. Since the repellent is phytotoxic to emerging foliage, spraying must be confined to the period mid-November to the end of February.

Control of rabbit numbers

General

The optimum time for controlling rabbit numbers for tree protection is from the beginning of November to the end of February. In the north, this period may be extended to the end of March. Rabbit control may also be required, for example, to protect adjacent horticultural and agricultural crops, at any time of the year where there is a legal obligation to do so under the Pests Act 1954, Agricultural Act 1947 and the Agricultural (Scotland) Act 1948.

Kill trapping

Only approved spring traps may be used (Spring Traps Approval Order 1975). Traps are set inside a burrow or artificial tunnel entrance but need visiting each day. Non-target species are at risk.

Live trapping

Cage traps baited with attractive food such as carrots can be used to eliminate small numbers of rabbits that remain within or have subsequently entered ring fences around restock areas. They are also useful for taking rabbits outside the recommended control period when required to fulfil the owner's/occupier's legal obligation to control rabbits. In common with all live capture traps, once set, there is a legal requirement to visit them every day. It may sometimes take several days before rabbits enter the traps.

Box traps, wooden or metal, permanently sited along or through fence lines, can take substantial numbers of rabbits. They can be particularly useful on perimeter fences between woodland and fields. The capital cost of box traps can be high.

Snaring

Although reasonably effective in skilled hands, snaring is not recommended as the sole form of management. It is unselective, considered inhumane and can generate antagonism from visitors to forests. Before considering the deployment of snares, all other methods should have been tried and found to have failed. The Wildlife and Countryside Act 1981 prohibits the use of self-locking snares and requires snares to be visited daily.

Shooting

Shooting should only be used as an adjunct to other methods. One person with a dog and gun can make little impact on a rabbit population unless considerable time and effort are expended. It is only possible to shoot a limited number of rabbits at any one time in one place before the remainder take flight. In order to kill substantial numbers, it is necessary to make regular visits to several places in turn. However, rabbits become wary after repeated shooting and do not show themselves, giving the erroneous impression that they have all been killed or driven away. Suitable terrain for shooting, that is open ground with a minimum of cover, is not generally available in woodland, other than fenced areas prior to planting.

Ferreting

This is not generally an effective method of reducing population size on its own. Generally, more female rabbits are captured than males.

Fumigation

The fumigation of burrow systems with phosphine gas (aluminium phosphide) is the most effective method of control where the burrows can be reached but can be hazardous to the operator if the prescribed methods are not fully observed. Carbon monoxide, judged to be a more acceptable gas to achieve euthanasia, may be available as an alternative fumigant in the future. Fumigation should only be undertaken by properly trained (certificated) and equipped operators and under HSE regulations and product label instructions. It should not be carried out in rainy or windy conditions.

It is imperative that rabbits are driven below ground before fumigation and that every entrance to a burrow system is found and treated. Phosphine tablets should be applied by injector in preference to hand application. Any missed hole will allow rabbits a safe escape route. A single fumigation treatment should account for approximately 65% of the rabbits present.

After at least two fumigation operations are complete, consideration should be given, wherever practical, to ripping out these large burrow systems using a tine followed by reconsolidation but only after at least a further 48 hours. Any subsequent new burrows will initially be smaller and can be dealt with by single entrance treatment.

The effectiveness of fumigation operations should be monitored by recording the number of burrow entrances treated and then recording the number of open entrances re-treated at subsequent follow-up visits. A follow-up visit and treatment should be at least 48 hours after the initial treatment.

Table 1.18 details possible remedial control measures against rabbits.

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Table 1.18 Remedial control measures for rabbit damage.

Method	Cost per treated ha per operation	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks	Comments
Non-chemical methods					
Fencing	£3.50 to £4 per m	For 25 ha enclosure £320 ha^{-1} For 4 ha enclosure £1050 ha^{-1} For 0.5 ha enclosure £2400 ha^{-1}	100% if fence specification correct and fence well maintained.	No significant risks. Eliminates browsing and grazing which may result in losses or gains in plant diversity.	The larger the area enclosed the lower the cost of fencing per hectare. Cost effective for large areas and high stocking densities. Areas in excess of 25 ha are difficult to manage if there are rabbits within the fenced area. Some reduction of animal numbers outside the fence will also be necessary when populations are high. Ferreting or shooting inside fences can clear enclosed infestations.
Tree guards and treeshelters	£1.20 per guard/ shelter, average £3000	£3000	100% if regularly inspected and maintained.	Unless fully biodegradable or removed, they form a source of chemical pollution.	Cost effective for small areas and low stocking densities. Do not prevent herbivore impacts on ground vegetation. Need to be removed after damage period.
Cage, spring and box traps	Traps reusable on many different sites. £100; based on a 5–20 day duration using 5–10 traps within treated area and visited daily. Not always completely effective.		10–100%.	No significant risks if traps checked daily. Occasionally non-target mammals or birds may be trapped and killed.	Used for the removal of the occasional rabbit inside fenced areas, for maintaining good relations with neighbours and for complying with the legal obligation to control rabbits. Unsuitable for removing substantial numbers of rabbits.
Chemical methods					
Chemical repellent ziram (Aaprotect)	£820	3 years of protection £2460	90% effective. Other PSD approved chemicals less effective.	Ziram is phytotoxic to actively growing foliage. Potential risk to the operator as ziram is an irritant. Potentially harmful to aquatic life. Not hazardous to insects.	May only be applied to whole tree in winter. Cost effective for small areas.
Fumigation of burrows with aluminium phosphide	71p per burrow entrance. Average 30 burrow entrances per ha: £21.30 Two operations needed per year: £42.60 per year	£128 – very variable depending on rabbit warren density	One operation accounts for 65% of rabbits.	Very toxic by inhalation or skin contact. Requires properly trained and equipped personnel. Will kill any non-target animals in burrows. Potentially dangerous to aquatic life.	Fumigation should only be used for rabbit control for tree protection from November to March when both vegetation around burrows and rabbit numbers are low. Do not use without consulting HSE Agriculture Information Sheet 22.

[1]Control sufficient to allow tree establishment until no longer vulnerable to damage, i.e. 3 years of control/protection.

[2]Costs per ha based on 2500 trees planted and include chemical and application cost.

Grey squirrel (*Sciurus carolinensis*)

The grey squirrel is a damaging pest spreading rapidly throughout Britain.

The grey squirrel (*Sciurus carolinensis*) was introduced from eastern North America into different parts of Britain between 1876 and 1929. It became illegal to import, keep or release a grey squirrel in 1937 and remains so under the Wildlife and Countryside Act 1981. The grey squirrel adapted well to its new environment and spread rapidly, especially in the lowland areas of broadleaved and mixed woodland. The animal does not suffer to any meaningful extent from diseases or natural predation, and continues to extend its range in Wales, northern England and Scotland.

As well as displacing the native red squirrel (*Sciurus vulgaris*), the grey squirrel can become a nuisance due to a variety of activities, from robbing litter bins to taking seed and fruit crops. However, the most important damage is caused by the stripping of bark on the main stems of trees.

Consequences

Trees aged 10–40 years old (pole stage) are the most vulnerable. Trees younger than 10 years old are generally not large enough to attract and support squirrels, while, apart from side and upper branches, the bark of trees older than 40 years is usually too thick to be stripped. All conifer and broadleaved species are at risk of damage. Sycamore (*Acer pseudoplatanus*), beech (*Fagus sylvatica*), oak (*Quercus* spp.), pine (*Pinus* spp.) and spruce (*Picea* spp.) are most vulnerable. Bark stripping generally occurs during the months of May, June and July. The risk of bark stripping increases with increasing population numbers and a successful spring breeding and recruitment (Mayle *et al.*, 2004). Therefore, the number of juvenile squirrels present and the overall population size during the damage period, and consequently the amount of damage caused, are related to the size of the tree seed crop the previous autumn.

The vulnerability of a tree to damage is linked to vigour. The more vigorous the tree, the greater the risk of damage as the bark becomes easier to strip, particularly in May and June. However, more vigorous trees grow out of the vulnerable size range more quickly.

Bark stripping is variable in severity. It is very serious in some years and places but not others. Less than 5% of damaged trees are killed. It is the accumulation of damage over the years that causes both a loss of timber volume and a reduction in timber quality. Damaged bark also provides entry points for pathogens. Grey squirrel damage can therefore act as a disincentive to planting broadleaved trees in particular.

Grey squirrels are now an established part of our wildlife and many people enjoy their presence in parks, gardens and woods. It is not practical to exterminate them but targeted control to protect valuable and vulnerable tree stands is often necessary.

Severe bark stripping by squirrels.

Options for control

▷ TAKE NO ACTION

Grey squirrel damage is variable in its severity and often sporadic. Damage may be serious in some years and places but not others. It is the accumulation of damage over the years that has the greatest impact on timber quality as well as the form and longevity of the tree. Where damage occurs, therefore, to take no action is not usually acceptable.

However, in small isolated plantations control may not be worth while as it has been shown that damage is usually less severe in isolated woods. In addition, small areas of stands will not hold large populations of squirrels. An annual assessment of vulnerability should be made on which to base management decisions.

▶ AVOID THE PROBLEM

The risk of damage may be reduced by planting less vulnerable species such as ash (*Fraxinus excelsior*) and cherry (*Prunus avium*) and planting fewer large seeded broadleaves to reduce squirrel numbers. The amount of damage is related to the thickness of the phloem which in turn is related to tree growth. The more vigorous the trees, the thicker the phloem, the easier it is to strip off the bark and therefore the greater the risk of the trees being damaged. Phloem thickness may be depressed by high stocking density and no thinning. High initial stocking density is usually a prudent management measure, but leaving such areas unthinned is only acceptable on very exposed sites.

▶ TAKE REMEDIAL ACTION

Control of grey squirrel numbers

The protection of woodlands can only be achieved by carefully targeted control of squirrel numbers in and around vulnerable woodland areas between April and July, i.e. before and during the main damage period of May to July. Killing squirrels at any other time of year will not reduce subsequent levels of damage, because they can recolonise cleared areas in as little as one month.

- Poisoning with warfarin-coated wheat placed in hoppers is the most cost-effective method, but must not be used in areas where there are red squirrels or pine martens (*Martes martes*). Five hundred millilitres of the Warfarin Grey Squirrel Liquid Concentrate (0.5% w/w warfarin) is mixed with 12.5 kg wheat, to give a 0.02% concentration of warfarin per kg of wheat. To be effective, each squirrel needs to consume 200–250 g of warfarin-treated bait over a 10-day period. Hoppers must be labelled and visited regularly to ensure that a continuous supply of bait is available (at least once a week at first, then fortnightly as bait consumption falls). At each visit, any spillage of bait from outside the hopper must be cleared up and incinerated along with any spoilt bait. Hopper density must not exceed one per hectare; the recommended density is one hopper to every 1–4 hectares. Each hopper should be placed at the base of a tree and firmly secured with branch wood or stakes and wire. Where badgers (*Meles meles*) are present hoppers should be sited at least 1 m above ground either in a fork of a tree or on a table. After use, and not later than 14 August, hoppers must be emptied completely and all the unused bait removed. Empty hoppers may remain *in situ* after treatment, but it is advisable to remove them in most situations.

- Control by cage trapping relies on attracting squirrels into the traps with yellow whole maize bait. Only a minimum of expertise is required, but it is expensive in labour and materials.

- Approved spring traps used in tunnels, although legal, are indiscriminate and will kill animals other than grey squirrels.

- Shooting has been shown to be insufficiently effective on its own to have an impact on damage levels.

Protection through chemical repellents

Bark stripping can be prevented by applying the chemical repellent ziram to vulnerable areas of a tree. This treatment is too expensive for woodlands, but may be practical for amenity trees.

Physical barriers

The feasibility of protecting individual trees by climb-proof tubes has been investigated. Such physical barriers may be appropriate in seed orchards and for individual widely spaced trees of high amenity or timber value.

Table 1.19 details possible remedial control measures for grey squirrels.

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Table 1.19 Remedial control measures for grey squirrel damage.

Method	Cost per treated ha per season[1]	Total cost per ha for complete control[1,2]	Efficacy	Environmental risks	Comments
Non-chemical methods					
Cage trapping	£12.50–17	£125–680	Will contain bark stripping damage to acceptable levels if carried out as recommended and with sufficient trapping sessions.	Non-target mammals or birds are occasionally captured and may die.	Advantages: Live capture allows selective control of target species. Known number of squirrels controlled. Disadvantages: Intensive (daily) labour requirement. Ranger availability for other tasks limited during control season. Recolonising squirrels may strip bark between trapping sessions. The timing of each trapping session is important. The continual redeployment of traps results in increased wear and tear and the subsequent need for increased maintenance. Cage traps are difficult to camouflage and are easily found by the public and by unleashed dogs, particularly when they contain a captive squirrel. The maize bait is often taken by mice, pheasants etc., before it can attract squirrels. Deer, particularly fallow, are attracted by the maize bait and will upset trap. Once set, cage traps must by law be visited once a day, irrespective of weather conditions. Contingency plans must be in place to provide absence cover.
Chemical methods					
Ziram repellent	High in woodland – £1000+	>£5000	Effective in the short term.	Ziram is phytotoxic to actively growing foliage. Potential risk to the operator as ziram is an irritant. Potentially harmful to aquatic life. Not hazardous to insects.	Not practical on a woodland scale; more useful for individual amenity or valuable trees, particularly to give rapid protection whilst more long-term solutions are prepared.
Warfarin poison	£7–8.60	£70–344	As effective as cage trapping.	Warfarin is toxic to operators and non-target mammals. Hence, there is a risk of poisoning to non-target wildlife from misuse or malfunction of hoppers. Risk of secondary poisoning to predators and carrion-eaters though evidence collected by the FC indicates that this is low; very low in the case of birds. Animals must consume a minimum dose (200–250 g of treated bait over a 10-day period for squirrels) before death occurs. The UK Wildlife Incident Investigation Scheme has reported very few instances of poisoning of non-target wildlife to be associated with use of warfarin to control grey squirrels (e.g. cases between 1978 and 1990).	Advantages: Less intensive labour input, releasing ranger time for other tasks. Continuous control over the period hoppers are in place. Recolonising animals are at risk as they enter the wood. Hoppers relatively easy to camouflage from public. Disadvantages: Hopper tunnels can become blocked by mouse nest material. Infrequent visits can result in loss of control cycle if bait runs out or tunnel becomes blocked. Uncertainty about exact number of squirrels controlled. Unused bait MUST be treated as Controlled Waste and disposed of through a registered contractor. At the time of writing, the use of warfarin is under review.

[1]Per season cost may be required for 10–40 years.
[2]Cost includes chemical and application costs.

Field vole (*Microtus agrestis*) and bank vole (*Clethrionomys glareolus*)

Field vole, a native mamal, which occasionally damages young trees.

The field vole (*Microtus agrestis*) is a common native resident of rough grassland. Its presence is betrayed by a network of runs, containing small piles of grass clippings and droppings, on or just below the surface of the ground. Young tree plantations often have a thick mat of grass which is ideal vole habitat, providing abundant food and cover. This enables voles to increase to very high numbers until the trees suppress the vegetation. Although grass is the vole's main food, it also eats the bark of the lower stem and roots of young trees.

Vole numbers can fluctuate considerably. Damage to trees is most likely in late winter or early spring when numbers are high and food is scarce, but serious damage can occur at any time of the year if there is thick vegetation around the base of the tree.

Consequences

Field voles can cause significant damage, requiring heavy beating up or even complete replanting. Damage to trees is confined to below the height of surrounding herbs. Small trees may be girdled, or felled when their stems are gnawed through. Trees with a stem diameter as large as 27 mm have been felled in this way. Only bank voles (*Clethrionomys glareolus*) can climb well, and any vole damage found above the level of surrounding vegetation or high up in treeshelters is usually caused by bank voles. Bank vole damage is a rare occurence whereas field vole damage is relatively common.

The risk of damage occurring is related to animal density. It is not possible to predict either vole plagues or their collapse. However, the frequency of fresh droppings and grass clippings in the runs together with the presence of predators gives an indication of numbers. If fresh grass clippings are found in the runways of more than 10 squares out of a sample of 25 (each square being 25 cm x 25 cm), then vole damage may be significant.

Basal bark stripping by voles.

Mulch mat ripped by foxes searching for voles.

Options for control

▷ TAKE NO ACTION

Because field vole damage can be serious enough on occasions to require replanting, taking no action is not an acceptable option. At the very least, an appraisal of the status of the field vole population should be made by assessing the abundance of fresh droppings and grass clippings. Bank vole damage is rare and unpredictable, therefore in this case to do nothing is the only practical option.

▶ AVOID THE PROBLEM

Trees surrounded by bare soil, at least 1 m diameter, suffer less damage than those growing in weeds. Voles are reluctant to cross open ground because they are more vulnerable to predators. Voles often nest beneath mulch sheets and will penetrate organic mulches. If vole numbers are high, foxes may damage the mulch mat to feed on them.

▶ TAKE REMEDIAL ACTION

Plastic guards
Narrow plastic tubes 200–250 mm in length, pushed partly into the soil, are the best option (Hodge and Pepper, 1998). Voles may gain access to trees through the mesh of some guards, through spiral guards or through any ventilation holes. Conventional tall treeshelters are less effective than vole guards, but do offer some protection and are a worthwhile option if they are required to protect against other mammals. Bank voles can sometimes enter at the base of treeshelters if they are not pushed at least 5 cm into the ground or if the soil cracks in the summer, and they can then climb inside to damage the whole stem.

Weeding
See 'Avoid the problem'.

Trapping
Voles, like most rodents, are easy to trap, but as a method of controlling damage trapping is inordinately laborious and quite impractical.

Chemical repellents
The vulnerable lower stem of trees can be painted or sprayed with the repellent Aaprotect (ziram). To provide continued protection the chemical must be reapplied every 6 months. The technique is therefore labour intensive.

Poisoning
Poisoning voles is not approved under the Control of Pesticide Regulations 1986 and therefore may not be used.

Table 1.20 details possible remedial control measures for vole damage.

References and useful sources of information

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Table 1.20 Remedial control measures for vole damage.

Method	Cost per treated ha per operation	Total cost per ha for complete control[1]	Efficacy	Environmental risks	Comments
Non-chemical methods					
Weed control through hoeing/ screefing	£1500–7000	£3000–245 000[2]	1 m diameter 60% effective, if surrounding growth is not too high to cover the bare spot.	Small risk of soil damage.	See earlier sections on weed control. Only practical on very small areas. Up to 7 hoeings a year may be needed to control weeds on very fertile sites. Vole damage to trees in 1 m diameter weed free areas is generally slight and acceptable. Prolonged snow cover will negate effect of weed free effect. Voles move around under the cover of the snow. Weed control may be necessary anyway for tree establishment, so effectively might be a zero cost option.
Split plastic tube voleguards	60p per tree: £1500	£1500	95% effective	Unless fully biodegradable or removed they can form a source of chemical pollution.	The recommended option if there is a high damage risk. Other types of tree guard are less effective. Treeshelters are adequate if pushed into the ground on non-cracking soil.
Chemical methods					
Weed control through use of herbicides	£50–800	£50–4000[3]	1 m diameter 60% effective, if surrounding growth is not too high to cover the bare spot.	If misused, all herbicides present a risk to operator health, risk of soil and water pollution, potential risk of poisoning of wildlife and damage to non-target vegetation. Once dry and absorbed by soil or plants, herbicides offer little risk to health.	See earlier sections on weed control (pages 51–63). Vole damage to trees in 1 m diameter weed free areas is generally slight and acceptable. Prolonged snow cover will negate the weed-free effect. Voles move around under the cover of the snow. Weed control may be necessary anyway for tree establishment, so effectively can be a zero cost option for vole management.
Chemical repellent ziram (Aaprotect)	£1094	For 5 years of protection £5470[3]	90% effective	Ziram is phytotoxic to actively growing foliage. Potential risk to the operator as ziram is an irritant. Potentially harmful to aquatic life. Not hazardous to insects.	Spray applications may only be made in the winter. Paint applications to the bark may be made at any time of year.

[1]Costs per ha based on 2500 trees planted, for 5 years of control.
[2]For 5 years of weed control, 1 m diameter wide spots.
[3]Costs include chemical and application costs.

Deer

Roe deer browsing trees.

Six species of deer are established in the wild in Great Britain. Red (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) are native to Britain; fallow (*Dama dama*), sika (*Cervus nippon*), muntjac (*Muntiacus reevesi*) and Chinese water deer (*Hydropotes inermis*) have all been introduced. Deer form an important component of natural ecosystems but, as they have no natural predators, populations have been increasing in numbers and distribution over the past few decades. There are currently estimated to be around 1 million deer present in Great Britain, mainly in woodland habitats. There is no overall strategy with regard to deer management in Great Britain although the Deer Commission for Scotland has legislative authority for deer management in Scotland and the Scottish Forestry Strategy specifically seeks to 'tackle deer problems'. Population management is essentially the responsibility of the landowner and his tenants.

Consequences

Increased woodland planting is providing more suitable habitat for deer and encouraging population expansion. Lack of effective deer management or population control allows populations to increase, leading to increased damage to woodland and other habitats. In the uplands, densities above 7 km^{-2} (0.07 ha^{-1}) will limit or prevent natural regeneration and damage sensitive flora and fauna. Deer densities are often above this level and as high as 25 km^{-2} in many sites. Fencing merely channels populations away from favoured sites to other vulnerable areas.

Damage to trees by browsing and bark stripping is the result of feeding. Most fraying damage is a behavioural activity that occurs immediately prior to the rut in all species and in the spring when roe deer establish territories. A damage risk assessment should be made by Nearest Neighbour Assessment (Pepper, 1998), together with an assessment of population size (Mayle *et al.*, 1999).

Stripping damage to Sitka spruce by Sika deer.

*Bluebells (*Hyacinthoides non-scripta*) grazed by muntjac deer.*

Options for control

TAKE NO ACTION

Deer browsing at high deer densities can prevent natural regeneration or completely destroy planted trees. The deer density at which these impacts occur will vary depending on the habitat and species involved. As trees can remain vulnerable to stripping for a considerable period of time, the 'take no action' option is unacceptable in young or regenerating woodlands.

AVOID THE PROBLEM

Damage by deer can be reduced, but not avoided, by:

- Being aware of the species present and the population levels.
- Managing populations at levels below which unacceptable impact occurs.
- Rapid establishment of trees to ensure that they quickly grow beyond browsing vulnerability.

TAKE REMEDIAL ACTION

There are no new techniques available for population control and although immunocontraception is being investigated for some species in North America and other parts of Europe, it is unlikely to become a widely applicable tool for management of wild deer populations.

Control of deer numbers
The aim of control should be to maintain populations at densities which reduce impacts to acceptable levels. Shooting is the only permissible method of killing deer, and may be required even if other methods of remedial control such as fencing, treeshelters or repellents are used. Often a combination of techniques is required (see Management, below).

Barriers: fencing
Areas can be deer-fenced prior to planting, ensuring that animals (particularly the small species) are not fenced into the area. See Pepper (1992) or Agate (2001) for specifications, and Pepper (1999) for lightweight or temporary fencing. For fencing in capercaillie (*Tetrao urogallus*) habitats, see Trout *et al.* (2001). Electric fencing can give short-term protection, but temporary fencing is usually more cost effective.

Barriers: treeguards and treeshelters
As with fencing, the height of shelter required depends upon the largest deer species present. For red, fallow and sika deer, 1.8 m shelters should be used; for roe, muntjac and water deer, 1.2 m. Depending on tree spacing, fencing tends to be cheaper than individual tree protection on areas greater than 1 ha.

Chemical repellents
On small areas the application of an effective repellent can provide a more economical method of protecting trees than either fencing or individual protection with guards or shelters. However, this advantage is lost if repeated annual applications are necessary. Aaprotect (ziram) has proved to be the most consistently effective repellent when applied by spraying to the whole tree to protect against browsing or by painting or spraying onto vulnerable areas of bark. Only the parts of the tree actually treated with repellent are protected. Untreated areas, however close they may be to treated areas, are at risk of damage. This means growth produced in the spring is not protected and, since the repellent is phytotoxic to emerging foliage, spraying must be confined to the period following mid-November to the end of February.

Management
Management should aim at reducing populations to acceptable and sustainable densities across their range. The aim should be to protect tree crops and woodland habitats through planned management based on a considered need for:

- The conservation of wildlife habitats.
- Co-operative deer control. Deer management groups encourage discussion and agreement between neighbours on whose land the deer reside and a collaborative approach to deer control.

- Woodland design incorporating safe shooting areas and access to these.
- Culling during the legal open seasons targeted at reducing numbers of reproductive females in the population.
- Ranger/stalker training.
- Regular communication between stalkers and their managers.
- Local and national markets for wild venison.
- Fencing of small vulnerable areas such as coppice or restock sites where densities cannot be reduced sufficiently.

Deer populations are an important element of woodland ecosystems and at low densities they benefit biodiversity. However, low densities will only be maintained by effective population control across the whole population range. Deer control should therefore be considered as an integral part of land management.

Table 1.21 details possible remedial control measures for deer.

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Table 1.21 Remedial control measures for deer damage.

Method	Cost per treated ha per operation	Total cost per ha for complete control[1]	Efficacy	Environmental risks	Comments
Non-chemical methods					
Population control by shooting	£5–10 per year – very variable	£25–700 (5–70 years)	100% if population reduced sufficiently.	No significant risks.	Some income from letting stalking and venison sales is possible to off-set costs. Cost varies considerably depending on whether stalking is let to third parties or carried out by owner, and the presence of fencing etc. Shooting is often required in any case in addition to other control measures, perhaps throughout the entire rotation therefore direct comparison of costs may not be valid.
Fencing Permanent Temporary	£4–7 per m £400 (for 25 ha enclosure) £1313 (4 ha) £3200 (0.5 ha) £0.75–1.50 per m £60–120 (25 ha) £197–394 (4 ha) £480–960 (0.5 ha)	£320–400 (25 ha) £1050–1313 (4 ha) £2960–3200 (0.5 ha) £60–120 (25 ha) £197–£394 (4 ha) £480–960 (0.5 ha)	100% if fence specification correct and fence well maintained.	Eliminates browsing and grazing which may result in a loss of plant diversity. Fences can impact on archaeological sites, and can result in the death of capercaillie and some other rare bird species if not correctly sited.	The larger the area enclosed the lower the cost of fencing per hectare. Cost effective for large areas and high stocking densities.
Treeshelters	£1.70 per 1.2 m guard/shelter – £4250 per ha £2.20 per 1.8 m guard/shelter – £5500 per ha	£4250 £5500	100% if regularly inspected and maintained.	Unless fully biodegradable or removed they form a source of chemical pollution.	Cost effective for small areas and low stocking densities. Do not prevent herbivore impacts on ground vegetation. Need to be removed after damage period.
Chemical methods					
Chemical repellent ziram (Aaprotect)	£820	3–5 years of protection £2460–4100[2]	Aaprotect 90% effective only. Other PSD approved chemicals less effective.	Ziram is phytotoxic to actively growing foliage. Potential risk to the operator as ziram is an irritant. Potentially harmful to aquatic life. Not hazardous to insects.	May only be applied to whole tree in winter and will only protect parts to which it is applied. New season's growth is unprotected.

[1] Costs per ha based on 2500 trees planted; control sufficient to allow tree establishment, i.e. for 5 years.
[2] Cost includes chemical plus application cost.

Part 2 Minimising the environmental impacts of pesticide use

2.1 Pesticide characteristics

All pesticides require detailed evidence covering environmental fate and behaviour, ecotoxicology, consumer exposure, mammalian toxicology, physicochemical properties and efficacy to be submitted for thorough examination by both government and independent scientists. Only when the environmental risk is judged to be acceptable under normal use is the product granted approval. Approvals are designed to ensure that as long as label instructions are rigorously followed, risk of environmental damage or harm to operators is likely to be minimal. The product label provides the primary source for safety information. Compliance with any instructions on the product label is vital to ensure operator and environmental safety.

Selecting pesticides to minimise environmental impacts

When using pesticides, particular care must be taken when handling undiluted pesticides as spillages at this stage present probably the greatest potential for environmental damage. However, it is also prudent to select a product that offers the least risk of environmental damage in normal usage. This is likely to be a difficult decision in many cases. In Table 2.1 a number of attributes, some drawn from product labels, are listed for the active ingredients referred to in Part 1. This helps to categorise the risks associated with their use.

In general, and assuming that all legal requirements have been met, the least toxic (to mammals, aquatic life and non-target insects), most selective (least likely to damage non-target species) and most active pesticide should be chosen. However, this choice should be consistent with achieving effective control of the pest or weed.

The relative importance of each pesticide attribute will vary depending on the site on which it is being used. Users should decide on the relative importance of the various pesticide characteristics based on an assessment of specific site conditions using their professional judgement. For example, on an upland restocking site which has little non-target vegetation, but which is bounded by streams, the most important consideration may not be how selective the product is or its hazard classification (assuming operators are of course fully protected), but whether or not it might prove toxic to aquatic life. Similarly, the use of a pesticide classified as toxic to operators may not be the most important consideration if it is applied through a vehicle mounted sprayer with a sealed cab with air filtration.

The pesticide decision key (page 5) summarises the approach to take when selecting a pesticide. An example decision aid for this stage of the process is given in Appendix 4. With experience, it will often not be necessary to break down and record the process in such detail. Instead, a reasoned professional judgement can be made and summarised directly on the decision recording sheet on page 3.

Adjuvants and additives

Adjuvants or additives are not pesticides, so some of the categories used in Table 2.1 are not appropriate. In addition it would not be practical to list the large number of adjuvants approved for use in forest situations by the Pesticides Safety Directorate. Only three adjuvants and one additive are listed here (Table 2.2), as they are commonly used with forestry approved herbicides. The omission of other adjuvants or additives does not imply they are inappropriate for use. Managers should assess each on their individual merits, obtaining information on approval status, likely utility and environmental safety from the label, and by approaching manufacturers directly.

Table 2.1 Pesticide characteristics: Aluminium ammonium sulphate–Glyphosate

Pesticide	Mode of action	Rate applied active ingredient (kg ha^{-1})	Rate applied active ingredient (mg m^{-2})	Toxicity to mammals (rats): oral (LD_{50}, mg kg^{-1})	Toxicity to mammals (rats): contact (LD_{50}, mg kg^{-1})
Aluminium ammonium sulphate	Mammalian repellent	2.08	208	Unknown (Repellent)	Unknown
Alpha-cypermethrin	Insecticide	0.025–0.05	2.5–5	79–400	>2 000
Aluminium phosphide	Rodenticide	0.084	8.4 (underground, very variable)	8.7	Unknown
Ammonium sulphamate	Herbicide	80–280	8 000–28 000	3 900	Unknown
Asulam	Herbicide	2–4	200–400	>4 000	>1 200
Atrazine[1]	Herbicide	2.5–4.5	250–450	1 869–3 090	>3 100
Carbosulfan	Insecticide (granular formulation)	2–3	200–300	185	>2 000
Chlorpyrifos	Insecticide	0.72	72	135–163	>2 000
Clopyralid	Herbicide	0.1–0.2	10–20	2 675	>2 000
Cyanazine[1]	Herbicide	2–2.6	200–260	182–334	>1 200
Cycloxydim	Herbicide	0.45	45	5 000	>2 000
2,4-D	Herbicide	3.2–5.2	320–520	639–764	>1 600
2,4-D+ dicamba+ triclopyr	Herbicide	1.05–1.75	105–175	639–764[2]	>1 600[2]
Dichlobenil	Herbicide (granular formulation)	3.78–8.44	378–844	1 707	>2 000
Diflubenzuron	Insecticide	0.072	7.2	>4 640	>10 000
Diquat + paraquat	Herbicide	1.1	110	157[2]	235–500[2]
Fluazifop-p-butyl	Herbicide	0.13–0.38	13–38	>2 000	>2 000
Glufosinate ammonium	Herbicide	0.45–0.75	45–75	1 620	>4 000
Glyphosate	Herbicide	0.54–3.6	54–360	>5 010	>5 000

Table 2.1 Pesticide characteristics: Aluminium ammonium sulfate–Glyphosate (continued).

	Toxicity to mammals (rats): oral NOEL (mg kg^{-1} by diet or b.w. (duration))	Hazard classification of product formulations	Toxicity to invertebrates (bees) (LD_{50} µg per bee)	Hazard classification: potential risk to aquatic life	Selectivity	Activity	Potential volatiliser
	Unknown	**Not hazardous**	**Not toxic** (LD_{50} unknown)	**Not harmful**	Medium	Medium	No
	60 diet (90 days)	**Toxic** if swallowed **Harmful** in contact with skin **Irritating** to skin and respiratory system **Risk of serious damage to eyes**[3]	**Not toxic**[7] 0.059	**Very toxic** **Dangerous** for the environment	Low	Medium	No
	Unknown	**Very toxic** by inhalation, skin contact or if swallowed	Unknown	**Dangerous**	Low	High	Yes
	10 000 diet (105 days)	**Not hazardous**	**Not toxic** (LD_{50} unknown)	**Harmful**	Low	Low	No
	400 diet (90 days)	**Not hazardous**	**Not toxic** <2% w/v	**Not harmful** *	High	Medium	No
	10 diet (2 years)	**Not hazardous**	**Not toxic** 97	**Harmful**	Medium	Medium	No
	20 diet (2 years)	**Harmful**[4,5] if swallowed	**Dangerous**[8] (LD_{50} unknown)	**Dangerous**	Low	Medium	No
	0.03 b.w. (2 years)	**Harmful**[5] if swallowed **Harmful** in contact with skin (except Alpha Chlorpryifos which is a **Skin sensitiser**) **Irritating** to skin	**Dangerous**[8] 0.59	**Extremely dangerous** (except Barclay Clinch II: **Dangerous**)	Low	High	No
	15 b.w. (2 years)	**Not hazardous**	**Not toxic** >100	**Not harmful**	High	High	No
	12 diet (2 years)	**Harmful** if swallowed or in contact with skin	**Not toxic** >190	**Harmful**	Medium	Medium	No
	7 b.w. (18 months)	**Irritating** to eyes or skin	**Not toxic** >150	**Toxic** **Dangerous** for the environment	High	High	No
	5 b.w. (2 years)	**Harmful** if swallowed or skin contact **Irritating** to eyes and skin **Skin sensitiser** (except Easel, not an **Irritant** or **Sensitiser**)	**Not toxic** 104.5	**Harmful** *	Medium	Medium	Yes
	3 b.w. (2 years)[2]	**Harmful** if swallowed. **Irritating** to eyes and skin	**Not toxic** >100	**Dangerous**	Medium	Medium	Yes
	50 diet (2 years)	**Not hazardous**	**Not toxic** >100	**Harmful** *	Low	Medium	Yes
	40 diet (2 years)	**Not hazardous**	**Not toxic** >100	**Not harmful**	Medium	High	No
	0.25 b.w. (2 years)[2]	**Toxic** if swallowed **Harmful** in contact with skin **Irritating** to eyes and skin[6]	**Not toxic** (LD_{50} unknown)	**Not harmful**	Low	Medium	No
	10 diet (2 years)	**Irritating** to skin	**Not toxic** >200	**Very toxic** (Fusilade 250, **Toxic**) **Dangerous** for the environment	High	High	No
	2 b.w. (2 years)	**Harmful** if swallowed or in contact with skin **Irritating** to eyes	**Not toxic** >100	**Harmful**	Low	High	No
	410 diet (2 years)	Barclay Barbarian, Barclay Gallup 360, Buggy SG: **Risk of serious damage to eyes** Roundup Pro Biactive, Envision, Tumbleweed Pro, Barclay Gallup Biograde, Barclay Gallup Biograde Amenity, Barclay Gallup Hi-Aktiv, Glyfos, Glyfos Gold, Glyfos Pro Active, Greenaway Gly-490, Hilite, Habitat, Kernel, Manifest, MSS Glyfield, Roundup Greenscape: **Not hazardous** Glyper: **Skin sensitiser** All other formulations: **Irritating to eyes and skin**	**Not toxic** >100	**Harmful** (except Roundup Pro Biactive, Envision, **Not harmful**) * (except Barclay Gallup, Cardel Glyphosate 360, Greencrop Gypsy, Hilite, Reliance, Stirrup)	Low	Medium	No

Table 2.1 Pesticide characteristics: Isoxaben–Ziram

Pesticide	Mode of action	Rate applied active ingredient (kg ha^{-1})	Rate applied active ingredient (mg m^{-2})	Toxicity to mammals (rats): oral (LD_{50}, mg kg^{-1})	Toxicity to mammals (rats): contact (LD_{50}, mg kg^{-1})
Isoxaben	Herbicide	0.25	25	>10 000	>2000
Lenacil	Herbicide	1.76	176	>11 000	>5000
Metamitron	Herbicide	3.5	350	1 200	>4000
Metazachlor	Herbicide	1.25	125	2 150	>6810
Napropamide	Herbicide	0.95–4.1	95–410	4 680	>2000
Oxadiazon	Herbicide	1–2	100–200	>5 000	>2000
Paraquat	Herbicide	1.1	110	157	235–500
Pendimethalin	Herbicide	2.0	200	1 050	>5000
Phlebiopsis gigantea	Biofungicide	<0.01	4 000 000 spores m^{-2} (<1mg)	Unknown (but fungus is classed as edible)	Unknown
Propaquizafop	Herbicide	0.07–0.15	7–15	>5 000	>2000
Propyzamide	Herbicide (granular and liquid formulation)	1.5	150	5 620	>3160
Simazine[9]	Herbicide	1.5	150	>5 000	>2000
Triclopyr	Herbicide	0.96–3.84	96–384	577	>2000
Urea	Fungicide	6–24	600–2 400	>5 000	Unknown
Warfarin	Rodenticide	0.0008	0.08	186 (1 mg kg^{-1} for 5 days)	Unknown
Ziram	Mammalian repellent	6.4–52	640–5 200	320 (repellent)	>2000

This table contains information on all pesticides approved for use in forestry situations at the time of writing. However, it is always advisable to check product labels for the most up to date information on current approval status.

[1]Likely to be withdrawn by the end of 2007 following the EU review of pesticides.
[2]Of the most toxic component.
[3]The Electrodyn formulation, Alpha C 6ED, used only in nurseries, is **Harmful** by inhalation or if swallowed, a **Skin sensitiser**, **Very toxic** to aquatic organisms and **Dangerous** for the environment.
[4]Dangerous to wild animals – bury spillages (see product label). Used as a buried tablet which has low risk to wild animals and bees.
[5]An anticholinesterase compound which may be dangerous to some users.
[6]A poison: can kill if swallowed; 24 hour withholding period for livestock.
[7]Although the active ingredient is clearly toxic to invertebrates, the formulation is not judged to be dangerous to bees when used as directed.
[8]Dangerous to bees – do not apply when flowering vegetation present.
[9]Likely to be withdrawn by the end of 2004 for forest use, 2007 for nursery use, following the EU review of pesticides.
[10]Although warfarin itself is clearly toxic to mammals, the product as formulated is not classified as hazardous due to the large quantities that would need to be consumed to have a toxic effect.

Table 2.1 Pesticide characteristics: Isoxaben–Ziram (continued).

	Toxicity to mammals (rats): oral NOEL (mg kg^{-1} by diet or b.w. (duration))	Hazard classification formulation	Toxicity to invertebrates (bees) (LD_{50} µg per bee)	Hazard classification: potential risk to aquatic life	Selectivity	Activity	Potential volatiliser
	5.6 b.w. (2 years)	**Not hazardous**	**Not toxic** >100	**Not harmful**	Medium	High	No
	No effects, dose unknown (2 years)	**Irritating** to eyes, skin, respiratory systems	**Not toxic** >25	**Harmful**	Medium	Medium	No
	250 diet (2 years)	**Harmful** if swallowed	**Not toxic** (LD_{50} unknown)	**Not harmful**	Medium	Medium	No
	3.6 b.w. (unknown)	**Harmful** if swallowed **Irritating** to skin	**Not toxic** (up to 3.6% solution)	**Very toxic** **Dangerous** for the environment	Medium	Medium	No
	30 b.w. (2 years)	**Not hazardous**	**Not toxic** 120	**Harmful**	Medium	Medium	No
	10 diet (2 years)	**Irritating** to eyes and skin	**Not toxic** >400	**Dangerous**	Medium	Medium	No
	170 diet (2 years)	**Toxic** if swallowed **Harmful** in contact with skin **Irritating** to eyes and skin[6]	**Not toxic** (LD_{50} unknown)	**Not harmful** (except Dextrone X: **Harmful**)	Low	Medium	No
	100 diet (2 years)	**Not hazardous**	**Not toxic** >50	**Very toxic** **Dangerous** for the environment	Medium	Medium	No
	Unknown	**Not hazardous**	Unknown (but assumed to be **Not toxic**, as a natural part of ecosystem)	**Not harmful**	High	High	No
	1.5 b.w. (2 years)	**Irritating** to eyes and skin	**Not toxic** >20	**Harmful**	High	High	No
	200 diet (unknown)	**Not hazardous**	**Not toxic** >100	**Not harmful**	Medium	Medium	No
	0.5 b.w. (2 years)	**Not hazardous**	**Not toxic** >99	**Dangerous**	Medium	Medium	No
	3 b.w. (2 years)	**Harmful** if swallowed or in contact with skin **Irritating** to eyes and skin **Skin sensitiser**	**Not toxic** >100	**Dangerous**	Medium	Medium	Yes
	Unknown	**Not hazardous**	Unknown	**Not harmful**	High	Low	No
	Unknown	**Not hazardous**[10]	Unknown	**Not harmful**	Low	High	No
	5 b.w. (1 year)	**Irritating** to eyes, skin and respiratory system	**Not toxic** >100	**Harmful**	Medium	Low	No

The term Unknown as used in the table indicates characteristics for which information is unavailable.
Products approved for use in or near water are marked with '*'.
Further information on pesticide characteristics can be found in Tomlin (2003).

Table 2.2 Adjuvant and additive characteristics.

Adjuvant product name	Composition	Rate applied, % of product per final spray volume	Pesticides commonly used with adjuvant	Toxicity to mammals (rats) oral LD_{50}, mg kg^{-1}	Toxicity to mammals (rats) contact LD_{50}, mg kg^{-1}	Hazard classification formulation	Toxicity to invertebrates (bees) LD_{50} µg per bee	Hazard classification – potential risk to aquatic life
Partna	Surfactant/ mineral oil blend	0.5%	Fluazifop-p-butyl (Fusilade)	>2000	>2000	**Irritating** to eyes and skin	Unknown LD_{50} but mineral oils can kill over-wintering insect eggs	**Harmful**
Actipron	97% refined mineral oil plus additives	0.8%	Cycloxydim (Laser)	>4300	Unknown	**Not hazardous**	Unknown LD_{50} but mineral oils can kill over-wintering insect eggs	**Not harmful**
Mixture B	50% nonyl phenol ethylene oxide condensate +50% primary alcohol ethylene oxide condensate	2%	Glyphosate Triclopyr	Unknown	Unknown	**Harmful** if swallowed or in contact with skin. **Irritating** to eyes and skin	Unknown LD_{50}	**Harmful**
Dysol Turquoise ANX 50	50% Erioglaucine – Colour Index Acid Blue 9, CI 42090	2% for herbicides, 0.02% for urea	Urea, or dilute herbicide sprays	>2000	Unknown	As a dye marker, not subject to pesticide or adjuvant legislation. Acid Blue 9 is an approved food and cosmetic additive, and as such is effectively **Not hazardous**.		

Explanation of pesticide characteristics

Tables 2.1 and 2.2 provide information on all pesticides approved for use in forest situations at the time of writing. Information in the tables is intended only as a guide for comparison. **The key source of information on environmental safety is the product label.** The information in these tables is not intended as an endorsement or approval of any product or service to the exclusion of others that may be available.

Rate applied

These columns give an idea of the rates of active ingredient applied per hectare and per square metre. Actual amounts applied may be considerably lower as an entire hectare is rarely treated. Highly active pesticides require less active ingredient to be applied hence potentially reducing environmental impacts.

Toxicity to mammals

LD_{50} is a statistical estimate of the amount of active ingredient required (in mg, i.e. 0.001 g) per kg of animal bodyweight to kill 50% of the test population (usually rats, *Rattus* sp.). Rates are quoted as a standard toxicological measure, and are expressed in two ways; oral – the amount that would need to be consumed to be toxic; and contact – the amount that would be required to be in contact with skin to be toxic.

To set these measures in some sort of context, it may be helpful to consider the oral LD_{50} of some naturally occurring and synthesised chemicals that are familiar to most people:

Retrorsine (found in ragwort, *Senecio jacobaea*, 0.4% dry weight)	35 mg kg^{-1}
Nicotine	50 mg kg^{-1}
Caffeine (100–500 mg per cup of coffee)	192 mg kg^{-1}
Aspirin	200 mg kg^{-1}
Vitamin B2 (riboflavine)	365 mg kg^{-1}
Paracetamol	2 400 mg kg^{-1}
Vitamin A	4 760 mg kg^{-1}
Sucrose (cane sugar)	29 700 mg kg^{-1}

The LD_{50} for pesticides refers to active ingredients only and does not refer to the product as a whole. A more realistic measure of toxicity is that of the formulation used. A disadvantage of LD_{50} tests is that by definition they kill 50% of the test animals, and also provide little information on the health of the remaining population. An alternative toxicity test is the 'no observable effect level' (NOEL). This measures the highest dose at which no significant increase in the severity or frequency of an effect on the test animal is observed. Values given in Table 2.1 are for the quantity in milligrams (mg) of active ingredient that needs to be consumed per kilogram (kg) of rat bodyweight (b.w.) or of rat diet, to have a measurable effect.

Hazard classification: formulation

This is probably the most useful measure of toxicity of a pesticide as it takes the preceding information on rates applied and LD_{50}, as well as additional information on toxicology **as it applies to the pesticide formulation** (active ingredients, surfactants and carriers), to give a simple hazard rating. Table 2.1 identifies where an ingredient has different formulations with different hazard classifications. There are few such cases among forestry pesticides.

The hazard rating is a European Union system, essentially the same as that of the World Health Organisation (WHO): see Table 2.3. It gives a measure of the acute risk to health that might be encountered accidentally by any person using the product. Classification is based upon acute oral LD_{50} to the rat, unless a contact LD_{50} gives a higher hazard. Cumulative or irreversible effects result in a higher hazard rating. Hazard classifications are assigned by the UK Pesticides Safety Directorate (PSD). Where no hazard classification is required on the product label, Tables 2.1 and 2.2 refer to these products as 'not hazardous'.

Table 2.3 Hazard classification: formulation.

PSD classification	Equivalent WHO classification[a]	Oral LD_{50} solids mg kg^{-1}	Oral LD_{50} liquids mg kg^{-1}	Contact LD_{50} solids mg kg^{-1}	Contact LD_{50} liquids mg kg^{-1}
Very toxic	Extremely hazardous	≤5	≤25	≤10	≤50
Toxic	Highly hazardous	5–50	25–200	10–100	50–400
Harmful	Moderately hazardous	50–500	200–2000	100–1000	400–4000
No hazard classification required, referred to in this guide as 'not hazardous'	Slightly hazardous	>500	>2000	>1000	>4000
	Negligible hazard	>2000	> 3000	–	–

[a]The full wording of the World Health Organisation (WHO) classification is as follows: '*The WHO classification is open ended but it is clear that there must be a point at which the acute hazard posed by use of these compounds is so low as to be negligible provided that the precautions are taken that should be used in dealing with any chemical…….it has been assumed that this point is an oral LD_{50} of 2000 mg kg^{-1} for solids and 3000 mg kg^{-1} for liquids.*'

Products are further classed as:

- corrosive if they cause severe burns with less than 3 minutes exposure;
- irritant if they cause inflammation which is present for more than 24 hours;
- sensitisers if they can produce a sensitisation reaction.

The hazard rating also gives an indication of the potential hazard to humans or birds and mammals which may come into contact with the product after it is applied, by brushing against freshly treated foliage or soil. Pesticides are usually rapidly absorbed by the plant or soil. Granular products may take longer to be absorbed into the plant or soil, and therefore offer an increased risk of accidental consumption by wildlife, although the risk is very small. However, granular products are often easier and safer to apply for operators with less chance of accidental spillage or drift. Once products are applied and absorbed by the plant there is little risk of exposure unless the plant or soil is eaten. Herbicides are generally rapidly broken down either by the plant itself or by binding with the soil.

Toxicity to invertebrates (bees)

This provides a measure of the contact or ingested (whichever is lower) LD_{50} in µg per bee (*Apis mellifera*) (µg = 0.000001 g) of the pesticide active ingredient. This gives an indication of toxicity to other terrestrial invertebrates of direct contact with the product. Values of 100 µg or higher are usually classified as non-toxic. Pesticide **formulations** judged to be toxic by the Pesticides Safety Directorate are listed in Table 2.1 as 'dangerous'. Recent approvals granted by the Pesticides Safety Directorate have used a more sophisticated risk based assessment, and use the phrase 'high risk to bees'. Where no hazard classification is required on the product label, Table 2.1 refers to these products as 'not toxic'.

Information on potential toxicity to soil fauna is not presented here, but this hazard is included in the Pesticides Safety Directorate's assessment.

Toxicity to aquatic life

The PSD hazard classification is based on the acute toxicity of individual pesticide formulations to the most sensitive aquatic species; standard test species include rainbow trout (*Salmo gairdneri*), zooplankton such as daphnia (*Daphnia magna*), duckweed (*Lemna* sp.) and algae. Toxicity tests are based respectively on the concentration levels that for 50% of the test population are lethal, show effects, or in the latter two species show growth inhibition.

With the implementation of the Chemical Hazard Information and Packaging for Supply Regulations (CHIP 3), new risk phrases relating to aquatic habitats are being introduced. The target date for full implementation is July 2004, but up to that date it is likely that both old and new phrases will be used on product labels. The majority of the information in Table 2.1 refers to the old risk phrases, but the equivalent risk phrases using the newer system are given in Table 2.4.

In addition, if substances are not readily biodegradable, a warning about the potential for long term adverse effects on the aquatic environment can be added.

Although damage to aquatic habitats from the application of approved pesticides can usually be avoided through careful and correct usage, it is nevertheless recommended that when a choice of pesticide is available, preference should be given to selecting one with a lower hazard rating.

Table 2.4 Aquatic hazard classification.

Old aquatic classification	New (CHIP 3) aquatic classification	Lowest acute toxicity level for test species
Extremely dangerous	Very toxic. Dangerous to the environment	<0.01 mg l^{-1}
Dangerous	Very toxic. Dangerous to the environment	0.01 mg l^{-1}–1 mg l^{-1}
Harmful	Toxic. Dangerous to the environment	1 mg l^{-1}–10 mg l^{-1}
Harmful	Harmful	10 mg l^{-1}–100 mg l^{-1}
Not classified	Not classified	>100 mg l^{-1}

Selectivity

For the purpose of this guide, selectivity refers to the efficacy of the pesticide within its target biological kingdom. In other words, here selectivity for herbicides refers to their effect on plants, for insecticides their effect on invertebrates, for fungicides their effect on fungi and for rodenticides/repellents their effect on mammals. For effects on non-target kingdoms, e.g. the effect of herbicides on insects, refer to other sections of Table 2.1. Each pesticide has been categorised using the following criteria for the purposes of this guide:

Low Broad spectrum, most species affected if treated directly, e.g. glyphosate, a broad spectrum herbicide, controls nearly all plant species.

Medium Some species are tolerant if treated directly, e.g. 2,4-D controls only dichotomous species.

High Only a limited number of species controlled or damaged if treated directly. Usually limited to a few species within a family, e.g. clopyralid controls around 10–20 mainly Compositae species, while cycloxydim controls a similar number of grass species.

The measure of selectivity gives a quick guide of the likely effect from directly spraying the pesticide, such as the effect of a herbicide on directly treated vegetation. However, many plants in particular are tolerant of even broad spectrum products depending on rate, timing and method of application. Detailed information on efficacy of herbicides is contained in Forestry Commission Field Book 8: *The use of herbicides in the forest* (Willoughby and Dewar, 1995).

For herbicides, in many cases a carefully directed spray of a broad spectrum product will be the most effective option and will offer the least risk to non-target species (e.g. to insects, if herbicides are used). Nevertheless it is good practice to use more selective products where consistent with good silviculture, as this can help to minimise impact on the environment. The use of selective herbicides may offer less impact than some non-chemical methods that are not species specific. This becomes more important when particularly rare or valuable species are present.

For insecticides, fungicides and rodenticides/repellents the most selective product should always be chosen if possible, as usually only a single species is causing the problem.

Method of application can increase selectivity considerably. For example granular herbicides such as propyzamide or dichlobenil reduce the risk of drift. Mammalian poisons are applied in carefully controlled environments so that there is very little risk to non-target mammals.

Activity

Highly effective pesticides are not necessarily potentially more damaging to the environment than those which are less effective. When comparing pesticides *with the same* potential hazard to non-target organisms, the use of highly active pesticides can reduce the amount of artificial chemical that needs to be applied to a site. For the purposes of this guide, pesticides are split into the classes shown in Table 2.5. For a more detailed picture refer to the actual amount of active ingredient applied per hectare.

Table 2.5 Activity classes.

Rate of application (per treatment) of active ingredient	Activity
< 1 kg ha^{-1}	High
1–10 kg ha^{-1}	Medium
>10 kg ha^{-1}	Low

Volatility

In very hot weather some products can suffer from volatilisation – the rapid evaporation of a pesticide once applied. Such a process can result in a cloud of evaporated product forming in the near-ground atmosphere, which may drift and be deposited in adjacent areas. The major risk is therefore to adjacent non-target vegetation or aquatic areas. Oil soluble formulations are more prone to this phenomenon than water based formulations, but risk can be effectively eliminated by avoiding applications in very hot weather (say for example, above 25°C).

For the purposes of this guide, products are classed as either potential volatilisers (yes) or not (no). Formulations classified as having a risk of volatilisation on the product label are included, as well as rodenticide gassing agents and active ingredients with a vapour pressure of >5 mPa.

Persistence

There is no one simple measure for persistence of a pesticide, so this characteristic is not included in Tables 2.1 and 2.2. Factors such as formulation, soil type, presence of organic matter and solubility all effect breakdown rates. All forestry approved herbicides will break down, usually within one growing season.

In some cases, pesticides with a greater persistence may be preferable, as they require fewer repeat visits and fewer potentially dangerous operations to take place, reducing the risk of drift, spillage or overdosing. Again, the key measure is their effect on non-target organisms. For two pesticides *with the same level of risk* to non-target organisms, residual pesticides may sometimes be preferable. Persistence is probably most important in its effect on the potential for movement of pesticides in soil water.

References and useful sources of information

TOMLIN, C.D.S (2003).
The pesticide manual, 13th edn. British Crop Protection Council, Alton, Hampshire.

WHITEHEAD, R. (2004).
The UK pesticide guide 2004.
CABI Publishing, Wallingford, Oxon/British Crop Protection Council, Alton, Hampshire.

WILLOUGHBY, I. AND DEWAR, J. (1995).
The use of herbicides in the forest.
Forestry Commission Field Book 8.
HMSO, London.

2.2 Water and aquatic habitat protection

Pesticides can pollute water supplies and have serious effects on the aquatic environment. Before using pesticides anywhere in the catchment where they might get into water, particularly where large-scale applications are involved, it is recommended that there should be prior liaison with the water regulatory authority. In Scotland this is the Scottish Environment Protection Agency (SEPA), in England and Wales the Environment Agency. Legislation makes it an offence to cause or knowingly permit the entry of poisonous, noxious or polluting material into any streams, rivers, lakes, groundwaters, and estuaries and coastal waters to three nautical miles from the shore. Drinkable supplies are particularly at risk, with some pesticide products having the ability to give obnoxious tastes and odours at extremely low concentrations. Stringent standards are therefore set for the protection of drinking water. Water undertakers have a statutory duty to limit the concentration of any individual pesticide in drinking water supplies to less than 0.1 $\mu g\ l^{-1}$ (i.e. one part pesticide per ten billion parts of water) and the total pesticide content to less than 0.5 $\mu g\ l^{-1}$. No distinction is made between the type of product and so users of all pesticides must ensure against the contamination of surface and groundwaters used for public or private water supplies. Where applications are made to land in close proximity to watercourses or water bodies used for public water consumption, the user should notify the relevant water undertaker (supply company) in England and Wales and SEPA in Scotland.

The main threat to non-drinkable waters is the risk of a pesticide damaging freshwater life. Some pesticides are extremely toxic to fish, invertebrates and aquatic plants and can be lethal at concentrations as low as 1.0 $\mu g\ l^{-1}$. Others, however, are much less toxic and may be approved for use in or near water to control weed growth or bank side vegetation. Applications of these products are strictly controlled and there is a legal requirement for prior consultation and agreement with the water regulatory authority or water undertaker. It is important to note that some adjuvants can also be harmful to aquatic life, such as Mixture B, and must not be applied in or near water. In the above context, ‘near’ generally means the banks of watercourses or lakes.

Risk of contamination

The timing and method of application, mobility of individual pesticides, careless disposal and accidental spillage largely determine the risk of contamination.

Timing

Timing is crucial in respect of the propensity of the weather and soil conditions to cause the drift or direct wash-off of the applied chemical to the nearest watercourse or to depth via cracks within the soil. This risk can be minimised by avoiding applications during very wet weather or when heavy rainfall is forecast, not using sprays during windy conditions (anything stronger than a light breeze, Force 2 on the Beaufort Scale, 3.2–6.5 km h^{-1}), and not treating ground that is waterlogged, frozen, snow-covered or baked dry after drought.

Method of application

Method of application determines the risk of pesticide drift away from the target site and is greatest for aerial treatments. The latter are strictly controlled and consultation with the water regulatory authority or water undertaker is a legal requirement under the Control of Pesticide Regulations 1986 and Control of Substances Hazardous to Health Regulations 1988 prior to any aerial application within 250 m of a watercourse. Consultation should take place at an early planning stage wherever possible, and legally must occur not less than 72 hours before an application begins. In addition, there may be a need to contact one or all of the following: the relevant authorities of Local, Marine and National Nature Reserves and Sites of Special Scientific

Interest, the Chief Environmental Health Officer, occupants or agents of nearby property, institutions such as schools and hospitals, and bee keepers.

Only asulam has full approval for aerial application, although it is seldom applied by this method (diflubenzuron has emergency specific off-label approval). Contamination of adjacent waters can be minimised by leaving broad, untreated buffer areas. These should be 160 m wide for conventional nozzles and 50 m for 'Raindrop' nozzles around permanent watercourses, lakes or boreholes/wells providing water supplies. A permanent watercourse is defined as an open drain that flows directly into a stream, or a stream or river that is delineated on a 1:10 000 Ordnance Survey map (note that drains that are separated from watercourses by a buffer area are excluded from this definition). The risk to non-drinkable supplies from aerial applications of both asulam and diflubenzuron is minimal due to their low toxicity (see below).

Non-aerial methods have a much lower risk of pesticide drift and therefore require narrower buffer widths. There is a legal requirement to leave a buffer zone of between 1 and 6 m width (depending on type of spray equipment, dose of application and width/status of the watercourse) for those pesticides that carry the greatest risk to aquatic life. The Forestry Commission has adopted a simpler approach to minimising the risk of contamination by recommending the use of a wider, standard buffer zone for all ground based pesticide applications, regardless of spraying technique or pesticide toxicity. Recommended widths are 10 m for permanent watercourses, 20 m for lakes and reservoirs and 50 m for boreholes or wells. Within these buffer zones it is recommended that applications are restricted to those pesticides approved for use in or near water by the UK Pesticides Safety Directorate. The only exception to this is the use of insecticide treated planting stock, which poses a minimal risk of water contamination provided the treated stock is dry and plants are not placed within watercourses. Since the most common method of application in forestry is the use of hand-held sprayers to provide spot treatments, these buffers provide a high level of protection for the freshwater environment. Nevertheless, for certain pesticides that are applied by ground crop sprayer there remains a legal obligation to carry out and record the results of a Local Environmental Risk Assessment for Pesticides (a LERAP).

Pesticide mobility

Pesticide mobility is a complicated issue, dependent on the physical and chemical characteristics of the individual product formulations and site conditions. Key pesticide characteristics are water solubility, soil adsorption and persistence (half-life). The mobility of individual products is evaluated during the approval process and reflected in the statutory conditions controlling their use. These are set out on the product label and must be complied with.

Another important pesticide characteristic that can influence off-site movement is volatility. Volatile pesticides can quickly evaporate when applied during hot and dry weather and then re-deposit downwind into adjacent watercourses. This risk is best minimised by not applying volatile pesticides when the air temperature exceeds 25°C.

Soil erosion also needs to be considered when assessing pesticide mobility. The movement in air or water of soil particles containing adsorbed pesticides provides a direct route for the contamination of watercourses. It is therefore very important that pesticides are not applied to actively eroding sites, e.g. where shallow gullies are present or the soil is subject to marked dust blow.

Careless disposal and accidental spillage

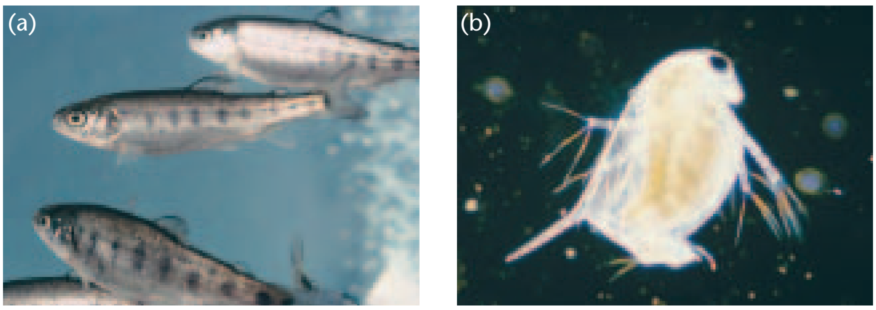
Other important sources of contamination arise from the careless disposal of surplus pesticide or waste material and accidental spillage. The safe disposal of surplus pesticide or waste material is paramount. Little unused dilute pesticide should remain after a well-planned application, but any such small amounts, including washings, may be applied to part of the treated area which has not received the full dose, onto untreated crops or onto non-crop land (subject to approval by the water regulatory authority, as required under the Groundwater Regulations 1998). Disposal onto non-crop land requires a waste disposal licence. Applications must avoid all permanent watercourses, and must not exceed the maximum application rate stated on the product label. Unopened surplus containers of pesticide concentrate should be offered back to the supplier. Any unopened concentrate not returned to the supplier is waste, and should be disposed of by prior arrangement with the local authority or by a licensed waste disposal contractor; this should also include any old or deteriorated concentrates, used concentrate containers, or solid waste, e.g. from the clean up of a spillage or spilled or unpalatable poison (warfarin) bait. Under the Environmental Protection Regulations 1992, users are required to obtain a controlled waste transfer note and retain this for a period of two years.

The impact of an accidental spillage can be minimised if a detailed contingency plan is available. This should establish clear lines of communication, ensure that there is adequate preparation for dealing with a spillage, and describe the emergency procedure to be followed on site in the event of an incident arising: the emergency action plan. The key elements of an effective action plan are **assessment, communication, containment and clear-up**.

Malicious damage can be another important cause of spillage. Sites of storage are most at risk and forest chemical stores must abide by the same stringent regulations that apply to other chemical stores. These must be secure, capable of containing spillage or leakage, and located away from watercourses. Containers of pesticide concentrate should also be secured in a lockable box or chemical safe during transport.

Pesticide toxicity

The degree of hazard or toxicity of an individual pesticide to the aquatic environment is an additional factor to be considered when planning applications to land draining to surface waters (see Table 2.1). The PSD hazard classification is based on the acute toxicity of individual pesticide formulations to the most sensitive aquatic species. Standard test species include rainbow trout (*Salmo gairdneri*), zooplankton such as daphnia (*Daphnia magna),* duckweed (*Lemna* sp.) and algae – see Table 2.4 (page 119) for hazard classifications. It is recommended that where a choice of pesticide is available, preference should be given to selecting one with a lower hazard rating.



Standard test species for pesticide toxicity testing: (a) rainbow trout and (b) daphnia.

Summary of specific measures to protect aquatic habitats

- Consult with, and obtain consent if necessary from, the water regulatory authority or water undertaker.

- Do not apply pesticides within 10 m of permanent watercourses, 20 m of lakes or reservoirs and 50 m of boreholes or wells. The only exceptions are products that are approved for use in or near water, or the use of planting stock pre-treated with insecticide at the nursery.

- Do not spray asulam or diflubenzuron from the air within 160 m horizontal distance of a permanent watercourse or a borehole/well when using conventional nozzles, or 50 m for ‘Raindrop’ nozzles.

- Do not apply pesticides during very wet weather or when very heavy rainfall is forecast. Some rainfall is required for residual herbicides to work effectively. Avoid applications to ground that is waterlogged, frozen, snow-covered or baked dry after drought.

- Wherever possible, restrict spray operations to periods with no more than a light breeze (Force 2 on the Beaufort Scale, 3.2–6.5 km h^{-1}) and when the wind direction is away from the adjacent watercourse.

- Do not apply volatile pesticides (Table 2.1) on sunny, warm days (e.g. >25ºC).

- Wherever possible, select a pesticide with a low hazard rating to aquatic life.

- Avoid pumped applications of aluminium phosphide to rabbit burrows within 25 m of main watercourses.

- Do not apply pesticides to actively eroding soils. Take corrective action to minimise further erosion and prevent sediment from entering streams, e.g. by installing silt traps.

- Never store or soak planting stock that has been treated with an insecticide in a watercourse prior to planting.

- Do not wash out sprayers, containers or the like near any watercourse, however small.

- Ensure that containers of pesticide concentrates are safely stored outside of the buffer area.

- Seek advice from the appropriate water or waste regulatory authority about the safe disposal of unwanted pesticides.

- Do not puncture, bury or burn empty containers or waste packaging and ensure they are disposed of by prior arrangement with the local authority or by a licensed waste disposal contractor, in line with Waste Regulations.

- Prepare a detailed contingency plan to deal with accidental spillage. The plan should include relevant phone numbers (water regulatory authority, downstream local landowners, water users, water undertaker, and accredited spill contractor) and record the availability of equipment (e.g. booms and absorbent sheets and/or pillows) to carry out remedial work in advance of the arrival of the water regulatory authority or accredited spill contractor.

A well-managed watercourse with buffer zones for environmental protection.

2.3 Protection of the public

Forest users

The Pesticides Safety Directorate assesses potential risk to the public from pesticide applications before any product approval is granted. As long as the instructions on the product label are followed, risk should be minimised. However, the following decision process is recommended as a means of further reducing any risk to forest users from pesticide applications in forestry situations. The level of potential risk will be affected by the type of forest user and the frequency with which they use the site as well as the toxicity profile of the pesticide used and its method of application.

1. Determine the potential risk

(a) Determine the potential for access to the work site and its margins. Consider if it contains or is adjacent to a formal recreation area such as a picnic site or a statutory right of way or permissive path. Consider if there is area-wide access (informal or through dedication) to the site.

(b) Determine the likely frequency of use of the site and its margins. This will affect the level and maintenance of controls that are required.

(c) Determine the nature of the potential users. Forest users may include visitors to recreation areas, permit holders, contractors, other staff etc. The nature of the user will affect the type of control measures required. For example, children may not be able to read signs stating the work site is closed, so barriers may need to be used instead.

2. Protection measures

(a) ***Exclude forest users***
In all cases, if practical and legally possible, it is preferable to totally exclude forest users from the work-site, or close the recreation site or footpath/right of way on the work-site margins. The method of exclusion, through barriers or signage, will depend on the type of user identified in step 1. The duration of exclusion will depend on the presence or absence of edible fruit or fungi.

(i) If edible fruit or fungi that are likely to be picked are present, close the site until the produce dies. Alternatively, treat the site at a time of year when no edible produce is present, or strim off the plants to prevent fruiting.
(ii) If no edible fruit or fungi are present, close the site for 48 hours after spraying, or until the pesticide dries and there is no liquid residue that might cause accidental contamination of the public.

(b) ***Establish a buffer zone***
If it is not practical to completely close the site or its margins to the public, establish a buffer zone between the public access and the work-site. Try to steer people away from the area where spraying is to take place by measures such as signage, providing alternative routes or temporarily closing car parks.

For hand-held sprayers, do not treat within 5 m of the public access or 10 m with tractor mounted sprayers. Buffer zones may need to be extended to 160 m for aerial spraying or 50 m for ‘Raindrop’ nozzles. Within the buffer zone, reconsider a non-chemical method of pest or weed control.

(c) ***Within the buffer zone***

In some circumstances, the level and type of public access may make establishing a buffer zone impractical. There may also be situations where there is no practical non-chemical alternative that can be used to control the pest or weed problem in the buffer zone. In these cases:

(i) Only use pesticides which the label indicates are 'Not hazardous' to operators.

(ii) Only use low or no drift systems, e.g. knapsack sprayers fitted with pressure control valves, dribble bars or direct applicators such as weed wipers.

(d) ***General measures***

At heavily used sites, consider whether it is possible to give advance notice of forest operations. Try to restrict spraying to quieter periods, mid-week or mid-winter for example, as far as the product allows. Ensure that contractors as well as directly employed staff are aware of the need to protect members of the public. If the only appropriate action is to stop spraying if someone is found to be in the area, contractors should be made aware of this.

3. Signage

Adequate signage is essential. It is recommended that the provisions outlined in the leaflet: *Managing public safety on harvesting sites* (FASTCo, undated) are followed. Erect threshold information signs in the proximity of the work site. Erect warning and prohibition signs at the start of the buffer zone. Erect further prohibition signs/barriers at the start of the work zone. Signs should remain in place for 48 hours or until pesticide is dry where no edible fruit/fungi is present, or if edible fruit/fungi is present, until it dies.

Neighbours

Residential dwellings adjacent to the work-site are highly sensitive. An unsprayed buffer zone should always be established around the property. For hand-held sprayers, establish a 10 m buffer zone, or 20 m for tractor mounted sprayers. Buffer zones may need to be extended to 160 m for aerial spraying, or 50 m for 'Raindrop' nozzles. Early communication with neighbours is important.

The presence of neighbouring organic farms can also be a highly sensitive situation. It would be prudent to initiate early communication and if necessary to apply buffer zones as above.

Reference

FASTCo (undated).
Managing public safety on harvesting sites.
FASTCo, Edinburgh.

Available from: 0131 334 0303.
Revised leaflet is to be issued by the
Arboricultural and Forestry Advisory Group,
and will be available from the Health and
Safety Executive: www.hsebooks.com/books

2.4 Application technology

In addition to specific characteristics of individual pesticides, the method of application and the type of application equipment chosen are of key importance. After selecting a pesticide, consideration must be given to its safe application. The objective of spraying is to apply any given herbicide, fungicide or insecticide at the recommended dose rate, safely and effectively, ensuring that the specified target is adequately covered while minimising wastage and drift.

To be effective and to minimise environmental impact, any applicator, whether hand-held or mounted on a tractor or all terrain vehicle, will have to be correctly calibrated and adjusted. To do this forward speed, volume rate, nozzle type, output and spray quality, and nozzle height above the target vegetation must be selected carefully. All of these calibration parameters are at the control of the operator. Suitable training and certification, as well as adequate equipment maintenance, are essential elements of effective and safe spraying operations.

Types of applicator

- *Granule based applicators* are easy to calibrate, have a very low risk of drift and produce little waste. However, there is a limited choice of pesticides.

- *Direct applicators* are usually wick based. Pesticide is applied directly to the target so there is very low risk of drift and calibration is simple. Pesticide choice is limited and wick based applicators are not suitable for all vegetation types. They are slow and expensive. Accurate calibration can be difficult as it is reliant on how much pesticide is 'wiped onto' target vegetation, and application can be difficult and time consuming. Mechanical roller systems are cheaper, but are only suitable when the target is at a different height from crop.

- *Hydraulic applicators* are available in a wide range of designs which utilise many different nozzle types and pressure settings. There is a high probability of being able to select a sprayer that can deliver the correct pesticide whilst minimising the operator and environmental impacts. However, hydraulic sprayers can be difficult to calibrate and can introduce risk of spray drift.

- *Rotary atomisers* require only low volumes of diluent, hence the applicators are generally light and easy to handle. The electric power source requires careful maintenance to ensure accuracy and reliability. They produce a small droplet size with a risk of drift.

- *Air-assisted fluid based delivery applicators*, e.g. Airtec, result in lower drift than conventional hydraulic nozzles, while still giving good vegetation coverage. Penetration of thick vegetation is possible with reduced volume rates due to the air-assisted delivery.

- *Electrostatic sprayers* offer reduced risk of drift as droplets are attracted to the target. Small droplets are possible giving good overall coverage with reduced risk of drift.

Forward speed

A constant speed is required to avoid local overdosing. Forward speed on tractors can be controlled by setting engine revs in an appropriate gear, or through the use of computer controlled systems which can alter nozzle output as the speed changes. With hand-held equipment, forward speed is the most variable parameter as it is affected by changes in ground conditions. The use of an automated pacer system, carried by the operator, that provides audible bleeps can help regulate progress over the work-site. The terrain and site conditions will be the limiting factor for forward speed. The operator should choose a speed that can be maintained during the working day and adjust other calibration factors accordingly.

Volume rate

The choice of the correct volume rate is essential to minimise environmental impact. Correct volume rate will vary depending on the product chosen and application type. They are usually expressed as a range of possible volume rates on the product label, and in general soil acting residual herbicides require higher volume rate than foliar acting products. The final choice will depend on the spray quality required to apply the pesticide in the specified manner to the target. Generally high volume rates should be avoided to minimise run-off. However, very low volume rates can cause problems of drift even with light wind speeds.

Hydraulic spray nozzles

Hydraulic sprayers generally offer the widest choice of nozzle types. For other applicator types, little choice may be available. Hence, for hydraulic sprayers, selection of the appropriate nozzle to give the required output and pattern – based upon volume rate, pressure and forward speed – is essential.

Nozzles designed to provide low drift qualities should be chosen wherever possible. Nozzle outputs should be as coarse as practicable, matched to target vegetation while minimising the problems of bounce or roll-off. In general, larger nozzles produce larger droplet sizes, that are less liable to drift. Larger nozzles are preferable for applications of soil acting residual herbicides. However, for applications to foliage, large droplets are not desirable as they tend to bounce off rather than cover the leaves. If the nozzle is too coarse for foliar applications, too few droplets will actually cover the target, even though the volume rate may be correct. For foliar applications nozzles producing smaller droplets are required, although care must be taken as risk of drift increases.

Care and maintenance of nozzle tips is essential as even the slightest damage can affect spray quality, volume and placement. The use of dye markers can be particularly helpful in highlighting application to target species but also to assess spray quality, drift or damage to nozzles.

Nozzle types and suitability

Flat Fan nozzles are hydraulic nozzles for tractor mounted sprayers only. This is the most common nozzle in use and is available in a wide range of outputs and droplet sizes. Coarser nozzles should be selected for soil acting herbicides. Medium to fine nozzles should be used for foliar acting products. Flat fan nozzles are usually manufactured to produce a spray angle of 80º or 110º. The latter should be preferred as it allows the boom to be set at a lower position. However care must be taken as the droplet size is smaller.

Anvil nozzles (Floodjet) are usually used with hand-held hydraulic applicators. They can operate at low pressures and generally they give a coarse spray with low drift. A wide range are available, so it is possible to choose those appropriate for soil (larger, coarser droplets) or foliar (smaller, finer droplets) applications.

Anvil nozzles (Very Low Volume) are usually used with hand-held hydraulic applicators. They utilise smaller droplet sizes in order to reduce the volume rate. This decreases the amount of diluent required, which is an important practical consideration for herbicide application in forestry situations where sources of water can be very distant. However, the smaller the droplet size the greater the risk of drift. Very low volume applications are only appropriate for foliar treatment.

Hollow Cone nozzles are most commonly used for the application of insecticides and fungicides. Operating pressures are higher and droplet sizes small to ensure good coverage and increase the chance of hitting the target. Drift can be a problem and care needs to be exercised to ensure that only target areas are treated.

Solid Cone nozzles are primarily used for spot application in applicators such as the Forestry Spot Gun. They produce a wide range of droplet sizes so care is required to ensure that smaller droplets do not drift.

Low Pressure nozzles are a type of flat fan nozzle operating at low pressures. They produce a coarse low drift spray, which may be useful for the application of soil acting herbicides using a Dribble Bar. They offer very low risk of drift and low potential for soil run-off as medium volume rates are used.

Boom/nozzle height

To ensure accurate placement at the required volume rate it is essential to maintain an accurate height above the target vegetation. For tractor mounted sprayers the use of gimbal mounted boom systems that provide good flotation of the boom over rough terrain help produce an even application. For hand-held applications, a height should be selected that is comfortable for the operator to maintain during the working day. This can be maintained by the use of simple measuring systems attached to the lance of the sprayer, such as a lightweight chain.

Weather

Weather is not under the control of the operator, but the decision of whether to spray or not is. Spraying should be avoided in very hot weather (e.g. >25 ºC to reduce risk of volatilisation of certain pesticides), or in windy conditions (do not spray at wind speeds of >9.7 km h^{-1} or 6 mph to avoid drift [Beaufort scale description – leaves rustling]) or during heavy rainfall or to waterlogged, snow-covered, frozen or very dry ground (to avoid run-off).

Safety considerations

Before making applications a risk assessment must take place (HSC, 1995), and a formal written assessment made under the Control of Substances Hazardous to Health regulations (HSC, 1995). Product label conditions of use must be followed, work practices follow the relevant Code of Practice (HSC, 1995), and work equipment must comply with the requirements of the Provision and Use of Work Equipment Regulations (1998). Crucially, users must be adequately trained and possess a recognised Certificate of Competence. Training will highlight formal safety legislative requirements, as well as raising awareness of the importance of correct choice of pesticides and application methods. Training will also highlight the choices available to operators taking into account pesticide minimisation and the effect on the environment.

Reference

HSC (1995).
The safe use of pesticides for non-agricultural purposes.
HSC Books.

2.5 Pesticide use checklist

Use this checklist along with the Decision recording sheet, Part 2 of this guide and product labels. Full references are given on pages 7–8.

Preparing

- If not already done, select a suitable (see product labels and Willoughby and Dewar, 1995):
  - Pesticide application rate
  - Applicator
  - Application method and timing
  - Volume rate
  - Walking/forward speed
  - Swathe width/boom height
  - Droplet size, nozzle type and delivery pressure to achieve the above variables
  - Dilution rate

- If ground crop sprayers are used, i.e. mechanised sprayers, make a local environmental risk assessment (LERAP) and record the results (see MAFF, 1999).
- Consult with relevant authorities as necessary.
- Make a Control of Substances Hazardous to Health (COSHH) assessment on the chosen pesticide (see HSC, 1995; HSE, 1991).
- Make a risk assessment for the operation ensuring that correct training, safety procedures and protective clothing are available to operators (see HSC, 1995).
- If necessary, re-consider the choice of pesticide and application technique.
- Check the weather forecast for the proposed day of treatment. If it is unsuitable, postpone the operation. Ensure an emergency strategy exists for dealing with accidental spillage and pollution, and that containment materials are readily available (see SEPA, 2002; Dewar, 1993).

Applying

- Check wind and weather conditions for suitability of spraying.
- Erect warning signs and notify all relevant authorities (see HSC, 1995).
- Calibrate the equipment to achieve the correct application rate (see Willoughby and Dewar, 1995).
- Mix the appropriate amount of pesticide that is sufficient for the day's work.

  Particular care must be taken when handling undiluted pesticide as spillages at this stage present probably the greatest potential for environmental damage.

- Dispose of washings and unused chemical correctly (see HSC, 1995; FC, 2003). Seek authorisation from the water regulatory authority as necessary.
- Arrange for safe storage/return of unwanted pesticide.
- Remove warning signs once chemical is dry and there is no further risk of contamination to the public, or where edible fruit is treated, once vegetation has died or fruit has dropped.

Recording

- Briefly record where, when and at what rate the pesticide was used, who applied it and prevailing weather conditions at the time. Note the results of the LERAP if appropriate (see HSC, 1995; UKWAS, 2000; MAFF, 1999; FC, 2003).
- Record any disposals or spillage (and action taken).
- Archive this information along with the decision recording sheet which notes why the chemical or non-chemical method was chosen, so it can be referred to at a later date.

Appendix 1

An introduction to the regulatory framework governing pesticide use

The principal aim of UK pesticide policy is to protect the health of humans, wildlife and plants and to safeguard the environment.

Before they can be used in the UK, new pesticides must be evaluated by one of three government agencies: the Pesticides Safety Directorate, the Veterinary Medicines Directorate or the Health and Safety Directorate. Applications for approval must show that products pose no unacceptable risk to humans, non-target species or the wider environment, as well as being effective for the purpose they are intended. The data package submitted to the appropriate agency must include physical and chemical properties, mammalian toxicology, environmental fate and behaviour, ecotoxicology, plant metabolism, residue chemistry, efficacy and information on potential exposure to users and consumers. The data are evaluated by agency scientists who make a recommendation to the Advisory Committee on Pesticides, an independent body of scientific experts. The Advisory Committee on Pesticides make their own recommendations on acceptability, and the final decisions on a pesticide's approval is taken jointly by the Ministers for the Department of Environment Food and Rural Affairs, Department of Health, Scottish Executive Environment and Rural Affairs Department and the National Assembly for Wales Agriculture Department.

If a product is approved, it must carry a label giving the statutory conditions of use and key guidance on minimising risks to operators and the environment.

Domestic legislation throughout the European Union will increasingly become harmonised as the European Plant Protection Products Directive (91/414/EC) is implemented. This process involves the review of all active ingredients used for plant protection to ensure their safety to the environment and to users. Materials that do not meet the criteria of the Directive will be withdrawn from use.

All those involved in the use, sale or storage of pesticides in forestry must be trained and certificated to ensure that they are aware of the regulatory framework and best practice. Potential users **must read and follow the product label** and should be aware of the general provisions in the following:

- *Code of practice for the safe use of pesticides on farms and holdings. The Green Code* (MAFF, 1998).
- *The safe use of pesticides for non-agricultural purposes. Approved Code of Practice* (HSC, 1995).

Reference to the following is also recommended:

- Forestry Commission Field Book 8: *The use of herbicides in the forest* (Willoughby and Dewar, 1995).
- *Using pesticides – a complete guide to safe effective spraying* (British Crop Protection Council, 1999).

More details on the regulatory framework affecting pesticide use can be obtained from www.pesticides.gov.uk

Appendix 2

Conservation designations affecting pesticide use

Several conservation designations exist that can affect the use of pesticides. These are usually best considered as part of the medium term management plan/forest design planning process, before making detailed decisions on forest operations.

1. Is the woodland a Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC), National Nature Reserve (NNR) or other designation which might have implications for pesticide use (i.e. as a Potentially Damaging Operation)?

For Forest Enterprise, refer to the Forester GIS for information on conservation designations. For the private sector, refer to your regional office for English Nature (EN), Scottish Natural Heritage (SNH), or Countryside Council for Wales (CCW). If an SSSI, refer to designation details for information concerning Potentially Damaging Operations as these may prohibit the use of certain pesticides. This can be done by contacting the regional office for EN, SNH, CCW, as appropriate.

2. Is the woodland type subject to a Habitat Action Plan (HAP)?

HAPs exist for upland oak woods, native pinewoods, lowland wood pasture and parkland, wet woodlands, upland mixed ash woods, lowland beech and yew woodlands and are in preparation for northern birch woods and lowland mixed broadleaved woods. HAPs contain information on:

- Current status
- Current factors affecting the habitat
- Current action (legal status; management, research and guidance)
- Action Plan objectives and proposed targets (restoration and expansion)
- Proposed action with lead agencies
- Future research and monitoring, communication and publicity

Refer to the *UK Biodiversity Group Action Plans* for latest information on HAPs (definitions are also provided by Forestry Commission Practice Guides on *The management of semi-natural woodlands*), or access the relevant www sites: www.jncc.gov.uk, www.ccw.gov.uk, www.english-nature.org.uk, www.snh.org.uk

Before using pesticides, or carrying out any forest planning or operations, managers should take account of these guidelines and take steps to protect and enhance the habitat.

3. Does the woodland provide potential or known habitat for Biodiversity Action Plan (BAP) species?

Refer to the websites listed in point 2, plus the *UK Biodiversity Group Action Plans* for latest information on BAPs. Action Plans contain information to identify threats to the species, plus habitat requirements and how management can protect and enhance populations.

Before using pesticides, or carrying out any forest planning or operations, managers should take account of these plans and take steps to protect and enhance the populations of these species.

Appendix 3

Worked examples of the decision recording sheet

Decision recording sheet

Completed by: *T. Reid* Date: *12/06/03*

Site name: .... Compartment name/no.: *3218*

STAGE 1: use Core decision key

What is the problem and what are the likely consequences if the problem is not addressed?

Invasion of sitka spruce stand by birch and rowan. Invading broadleaves form about 5% of crop. Possibility of some leader damage to conifers.

Which control option is most suitable?

TAKE NO ACTION	✓
AVOID THE PROBLEM	
TAKE REMEDIAL ACTION	

Continue to next step

Tick as appropriate and note reason for choice.

Pole stage crop – further invasions unlikely as canopy closed. Broadleaves add diversity to timber crop. Do nothing at present but monitor carefully.

Which remedial action is most suitable?

Non-chemical method	
Chemical method	

Continue to Stage 2

Tick as appropriate and note reason for choice. Record why a non-chemical method is unsuitable.

STAGE 2: use Pesticide decision key

Which chemical method is most suitable?

Note reason for choice.

If no suitable pesticide can be identified, a non-chemical method may need to be reconsidered.

Archive this sheet in a safe place for future reference.

Appendix 3 (continued)

Worked examples of the decision recording sheet

Decision recording sheet

Completed by: L. Martin Date: 12/06/03

Site name: Kings Wood Compartment name/no.:

STAGE 1: use Core decision key

What is the problem and what are the likely consequences if the problem is not addressed?

Likely profuse invasion of grass after overstorey beech is felled. Severe moisture competition with newly planted trees. Death and growth suppression of trees.

Which control option is most suitable?

TAKE NO ACTION	AVOID THE PROBLEM	TAKE REMEDIAL ACTION
	✓	
		Continue to next step

Tick as appropriate and note reason for choice.

Windfirm site, freely draining low fertility soil. Good existing overstorey of beech worth attempting to manage on continuous cover system. Monitor carefully - future weed control may be necessary as canopy is progressively thinned.

Which remedial action is most suitable?

Non-chemical method	Chemical method
	Continue to Stage 2

Tick as appropriate and note reason for choice. Record why a non-chemical method is unsuitable.

STAGE 2: use Pesticide decision key

Which chemical method is most suitable?

Note reason for choice.

If no suitable pesticide can be identified, a non-chemical method may need to be reconsidered.

Archive this sheet in a safe place for future reference.

Appendix 3 (continued)

Worked examples of the decision recording sheet

Decision recording sheet

Completed by: D. Evans Date: 12/06/03

Site name: New Wood Compartment name/no.: 1215

STAGE 1: use Core decision key

What is the problem and what are the likely consequences if the problem is not addressed?

New planting, established grass sward. Severe moisture competition with newly planted trees. Death and growth suppression of trees.

Which control option is most suitable?

TAKE NO ACTION	AVOID THE PROBLEM	TAKE REMEDIAL ACTION
		✓

Continue to next step

Tick as appropriate and note reason for choice.

Natural colonisation unlikely to form a woodland for several decades.

Which remedial action is most suitable?

Non-chemical method	Chemical method
✓	

Continue to Stage 2

Tick as appropriate and note reason for choice. Record why a non-chemical method is unsuitable.

Substantial quantity of old carpet available to use as a cheap mulch. Volunteer labour available to fix. Grass sward to be closely mown to aid fixing of mulch.

STAGE 2: use Pesticide decision key

Which chemical method is most suitable?

Note reason for choice.

If no suitable pesticide can be identified, a non-chemical method may need to be reconsidered.

Archive this sheet in a safe place for future reference.

Appendix 3 (continued)

Worked examples of the decision recording sheet

Decision recording sheet

Completed by: A. Ainsworth Date: 12/06/03

Site name: Old Piece Compartment name/no.: 4004

STAGE 1: use Core decision key

What is the problem and what are the likely consequences if the problem is not addressed?

Rhododendron, large established bushes in dense clumps. Swamping and death of young trees. Death of native flora.

Which control option is most suitable?

Tick as appropriate and note reason for choice.

- TAKE NO ACTION [ ]
- AVOID THE PROBLEM [ ]
- TAKE REMEDIAL ACTION [✓] — Continue to next step

Left untreated, rhododendron will dominate site.

Which remedial action is most suitable?

Tick as appropriate and note reason for choice. Record why a non-chemical method is unsuitable.

- Non-chemical method [ ]
- Chemical method [✓] — Continue to Stage 2

Flailing by itself excessively costly, and rhododendron will regrow. Overstorey trees too dense for mechanised access.

STAGE 2: use Pesticide decision key

Which chemical method is most suitable?

Glyphosate as a cut stump spray.

Note reason for choice.

Glyphosate has a low toxicity to insects and mammals. Broad spectrum, but little local non-target fauna to damage. Bushes will be cut to facilitate careful targeting of herbicides.
Regrowth will need to be treated.

If no suitable pesticide can be identified, a non-chemical method may need to be reconsidered.

Archive this sheet in a safe place for future reference.

Appendix 4a

Optional decision aid to assist in balancing the possible non-target effects of pesticides

Site name: ....

What are the remaining suitable pesticides, methods, and patterns of application?

1. ....
2. ....
3. ....

What are the possible non-target effects of each of the potential pesticides?

		Importance of factor at site			Level of risk*			Level of hazard*			**Overall suitability**		
		High	Norm	Low	High	Norm	Low	High	Norm	Low	✘	✔	✔✔
Effect on operators: Risk/hazard of contamination given suitable protection and control measures are in place.	1.	✔											
	2.	✔											
	3.	✔											
Effect on aquatic environment Risk/hazard of contamination given suitable buffer zones and control measures are in place.	1.												
	2.												
	3.												
Effect on biological environment Risk/hazard of contamination given control measures are in place e.g. rare/ sensitive plants, invertebrates, birds etc.	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on neighbouring sites	1.												
	2.												
	3.												
Effect on forest users	1.												
	2.												
	3.												

* Risk = likelihood of effect occuring, given suitable protection and controls. Hazard = likely harm that may occur if risk is realised.

Notes
- Use after approved, crop safe, effective, cost-effective, pesticides have been identified.
- Operator protection is of the highest importance. This process does not replace a COSHH assessment in which adequate levels of engineering control or protective clothing should be identified.
- Note that if label instructions are followed, operator and environmental risk is likely to be minimal, but this process may help in the decision on which pesticide to use.
- Compare possible alternative pesticides and application patterns and applicator types, once protective clothing and buffer zones have been identified.

Reject the pesticide if you have ticked 'High' three times in one row.

Which pesticide is most suitable?

Appendix 4b

Examples of completed forms for the optional decision aid

Site name: Field Wood (pasture with rare grasses, invaded by ragwort, no streams or public access)

What are the remaining suitable pesticides, methods, and patterns of application?

1. 2, 4-D, overall spray, tractor with sealed cab.
2. 2, 4-D, spot spray, hand-held applicator.
3. Glyphosate, overall spray, tractor with sealed cab.

What are the possible non-target effects of each of the potential pesticides?

		Importance of factor at site			Level of risk*			Level of hazard*			**Overall suitability**		
		High	Norm	Low	High	Norm	Low	High	Norm	Low	✗	✔	✔✔
Effect on operators: Risk/hazard of contamination given suitable protection and control measures are in place.	1.	✓					✓	✓					✓
	2.	✓				✓		✓				✓	
	3.	✓					✓			✓			✓
Effect on aquatic environment Risk/hazard of contamination given suitable buffer zones and control measures are in place.	1.			✓			✓	✓					✓
	2.			✓			✓	✓					✓
	3.			✓			✓			✓			✓
Effect on biological environment Risk/hazard of contamination given control measures are in place e.g. rare/sensitive plants, invertebrates, birds etc.	1.												
	2.												
	3.												
Effect on biological environment Non-target grass species	1.	✓			✓					✓			✓
	2.	✓				✓				✓			✓
	3.	✓			✓			✓			✓		
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on neighbouring sites	1.			✓		✓				✓		✓	
	2.			✓			✓			✓			✓
	3.			✓		✓			✓			✓	
Effect on forest users	1.			✓			✓	✓					✓
	2.			✓			✓	✓					✓
	3.			✓			✓			✓			✓

* Risk = likelihood of effect occuring, given suitable protection and controls. Hazard = likely harm that may occur if risk is realised.

Notes
- Use after approved, crop safe, effective, cost-effective, pesticides have been identified.
- Operator protection is of the highest importance. This process does not replace a COSHH assessment in which adequate levels of engineering control or protective clothing should be identified.
- Note that if label instructions are followed, operator and environmental risk is likely to be minimal, but this process may help in the decision on which pesticide to use.
- Compare possible alternative pesticides and application patterns and applicator types, once protective clothing and buffer zones have been identified.

Reject the pesticide if you have ticked 'High' three times in one row.

Which pesticide is most suitable?

2, 4-D, overall spray, tractor with air filtration.

Appendix 4b (continued)

Examples of completed forms for the optional decision aid

Site name: High Wood (upload restock site, grass weeds, surrounded by valuable aquatic habitat, some flowering heather)

What are the remaining suitable pesticides, methods, and patterns of application?

1. Glyphosate, overall spray, 10 m buffer zone.
2. Cycloxydim, overall spray, 10 m buffer zone.
3. Glyphosate, spot spray, 10 m buffer zone.

What are the possible non-target effects of each of the potential pesticides?

		Importance of factor at site			Level of risk*			Level of hazard*			**Overall suitability**		
		High	Norm	Low	High	Norm	Low	High	Norm	Low	✗	✔	✔✔
Effect on operators: Risk/hazard of contamination given suitable protection and control measures are in place.	1.	✔				✓				✓			✓
	2.	✔				✓			✓			✓	
	3.	✔				✓				✓			✓
Effect on aquatic environment Risk/hazard of contamination given suitable buffer zones and control measures are in place.	1.	✓				✓				✓		✓	
	2.	✓				✓		✓				✓	
	3.	✓					✓			✓			✓
Effect on biological environment Risk/hazard of contamination given control measures are in place e.g. rare/sensitive plants, invertebrates, birds etc.	1.												
	2.												
	3.												
Effect on biological environment sparse heather vegetation	1.			✓	✓			✓				✓	
	2.			✓	✓					✓			✓
	3.			✓		✓		✓				✓	
Effect on biological environment Bees - hives sited locally	1.		✓				✓			✓			✓
	2.		✓				✓			✓			✓
	3.		✓				✓			✓			✓
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on neighbouring sites	1.			✓			✓			✓			✓
	2.			✓			✓			✓			✓
	3.			✓			✓			✓			✓
Effect on forest users	1.		✓				✓			✓			✓
	2.		✓				✓		✓				✓
	3.		✓				✓			✓			✓

* Risk = likelihood of effect occuring, given suitable protection and controls. Hazard = likely harm that may occur if risk is realised.

Notes
- Use after approved, crop safe, effective, cost-effective, pesticides have been identified.
- Operator protection is of the highest importance. This process does not replace a COSHH assessment in which adequate levels of engineering control or protective clothing should be identified.
- Note that if label instructions are followed, operator and environmental risk is likely to be minimal, but this process may help in the decision on which pesticide to use.
- Compare possible alternative pesticides and application patterns and applicator types, once protective clothing and buffer zones have been identified.

Reject the pesticide if you have ticked 'High' three times in one row.

Which pesticide is most suitable?

Glyphosate, spot spray.

Appendix 4b (continued)

Examples of completed forms for the optional decision aid

Site name: *Old Piece (rhododendron, no non-target flora, public access)*

What are the remaining suitable pesticides, methods, and patterns of application?

1. *Glyphosate plus mixture B, foliar spray, tall bushes.*
2. *Glyphosate, cut stump spray.*
3. *Triclophyr, cut stump stray.*

What are the possible non-target effects of each of the potential pesticides?

		Importance of factor at site			Level of risk*			Level of hazard*			**Overall suitability**		
		High	Norm	Low	High	Norm	Low	High	Norm	Low	✘	✔	✔✔
Effect on operators: Risk/hazard of contamination given suitable protection and control measures are in place.	1.	✓			✓			✓			✓		
	2.	✓					✓			✓			✓
	3.	✓					✓	✓				✓	
Effect on aquatic environment Risk/hazard of contamination given suitable buffer zones and control measures are in place.	1.			✓			✓		✓			✓	
	2.			✓			✓			✓			✓
	3.			✓			✓	✓				✓	
Effect on biological environment Risk/hazard of contamination given control measures are in place e.g. rare/sensitive plants, invertebrates, birds etc.	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on biological environment	1.												
	2.												
	3.												
Effect on neighbouring sites	1.												
	2.												
	3.												
Effect on forest users *Weekend public access*	1.		✓			✓		✓				✓	
	2.		✓				✓			✓			✓
	3.		✓				✓	✓				✓	

* Risk = likelihood of effect occuring, given suitable protection and controls. Hazard = likely harm that may occur if risk is realised.

Notes
- Use after approved, crop safe, effective, cost-effective, pesticides have been identified.
- Operator protection is of the highest importance. This process does not replace a COSHH assessment in which adequate levels of engineering control or protective clothing should be identified.
- Note that if label instructions are followed, operator and environmental risk is likely to be minimal, but this process may help in the decision on which pesticide to use.
- Compare possible alternative pesticides and application patterns and applicator types, once protective clothing and buffer zones have been identified.

Reject the pesticide if you have ticked 'High' three times in one row.

Which pesticide is most suitable?

Glyphosate as a cut stump spray.

UK Government and European Union policy is to minimise pesticide use as far as possible. Covering pest, disease, vegetation and wildlife management, and based upon the latest research, *Reducing pesticide use in Forestry* can help forestry practitioners to assess the impact of any problem and select a non-chemical solution. Two simple flowcharts summarise the decision process and link to comprehensive reference material in the rest of the guide. If pesticide use is unavoidable, the guide should help managers to keep chemical use to the minimum level necessary consistent with good practice while at the same time reducing the risk of damage to the environment.

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