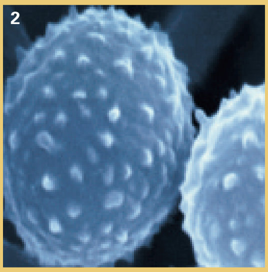
Jim Pratt

Stump treatment against Fomes

The Forestry Commission had a policy of ubiquitous treatment of stumps to prevent their infection by *Heterobasidion annosum*. During the past few years, Forest Research has established where the risk from the disease no longer justifies stump treatment, has obtained statutory approval for the use of two chemical and one biological treatment agents, and has identified weaknesses in existing application systems mounted on harvesters. The consequences of this work are now described and the potential for increasing the scope of biological control onto spruce stumps is also discussed.



1. Fomes decay in Norway spruce heartwood.
2. Basidiospores of *H.annosum*.
3. Measuring stump treatment applied by harvesting machine [Jim Pratt].
4. Testing the effect of incomplete coverage of a control agent in a stump treatment trial.

BACKGROUND

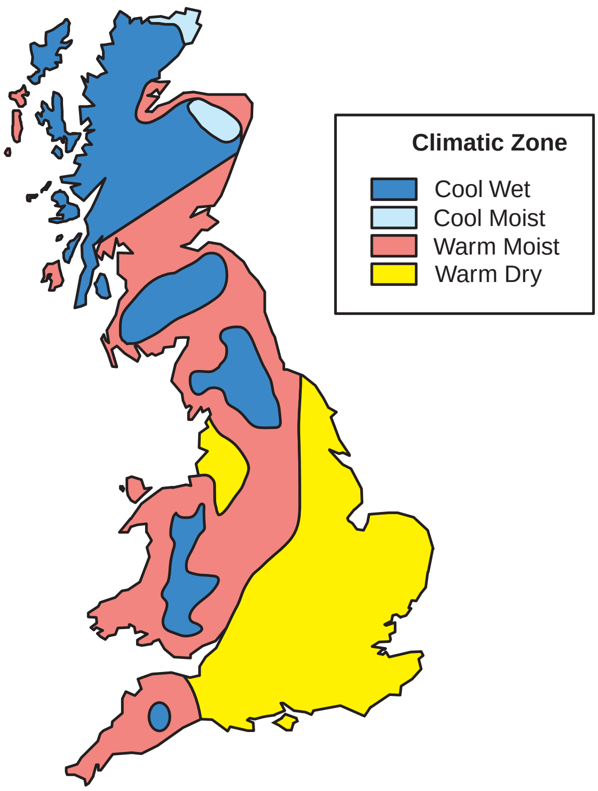
Heterobasidion annosum (more commonly known as Fomes) is a pathogenic fungus that kills the roots and decays the heartwood of most species of conifer used in commercial forestry. Up to 40% of the value of standing trees can be lost in a few years (Pratt, 1979). In Britain, airborne spores of the fungus are present throughout the year. These infect freshly cut stumps during thinning or felling operations, and provide the fungus with the means to initiate disease in new plantations. Once the role of stumps in the infection cycle of *H. annosum* was recognised in the 1950s (Rishbeth, 1949), opportunities for controlling the disease were quickly realised. Chemicals which prevented infection by airborne basidiospores when applied to fresh stumps were identified and brought into use in conifer stands in about 1960. A biological stump treatment based on a competing fungus *(Phlebiopsis gigantea)* was also developed (Rishbeth, 1963) for use on pine. When mechanised felling started in the 1980s, the need to apply these materials by harvesters became evident: however, by 2000 it was clear that the application systems were unsatisfactory and required improvement if the treatments were to be considered environmentally acceptable and economically justifiable (Pratt and Thor, 2001). At the same time, external factors including forest certification, European pressures to adopt GPPP (Good Plant Protection Practice; Jørgensen, 2001) and financial stringency within the forest industry combined to reduce the use of pesticides. These pressures are having a profound effect upon attitudes towards stump treatment. This article reviews the crucial elements of an emerging policy and how it may be implemented.

WHERE TO TREAT

The Forestry Commission adopted ubiquitous stump treatment within its conifer woodland 40 years ago, as an insurance until research could demonstrate the actual size of the risks involved. Experiments designed to assess the hazard to Sitka spruce from *H.annosum* in crops on peat and mineral soils have clearly demonstrated that the risk on peat soils is very low (Redfern, 2001) because fungal transmission from stump to tree is inhibited by this soil. Redfern also reported that survival of the fungus in Sitka spruce stumps is attenuated in high rainfall areas, regardless of the soil type. These and other observations made in Britain and elsewhere (e.g. Ross, 1973) make it clear that the pathogen thrives best and grows fastest under mild conditions where the soil is well-drained, and they lend support to the view that the risk of serious outbreaks of the disease in many of our upland forests is much lower than was forecast when stump treatment was introduced. However, the effect of soil is not independent of climate, and a soil that presents a high hazard in one area may be less hazardous where temperatures are lower and rainfall is higher. Parameters that capture these climatic conditions include *accumulated temperature* and *soil moisture deficit*, which have been amalgamated (Figure 1) into a number of UK climatic zones (Pyatt *et al.*, 2001).

Figure 1

Climatic zones of Great Britain: based on accumulated temperature (day-degrees above 5°C) and annual soil moisture deficit (mm). Adapted from Pyatt *et al.*, 2001.



Disease hazards based on a combination of soil type and climatic zone have been allocated to three classes, namely high (score 3), medium (score 2) and low (score 1). These classes are based on estimates of the amount of disease that might develop in the absence of stump treatment in a stand over two consecutive rotations, as derived from the computer model of Pratt *et al.* (1988), modified to take account of recent thinnings practices (Methley and Friar, 2001), and an assessment of the risk from clearfelling stumps (Pratt, unpublished). Thus, there is considered to be a high probability that more than 5% of trees will be affected in high-hazard stands, 1–5% in medium-hazard stands, and less than 1% in low-hazard stands. The relationships between climate and soil and these hazard classes are summarised in Table 1.

Note that in Table 1 two phases of soil described as peaty gley are recognised, based on the depth of peat overlying the gleyed mineral horizons: the shallower form (soil type 6) has peat 5–25 cm deep, compared to

Figure 2

Soil types in an area of conifer forest in Scottish Borders.

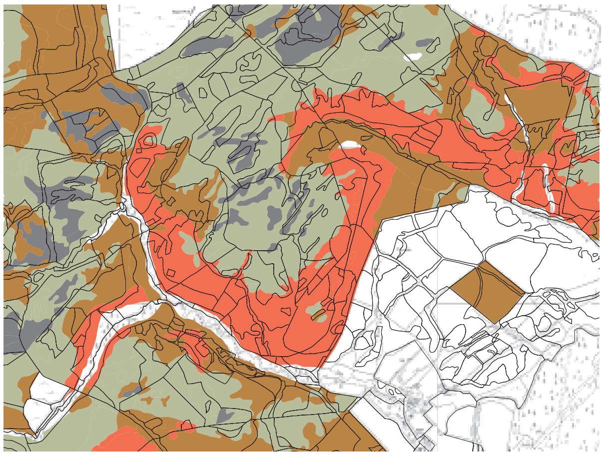


Table 1

***H.annosum* hazards associated with soil types and climatic zones. Notations and soil numbers as in Pyatt *et al.* (2001).**

Fomes hazard class	Climate zone				
	Cool Wet	Cool Moist	Warm Wet	Warm Moist	Warm Dry
High (3)	Nil	Calc soils, littorals 12,15	BE, Podzol, Calc soils, littorals 1,3, 13 b,z: 12,15	BE, Podzol, Calc soils, littorals 1,3, 13 b ,z: 12,15	BE, Podzol, Calc soils, littorals, ironpans, GWG SWG 1,3, 13 b,z: 12,15,5,7.
Medium (2)	Calc soils, littorals 12,15	BE, Podzol, SWG 1,3, 7,13 b,z	Ironpans, GWG, SWG 4,5,7	Ironpans, GWG, PG (shallow), SWG 4,5,6,7	PG (shallow) 6
Low (1)	BE, Podzol, Ironpans, GWG, PG (all phases), SWG, Peat 1,3,4,5,6, 6p, 7,8,9,10,11,13 b,,z, 14	Ironpans, GWG, PG (all phases), Peat 4,5,6, 6p,8,9,10,11,13p, 14	PG (all phases), Peat 6, 6p,8,9,10,11,13p, 14	Peat, PG (deep) 6p,8,9,10,11,13p, 14	Peat, PG (deep) 6p,8,9,10,11,13p, 14

BE = brown earth; Calc = calcareous pH > 6.0; GWG = ground water gleys; PG = peaty gleys; PG (shallow) = peaty gley with peat layer 15 cm or less; PG (deep) = peaty gley with peat layer greater than 15 cm; SWG = surface water gleys; Peat = peats deeper than 15 cm.

the deeper form (soil type 6p), where peat is between 25 and 45 cm thick. Observation suggests that in practice the hazard from Fomes is greater in peaty gley where peat horizons are thinner than 15 cm, since at greater thicknesses the majority of roots are likely to be growing entirely in peat. However, 15 cm is not recognised as a threshold depth for identifying a separate peaty-gley phase in standard soil mapping. Where the suspected depth of peat is seen as a critical factor in determining hazard, judgement should be used in deciding whether peaty gleys are classified as soil type 6 or as the lower-hazard type 6p.

Examples of disease hazards derived from a knowledge of soil and climate are shown in Figure 3 (page 81). Soil types in a sample of woodland have been amalgamated into four major soil groups as shown in Figure 2, each of which will pose a different hazard. Figure 3 shows the estimated hazard ratings for each of these soil groups, and assumes that the woodland block is in one of four climate zones, namely cool wet and moist, and warm moist and dry. Nearly 60% of Forest Enterprise high forest exists in the former (cool) areas, and 37% in the two 'warm' zones.

The actual risk from *H.annosum* on a site of known hazard is determined both by the hazard *per se*, and by the management options. Thus, if risky options are selected for a high-hazard site, the losses that will occur will probably be higher in the long term than on other, less-hazardous sites. The risk can, of course, be minimised by stump treatment. In general terms, high-risk management options would involve the exposure of large numbers of stumps that are susceptible to infection by Fomes spores and which spread the disease to trees that are prone to it. Examples of risk associated with management operations are grouped under four disease risk classes in Table 2.

The scores associated with disease hazard and disease risk are mutually independent, and can thus be multiplied together to produce an overall risk score that can be used to inform decisions on stump treatment (Table 3).

Table 2

Disease risks associated with management practices.

Operation	Disease risk: High risk (3)	Medium risk (2)	Low risk (1)	No risk (0)
Thinning	Thin regularly, early and heavily	Reduce frequency and intensity of thinning	Non-thin	None
Stump treatment	No stump treatment	Allow poor practice	Practice high-quality stump treatment, treatments especially in early thinnings	None (no stump treatment is always 100% effective)
Remedial treatment of badly diseased sites.	No stump removal	Remove only rotted stumps, or stumps from the clear-fell	Remove all stumps	None. Stump removal cannot be 100 % effective
Species selection in next rotation: 1. following pine	Pure spruce, larch or DF	Hardwoods in mixture with spruce, larch or DF	Pine[a], grand fir, hardwoods	Hardwoods
2. following spruce, larch or DF	Western hemlock, larch	Spruce, DF	Pine[a], grand fir, hardwoods	Hardwoods

[a] Generally, pine is not at risk from Fomes except in soils where the pH exceeds 6.5–7.0; under these conditions, it is very susceptible and can be killed in large numbers at any age. Pine stumps are very susceptible to infection by Fomes spores, and readily pass on the disease to other species in mixtures. DF: Douglas fir.

Table 3

Assessing the need for stump treatment.

Management risk	Site hazard High (3)	Medium (2)	Low (1)
High (3)	HH (9)	HM (6)	HL (3)
Medium (2)	MH (6)	MM (4)	ML (2)
Low (1)	LH (3)	LM (2)	LL (1)
Nil (0)	NH (0)	NM (0)	NL (0)

Stands with a score of 6 or higher will justify stump treatment, while stands with a score of 3 or less do not. There are a number of options for dealing with other stands where the decision is not clear-cut:

- Relate the decision to treat or not to the value of the stand.
- Adopt low-risk policies for the stand.
- Assess the likelihood of stump infection from local spore sources, and adjust score accordingly.

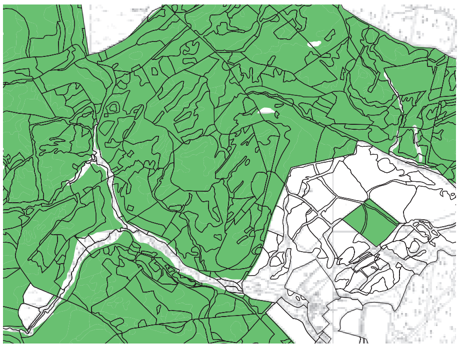
The scale at which decisions on investing in stump treatment are taken can be varied depending on intensity of management and the degree of site variation. The key to the decision is to accept that some losses in value will inevitably occur in the absence of effective prophylactic treatment, but as long as they are smaller than the savings made by not treating stumps, a policy of non-treatment is justifiable. The investment decisions that are taken in relation to stump treatment are long term (Pratt, 1998), and should extend to at least two rotations, during which expenditure on control will be offset by the benefits of an absence of disease. The use of standard discounting methods for measuring the economic benefits of stump treatment has proved difficult, because of the need to reconcile a stream of costs with a stream of losses over a long time period. However, an adequate approximation of the relative size of the benefits can be obtained by making simple assumptions on the costs of treatment and the value of the timber that would be saved, using current values for both. If the accumulated costs over two rotations are lower than the predicted losses over the same period, treatment is probably justifiable. In the following example, an average cost of 30p/m^3 has been selected for treatment. Timber values have been variable, but a 10-year weighted average of £15/m^3 was used. The losses caused by decay can be simply estimated by assuming that each decayed tree will lose 30% of its volume, or 40% of its value. Although these relationships were established for Sitka spruce (Pratt, 1979), similar losses through decay can be expected to occur to all other butt-rot susceptible species (with the exception of Grand fir: see Redfern and MacAskill, in press). Applying the '40%' rule shows that in high-hazard crops where at least 5% of trees may become diseased, the losses would be more than 2% of value, and thus close to the notional cost of treatment (30p/m^3) and treatment would be justified. In medium hazard crops, between 1% and 5% of trees may become decayed, with losses in value of between 0.4% and 2%. Here, the decision to treat or not is marginal, and is likely to be affected by factors other than those of strict economics. Losses in low hazard crops are unlikely to exceed 0.4% of value, and cannot justify treatment.

STUMP TREATMENT MATERIALS

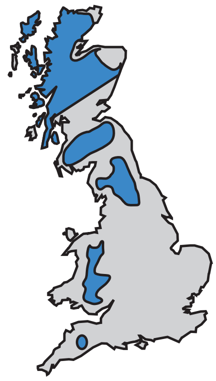
The materials available for stump treatment were all identified by Rishbeth in the 1950s (Rishbeth, 1959a, 1959b, 1963). He recognised the need for substances that were inexpensive, readily available and safe to apply in the forest. The first, creosote, was discarded when it became clear that this unpleasant chemical exacerbated the disease by preventing fungal competition within stumps. Sodium nitrite was selected as a successor, but after a number of years of use, it too was abandoned because of its inherent toxicity and explosive potential. The third choice fell on the nitrogenous fertiliser urea, which had shown promise in trials on pine stumps. Urea is inexpensive, widely available and of low mammalian toxicity and was approved for use in 1988 and again in 2001. It is effective for stump treatment only while it is being hydrolysed by bacterial action within stump tissues into ammonia (Rishbeth, 1959b). During this process, the pH of urea-treated wood rises above a threshold that is toxic to *H. annosum* (Johansson *et al.*, 2002). Hydrolysis occurs more readily in pine than in spruce stumps, the

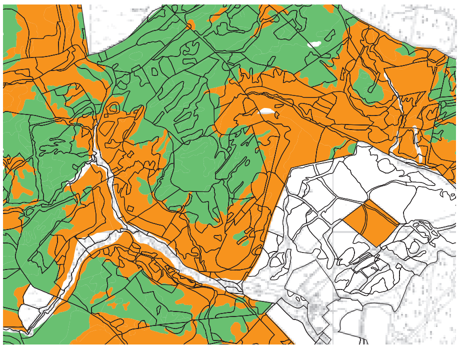
Figure 3

Disease hazard derived from climate and soil, for the area of forest shown in Figure 2, assuming it is located in each of four climatic zones from Figure 1. The proportion of the forest area within each disease hazard class is tabulated.

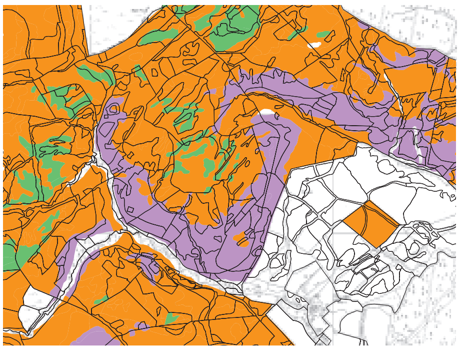


Climatic zone	COOL, WET		
Fomes hazard	Low	Medium	High
Per cent of area	100	0	0

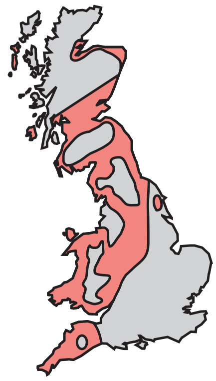


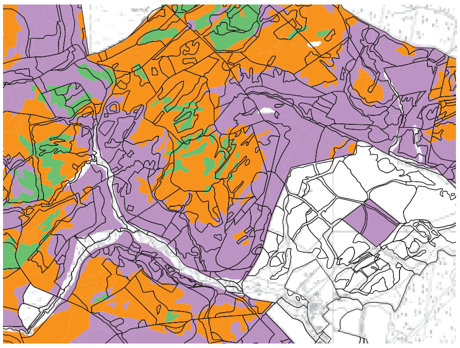


Climatic zone	COOL, MOIST		
Fomes hazard	Low	Medium	High
Per cent of area	51	49	0

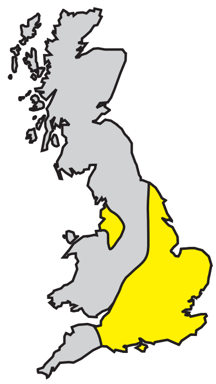


Climatic zone	WARM, MOIST		
Fomes hazard	Low	Medium	High
Per cent of area	12	56	32





Climatic zone	WARM, DRY		
Fomes hazard	Low	Medium	High
Per cent of area	12	23	65



rate being temperature dependent. This may explain why the efficacy of urea on stumps of Sitka spruce in upland Britain has been variable: in the absence of hydrolysis, urea acts as a fertiliser and it may even enhance the growth of the pathogen in diseased stumps (Pratt and Redfern, 2001). Large doses of urea are needed for the active process of hydrolysis to be maintained throughout the weeks when stumps remain susceptible to infection. In practice, however, the amount absorbed at the stump surface is limited by the dryness of the stumps during treatment, and it is rarely possible to apply more than 1 litre of fluid to each square metre of stump. Mechanised application at this rate has proved to be difficult, wasteful of material and responsible for unacceptable collateral damage to local vegetation (Westlund and Nohrstedt, 2000). In addition to these problems, urea is corrosive and is not a material well-fitted for use with modern harvesting equipment. As a consequence, an alternative chemical based on boron, namely disodium octaborate tetrahydrate (DOT), has been evaluated and approved for use in Britain (Pratt, 1994, 1996; Pratt and Lloyd, 1996; Pratt and Quill, 1996). Although DOT has many attributes that make it more acceptable than urea, the harmonisation of pesticides under European rules makes it unlikely that it will be available for stump treatment after 2003. There are currently no alternative chemicals other than urea.

The third material approved for stump treatment is biological, and relies on the ability of a saprotrophic fungus, *Phlebiopsis gigantea*, to decay the wood of stumps more rapidly than the pathogen, and thus exclude it. This form of treatment was devised in the 1960s (Rishbeth, 1963) and was the world's first commercially available biological agent for the control of a plant disease. The British-made product, PG Suspension, was approved for use on pine in Britain in 1998 and is manufactured on licence to the Forestry Commission by Omex Environmental Ltd, Kings Lynn. There would clearly be an advantage to have a biological agent for use on spruce as well, but extensive research has failed to find a British isolate of *P. gigantea* on species other than pine. However, a stump treatment product using an isolate of *P. gigantea* that grows on Norway spruce is manufactured in Finland and marketed in Scandinavia as Rotstop®. As a first step in its evaluation for use in Britain, pathogenicity trials of Rotstop® on living Sitka spruce were carried out in Denmark (Thomsen and Pratt, unpublished) and population studies using DNA markers (Vainio and Hantula, 2000; Webber and Thorpe, in press) were undertaken in Britain. Neither indicate that introducing this isolate into Britain and Ireland would involve unacceptable risk, and field trials are planned to determine its efficacy on Sitka spruce, Douglas fir and larch stumps. Following on from the work of Skrzecz (1994), the potential for Rotstop to affect populations of breeding weevils *(Hylobius abietis)* is being studied in both the UK and Ireland.

The high costs associated with testing and obtaining statutory approval of pesticides (about £5 million) does not encourage the development of new stump treatment materials. It is likely therefore that the forest industry will need to use and adapt those which are already available.

IMPROVING THE QUALITY OF TREATMENT

The general standard of harvester-applied stump treatment in Britain needs improvement. The chemical treatment (urea) crystallises at both high and low temperatures, corrodes all but a few metals and increases the cost of maintenance of the harvesting machines. It is awkward and bulky to handle and the equipment for applying it from harvesters has hardly changed during the past 15 years. Without close supervision there is little incentive for operators to achieve high standards of application and it is generally accepted that the quality of stump treatment in Britain is variable.

To improve the standard of treatment, there are three remedies:

- Ensure that machine operators and harvesting managers are familiar with the reasons why stump treatment is important.
- Apply treatment only where it is needed.
- Improve the equipment and the materials available for treatment.

The first issue is being tackled by means of a demonstration video (Whistler and Rushton, 2002), commissioned as part of a joint Forest Enterprise/Forest Research project. This will be used in training courses, and will also be made available to the private sector. A plan for meeting the second remedy using a decision support system for assessing the need for treatment is described above. Thirdly, changes that need to be made to equipment to improve the application system are considered below.

To qualify as best practice, stump protection requires that an appropriate dose be applied without compromising the safety of the machine operator, reducing the productivity of the harvesting operation or threatening the integrity of the environment. Application systems on harvesters are tending to become standardised for delivery of the protectant, which is pumped on demand from a storage tank to the felling head whence it is discharged onto the stump surface via holes spaced along the length of the chain saw bar. Sophisticated computer control systems may be fitted which determine when the pump is activated, and this affects the volumes discharged. The volumes applied to stumps will always be less than the total volumes discharged, since treatment inevitably produces waste that is sprayed onto the ground surrounding the target stump. The objective of further development must be to limit this waste to an acceptable minimum. Equipment has been developed to measure both the rate of discharge and its distribution (Pratt and Thor, 2001), and a standard has been devised to act as a benchmark (Table 4).

The two factors that contribute most to poor treatment are the over-capacity of pumps, and the arrangement of the delivery holes in the standard treatment bars (Pratt *et al.*, 2001). The former can only be modified once the performance of the delivery bars is improved, and work by Forest Research (Pratt *et al.*, in press) has demonstrated the beneficial effects of reducing the numbers of delivery holes, and of placing them more intelligently. Adequate coverage with less waste was achieved using bars with fewer holes that were positioned on either side of the centre of the cutting arc. In addition, the doses required were significantly reduced and there was less collateral waste (Table 5).

Table 4

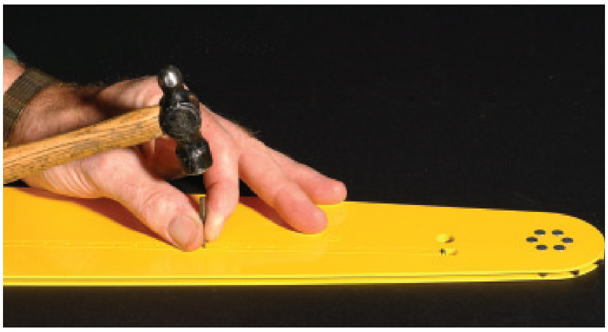
Proposed minimum standards for stump treatment.

Application rate (l m^{-2})	1.0	0.5
Maximum consumption (l m^{-2})	1.5	1.0
Minimum coverage per stump	90% of surface, with no area greater than 10 cm^2 untreated per stump	
Minimum incidence of stumps treated to this standard	95%	

These findings have been taken up by the major bar manufacturers (Oregon® Cutting Systems) and are being incorporated in new designs (G. Carruthers, personal communication, 2002). These will provide bars of superior performance, with prolonged life and reduced running costs. One such is a solid bar where the treatment holes are punched by the operator (Plate 1).

Plate 1

Protype harvester bar being punched by the operator to provide treatment holes in optimum positions.



DISCUSSION

The susceptibility of all our conifers to *H.annosum* has been clearly demonstrated in the UK (Greig *et al.*, 2001), and as long as commercial forestry is practised, prophylactic treatment will be required to maintain relatively disease-free stands. The problem is to arrange this form of control so that it is economically justified, ecologically acceptable and meets our commitments to long-term sustainability. Research over the past three decades has provided some of the answers. Firstly, we now have a means of predicting the likely progress of the disease on most sites, albeit

Table 5

Comparison between standard and modified bars: volumes applied, wastage and stump surface coverage. Means of 10 (or 5) samples per treatment.

Stump diameter (cm)	Bar type	Number and length of array of holes	Waste as a % of discharged volume	Volume applied to stump surfaces (l m^{-2})	Coverage (mean %)
22	Standard	42, 53 cm	48	2.4	100
(*n*=10)	Modified	3, 13 cm	32	1.6	97
44	Standard	42, 53 cm	18	1.71	100
(*n*=5)	Modified	4, 46 cm	8	1.07	92

with a low precision. Using this knowledge, it is possible to select options for treatment which are appropriate to the site.The climatic zones developed for ESC offer a sensitive means of identifying sites where the hazards from the disease depend on soil type, and decisions on the need for prophylactic control are enabled. The widescale use of this GIS-based system will require that data on climatic zones and soils are (or soon will be) widely available. Secondly, three materials suitable for stump treatment have been tested and approved. However, a move away from chemicals towards biologically based materials is a clearly stated long-term aim of the Forestry Commission, and there is much scope for improvement of the existing biocontrol agent, since virtually no research has been undertaken on methods of enhancing the growth or formulation of stump-inhabiting fungi, or for determining their collateral effect on other pests such as *Hylobius*. Unfortunately, the future development of chemical or biological pesticides for markets as small and specialised as those in forestry will be increasingly inhibited by the costs of providing data to the regulatory authorities and by the complexity of the data that are required. Thirdly, means of improving mechanised treatment have been identified and are being implemented. However, there is a relatively small market for stump treatment equipment and little competitive pressure for its development: improvements will not be fast. Finally, the need to provide harvester operators and managers with training in the treatment of stumps has been recognised and is in hand.

Acknowledgements

Almost none of the research that underpins these recommendations on stump treatment was made without considerable help from Grace MacAskill, to whom I offer my thanks.

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