Forestry Commission
231 Corstorphine Road
Edinburgh
EH12 7AT
www.forestry.gov.uk

Managing Brash on Conifer Clearfell Sites

PRACTICE NOTE

BY ANDY MOFFAT, BILL M JONES AND BILL MASON OF FOREST RESEARCH

FEBRUARY 2006

INTRODUCTION

Brash is an important product of forestry operations, and sustainable forest management requires that consideration is given to its use in harvesting and restocking operations, and its final placement on or off site. Brash mats are invaluable in protecting forest soils from physical damage (Figure 1), and this method of ground protection should normally be used when harvesting conifer crops. The method of brash removal or retention on site will depend on site factors, marketing opportunities for the brash and objectives for the restock site. This Practice Note gives guidance on the range of available options for brash management, and the possible consequences of each option.

Brash is defined here as the above-ground parts of the tree not normally removed from site for sale after thinning or clearfelling. It is usually composed of branches, the tops of trees and small dead trees unacceptable for conventional timber processing. Conifer brash will normally include needles. Brash management is considered briefly in *Forestry practice* (Hibberd, 1991), but is rarely mentioned in other standard forestry texts. Yet brash is an important component of the forest ecosystem, and its appropriate management can make a substantial difference to the sustainability of a site, the economics of harvesting and restocking and the subsequent performance of the restock crop (Figure 2). In addition, brash management is now not only just of interest to foresters, but also to those involved in environmental protection and woodfuel energy generation.

Figure 1 A forwarder travelling on a well-constructed brash mat.

Figure 2

Well-organised felling site with clearly demarcated brash mats between timber zones.

Some of the principles covered in this Practice Note will be relevant to thinning operations, broadleaf harvesting and continuous cover sites. However, the amounts of brash available are much lower than that from conifer clearfell sites and problems may result from a lack of brash for flotation and ground protection. These issues are not covered in this Note.

POLICY AND REGULATORY CONTEXT

How brash is managed, in particular whether it is left on site or removed from it, will affect several of the indicators used in the evaluation of sustainable forest management (Table 1). Both the Ministerial Conference on the Protection of Forests in Europe (MCPFE) and *The UK forestry standard* (Forestry Commission, 2004) encompass soil and water acidification and eutrophication in addition to the physical status of soils. The UKWAS accreditation system also examines these issues. The likelihood of ecosystem acidification and eutrophication is also considered under

Table 1

Impact of brash management on indicators of sustainable forestry.

Code*	Sustainability indicator	Impact of brash management
A6	Area of sustainably managed woodland	Use of brash to protect soil and retention where removal might impoverish site fertility.
A7	Management practices	This indicator is under development. Brash management methods may feature in its future formulation.
B7	Natural regeneration of woodland	Regeneration can be significantly affected by presence/absence of brash.
C1	Air pollutants	Burning brash can contribute to air pollution.
C2	Soil chemistry	Removal of brash may lead to soil acidification on sensitive sites.
C3	Water quality	(a) Poor siting of brash piles can create a risk of leachate from decomposing brash entering water courses. (b) Inadequate brash mats can result in soil erosion and a risk of sediment entering water courses.
C4	Surface water acidification	Brash removal can lead to water acidification in sensitive catchments (see C2).
C7	Pollution incidents	Decomposing brash stored on land adjoining water courses can lead to significant point-source pollution (see C3).
D5	Carbon storage	Removal or retention of brash will affect carbon capital of site.
E5	Historic environment and cultural heritage	Harvesting regime chosen to protect cultural heritage will affect brash management decisions.
F1	Financial return from forestry	There is potential for enhancing financial return from sale of brash into biofuel market, and reduction in restocking costs.

*Sustainability indicator code (Forestry Commission, 2002).

the aegis of atmospheric pollution control, an issue dealt with at both national and international levels under the Convention on Long-range Transboundary Air Pollution. Forest soil protection will be included in the forthcoming EU Soil Protection Strategy which will seek to conserve soil fertility, physical condition and function. These policies and strategies will require forest managers to be aware of the role of brash in soil sustainability and to be responsible for their actions in its management.

PROPERTIES OF BRASH

Physically, conifer brash has valuable soil protection properties when laid out on the forest floor in a continuous linear layer as a 'brash mat' (Figure 3). If brash type, density and construction are adequate, brash mats can support felling and other harvesting machinery. They enable the extraction of timber from wet sites of low bearing strength, and also protect the underlying soil from rutting, liquefaction, compaction and erosion. Brash can also affect the microclimate of the restock forest site, which can influence the performance of newly planted or naturally regenerated tree seedlings (Proe *et al.*, 1999; 2001).

Nutritionally, brash contains a significant proportion of the above-ground content of plant nutrients (Table 2). In the past, the traditional practice of brash removal, or 'litter raking', was carried out in many countries in Europe and beyond. The practice was found to cause widespread degradation of site fertility and a serious reduction in timber yield (Ebermayer, 1876). In the UK, it has been conventional practice to retain such material on infertile sites to maximise opportunities for nutrient uptake by the following rotation. Though not directly comparable to fertiliser inputs, the data in Table 2 suggest

Figure 3

Good brash mat construction with material transverse to direction of machinery travel.

Table 2

Nutrient content of brash; % of total = % of total above-ground tree crop at harvest.

Species	N kg ha^{-1}	% of total	P kg ha^{-1}	% of total	K kg ha^{-1}	% of total	Mg kg ha^{-1}	% of total	Ca kg ha^{-1}	% of total
Norway spruce[a]					65–71	53–59	19–28	50–55	128–229	51–55
Norway spruce[b]	280		23							
Scots pine[a]					82–102	55–66	7–22	40–47	39–94	40–49
Scots pine[b]	74		9							
Sitka spruce[c]	300	70	31	76	106	73			128	46
Sitka spruce[d]	219		20		71		26		91	

[a]Olsson *et al.* (1996); [b]Hyvönen *et al.* (2000); [c]Stevens *et al.* (1995); [d]Titus and Malcolm (1991).

that brash may contain approximately half the amount of phosphorus and potassium recommended in fertiliser prescriptions and double the normal nitrogen application rate (e.g. Taylor, 1991). Although deposition from atmospheric sources currently supplies nitrogen in valuable amounts for most conifer plantations in the UK, it is clear that brash removal may lead to an increase in the need for artificial fertiliser application, notably on sites where fertilisers have been used in the past. As well as the induction or exacerbation of site infertility, unrestricted brash removal can also lead to soil and water acidification on sensitive sites (Stevens *et al.*, 1995). Over successive rotations, brash removal may also reduce soil carbon content (Hyvönen *et al.*, 2000), but the magnitude of this effect in the UK is uncertain.

OPTIONS FOR BRASH MANAGEMENT

Table 3 summarises the potential advantages and disadvantages of a number of options for brash management. The methods suitable for an individual site will depend on the constraints imposed by the site and the objectives set for the site at harvest, and when restocked. Constraints may include:

- Location in an area where the critical load of acidity for freshwaters is exceeded (Forestry Commission, 2003). Brash extraction in these areas will increase the risk of soil and water acidification, and brash should be left on site wherever possible.
- Topography which may dictate timber extraction by cable crane with consequent removal of material which forms brash (Figure 4).
- Proximity to sensitive surface waters, which may affect brash storage location.
- Location in an area of nitrogen saturation, which may encourage the removal of brash.
- Location on sensitive soil types such as soft soils (e.g. peats, gleys) which are at risk of irreversible damage if not protected by brash mats during harvesting and timber extraction.
- Maximum access across the site (e.g. for recreation or future forest operations), which may affect how brash is laid out. For example, windrowed brash may not be acceptable.

Figure 4

Brash removal during whole-tree extraction using cable crane on steep slopes.

Table 3 Advantages and disadvantages of options for brash management after harvesting.

Leave brash in mats	
✔	No cost incurred in further processing. Affords some shelter and other microclimatic benefits. Return of nutrients to the soil over time.
✘	No potential revenue. Difficult to restock to desired number, spacing and standard. Considered unsightly by public. May provide habitat for tree browsers, e.g. rabbits. Regeneration may be hampered at brash positions. Mounding and scarification difficult through the mat.
Remove brash off site	
✔	May generate income (renewable energy). Site easy to cultivate and replant. Site neat and tidy; access unrestricted. May remove nitrogen (useful on nitrogen saturated sites). May raise soil temperature and thus promote early tree growth.
✘	Recovery operations may cause soil damage. Shelter effect is lost and early tree growth may suffer. Regeneration may be hampered by increased browsing. Potential reduction in carbon sequestered in the soil.
Burn off brash	
✔	Site easy to cultivate and replant. Site neat and tidy; access unrestricted. May help to suppress weed growth. Will remove nitrogen (useful on nitrogen saturated sites). May raise soil temperature and thus promote early tree growth.
✘	Burning carries risk and nuisance. Greater risk of base cation leaching and acidification on sensitive soils. Shelter effect is lost and early tree growth may suffer. Soil may suffer water repellancy. Regeneration may be hampered by increased browsing. Risk of *Rhizina undulata* and *Hylobius* attacks to next rotation. Potential reduction in carbon sequestered in the soil.
Redistribute brash	
✔	Facilitates restock cultivation and replanting. Produces an even spread of nutrient capital. Reduces the disadvantages of brash mats (see above).
✘	Operation may cause soil damage. Additional cost.
Windrow brash	
✔	Facilitates restock cultivation and replanting. May raise soil temperature and thus promote early tree growth. May provide shelter.
✘	Operation may cause soil damage. Additional cost for windrowing operation. May provide habitat for tree browsers (e.g. rabbits). Usually limits plantable area and can cause gaps in restocking. Nutrient leaching may pose risk of water pollution. May cause access restrictions (recreation or future operations).
Chipping and mulching	
✔	Reduces brash bulk and facilitates tree planting. Site neat and tidy; access unrestricted. May promote natural regeneration. May help to suppress weed growth.
✘	May exacerbate nutrient leaching and acidification. Some weeds can be encouraged (e.g. bracken). Additional cost. Risk of soil damage during operations on sensitive sites.
Infilling spoil trenches	
✔	Infills ditches, reducing risk to pedestrians. Exposes plantable area and facilitates planting.
✘	Increases risk of nutrient leaching, water pollution and acidification.

Objectives may include managing the forest:

- For timber production. As a primary objective, this will require ground conditions that encourage rapid growth during establishment and the remainder of the rotation.
- To promote natural regeneration. This will depend strongly on how brash is managed on the harvested site.
- As a wildlife habitat. Similarly, decisions on brash management will depend on which species are to be encouraged.
- To minimise use of chemicals. Brash removal may lead to increased use of fertilisers on infertile soils, and weed growth may be exacerbated by some management methods, leading to increased herbicide usage.
- For woodfuel recovery. If brash is required for woodfuel recovery, organisation of felling and extraction will need to be modified from conventional methods.
- For carbon sequestration. In a small way, brash removal will reduce the potential of forests to meet this objective.
- For recreation and amenity. Appropriate brash management can improve and encourage access to forests, and improve their visual appeal.
- Using continuous cover forestry or other alternatives to clearfell. These systems will affect the provision of brash for soil protection.

The actual course of action in brash management will depend on these factors and their interaction. For some combinations, there may be few options available, and in some circumstances a compromise solution may be necessary. For these reasons, it is not possible to be prescriptive about brash management – decision making must depend upon a proper evaluation of the local site factors and objectives for the site or forest.

BRASH AND HARVESTING

When planning harvesting operations, including both felling and extraction, it is important to consider site protection needs carefully. This requires a detailed evaluation of the soil and vegetation types, as well as needs of wildlife, archaeology and water protection. This information is likely to be considered initially, at the longer-term management planning stage, and later at the site planning stage. Here it will influence the choices with regard to operational planning, machinery selection, and in the case of conifer harvesting, the use of brash mats. Brash mats cannot be constructed from broadleaved harvesting residues.

Recent research has demonstrated that properly constructed and maintained brash mats formed from conifer harvesting residues are highly effective in soil protection (Hutchings *et al*., 2002; Wood *et al*., 2003a). Based on a mat width of 5 m, a brash mat volume of between 500 and 1000 m^3 ha^{-1} has been recommended for clearfell operations for Sitka spruce (Wood *et al*., 2003b) on most terrain types. Detailed field trialling has suggested that the efficacy of brash mats is maximised by the construction of mats with material from tree tops placed transverse to slope and direction of vehicular travel. However, on sites where direction of extraction is parallel to ploughing, brash mats composed of randomly distributed tree tops function better than those where tops are aligned in a single direction (Saunders, 2002). Some trials (Figure 5) have suggested that short top lengths (up to 2 m) produce level brash mats that can withstand vehicular traffic for longer than those constructed from miscellaneous longer lengths (Morgan, 2002a). Excessive larger diameter material and the placement of tops in one direction can cause unevenness in brash mats resulting in pressure points. The weight of the machinery can break the longer top lengths, which can then puncture through the upper soil layer on deep peat sites causing machinery flotation problems. Brash mats tend to fail at particular points on a site, e.g. where there is a change in topography, and soil protection is only assured if these positions are surcharged with brash and any mat breakdown repaired with further brash material. Attention to brash mat maintenance is of particular importance on peat and other wet areas. Failure to do so is likely to induce soil damage (Figure 6).

In continuous cover forestry (CCF), brash mat construction is severely compromised by the smaller amount of harvesting residues available, and at any one time risk of soil damage is likely to be greater than under clearfell systems (Mason *et al*., 1999). Research in progress is examining options for minimising risk, for example by the use of permanent access routes through the forest blocks which can be armoured with brash in a similar manner to clearfelled sites. Soil protection in broadleaved woodland is achieved through attention to machinery type and load, and timing of harvesting operations. Harvesting in summer and early autumn are usually the optimum times of year to ensure soil protection, and operations on soft and clayey soil types should be planned for these times.

Figure 5

Good example of brash mat construction using short-length material.

Figure 6

Soil damage caused by inadequate brash mat construction and maintenance.

OPTIONS FOR BRASH MANAGEMENT AFTER HARVESTING

Leave brash in mats

Brash mats may be left *in situ* following conifer harvesting, and the next crop established by planting between and through the mats. Tree planting in the brash zone will be necessary if uniform spacing is required. If performed by hand soon after harvesting, planting is slow and tree establishment can be poor. Instead, it is preferable to mechanically spot rake, to continuous mound (Figure 7) or to scarify through the brash to allow efficient planting to take place (Murgatroyd *et al.*, 2000; Morgan, 2001, 2002b; Morgan and Ireland, 2004). The choice will depend upon soil type, amount of brash and species used as brash. On wet sites, tree performance on mounds formed directly over brash appears to be generally acceptable, though it may suffer on dryer sites, on small mounds or those composed of fibrous peat (Nicoll, pers. comm.). Alternatively, the site may be left for a year or two before restocking, during which time much of the brash will have broken down – the length of time required will depend upon species, amount of brash and microclimate of the site.

Dense layers of brash can hinder natural regeneration, but there can be benefits for some aspects of the microclimate since brash can reduce wind exposure and snow lie. Trees planted within deep brash may also be protected from frost (Langvall *et al.*, 2001) and browsing (Bergquist and Örlander, 1998). Breakdown of the brash will return nutrients to the soil for potential uptake by the succeeding crop. However, brash left in mats can result in uneven or banded distribution of nutrients and subsequent uneven growth of the crop across the site. Brash mats can also reduce *Hylobius* larvae feeding on the cut tree stumps and this may reduce consequent attack on newly planted trees (Heritage and Moore, 2000).

Remove brash off site

Brash is normally removed off site during cable crane extraction on steep slopes. On level and gently sloping terrain, it may be purposefully removed by whole-tree harvesting to leave a clear site and facilitate planting (Figure 8). However, studies in the UK and elsewhere have shown that early growth may suffer significantly on certain site types (Nisbet *et al.*, 1997; Proe *et al.*, 1999) because shelter is reduced and wind speeds increased (Proe *et al.*, 2001). Soil temperatures may increase, relative to sites where brash is left, and this is normally considered favourable to early root and shoot growth. However, increased air temperatures at brash free sites may cause seedling stress (Zabowski *et al.*, 2000).

The effect on ground vegetation is unclear – some studies have shown an increase in the regrowth of herbaceous species compared with grasses, while other studies have suggested that brash left on site may shade out weeds to some extent, or promote a more diverse flora (Bergquist *et al.*, 1999). The effects will depend on the composition of the seed bank in the soil, and the proximity of natural seed sources. In Sweden, brash removal increased birch and pine regeneration in mixed conifer forests, probably because brash acts as a physical barrier and prevents tree seeds from reaching the soil (Karlsson *et al.*, 2002).

Figure 7

An excavator preparing a restock site for planting by placing mounds onto undisturbed brash mats.

Figure 8

Brash removed off-site during whole-tree harvesting using clam-bunk skidder.

The effect of brash removal on browsing intensity is quite equivocal, though some research suggests that deer browsing may increase on bare ground (Bergquist and Örlander, 1998). Brash can provide habitat for rabbits and will exacerbate browsing unless control measures are put in place.

Removal of brash may decrease nitrogen leaching, because such material is unavailable for breaking down and because brash is also thought to promote mineralisation and nitrification in the soil humus layer. Nevertheless, significant elevated leaching following harvesting is usually short-lived (Stevens *et al*., 1995) and this is rarely a reason for brash removal in itself.

Harvesting residues have been considered recently as a potential biofuel to support government renewable energy policies (Department of Trade and Industry, 1999). The greatest opportunity exists from harvesting residues resulting from cable crane or clambunk skidder timber extraction (Alexander, 1996; Drake-Brockman, 1996). Brash used in mats is unlikely to be suitable as a biofuel due to the mineral contamination caused by vehicular travel over the mat in the course of harvesting operations. However, it is possible that on some sites, brash could be subdivided into that necessary for soil protection during harvesting, and that which could support biofuel markets. It is vital that sufficient brash is used for the former purpose and that guidance contained in *Forests & water guidelines* (Forestry Commission, 2003) is followed. If removing brash off site for woodfuel, there may be options with regard to presentation at stump and delaying extraction may make it easier to collect and residues are able to dry on site prior to extraction and delivery. The potential options with regard to residue harvesting require further research.

Burn off brash

To reduce the difficulties sometimes faced by planting through brash, it is occasionally reduced in volume by burning (Figure 9). This is most appropriate for broadleaved lop and top, and conifer brash on small sites that do not justify the expense of transporting and using ground preparation machinery (Jones, 2002). Nevertheless, the *Forests and soil conservation guidelines* (Forestry Commission, 1998) recommend that burning should be avoided if possible. This is because some nutrients are released in potentially leachable forms which can lead to infertility and soil acidification on sensitive sites. Sites where brash is removed by burning will be affected in much the same way as if it was removed by other means. In addition, some organic soils may develop a water repellent surface. Burning may also facilitate the spread

Figure 9

Burning brash to reduce volume and facilitate planting.

and attack of *Rhizina undulata* (Group Dying syndrome) to conifers if present in the soil; it may also increase the risk of *Hylobius* attack (Heritage and Moore, 2000).

Burning residues carries risk of damage to adjoining vegetation and smoke pollution and nuisance. It must be carried out responsibly and with due regard to weather conditions and the views of local authorities (see Brash management and the law, page 9). Consideration must also be given to soil protection during the mechanical collection of brash into piles for burning on site.

Redistribute brash

Spreading brash evenly across a restock site may facilitate planting, but can be expensive. It is only worth considering where brash mat volumes are comparatively large and the provision of planting positions by spot raking through the brash mat (by excavator or the use of continuous mounders or scarifiers) is not possible. There remains a risk that soil will be damaged during brash movement operations and this probably outweighs the potential benefit of spreading the nutrients in the brash more evenly over the site.

Windrowing and spot heaping of brash

'Windrowing' or 'spot heaping' of brash across the whole site may be carried out to facilitate restocking (Figure 10). These operations involve the gathering of all brash materials into tall linear mounds (windrows) or individual piles (spot heaps) across the site. Windrows or heaps are perhaps most likely when timber has been harvested by cable crane or clam-bunk skidder, and delimbed at or near roadside. The operation also occurs where destumping is

Figure 10

Windrows of brash: tree stumps and roots on a restock site at Thetford Forest.

Figure 11

Mulched brash produced by chain flail mulcher in foreground, with excavator presenting brash for mulching in centre.

necessary, for example to minimise *Heterobasidion* fungal infection in Thetford Forest District. Windrows/heaps can be up to several metres in height, and result in a clean site for restocking, with provision of significant shelter. Nevertheless, such accumulations can provide habitat for rabbits, and leachate from fresh residues is a potential hazard to water quality for several years after placement. In addition, the width of the rows or heaps can produce gaps in restocking which could reduce the timber quality of the subsequent crop (Murgatroyd *et al*., 2000). Unless site planning can mitigate against these constraints, windrows or heaps should be avoided wherever possible by ground preparation through brash mats *in situ*. It may be possible to deal with the larger deposits at roadside by selling the material as biofuel, or using it for reinforcing extraction routes through conventionally harvested or continuous cover coups. The management of roadside heaps is covered in detail by Nisbet *et al*. (1997).

Brash chipping and mulching

There is increasing interest in the use of mechanical chippers and mulchers on site to comminute and redistribute brash materials so that the harvested site is easier to plant at regular tree spacing and is tidier in appearance (Figure 11). Such benefits must be balanced against added cost for chipping operations, risk of physical soil damage – particularly when large machines are used – and likelihood of increased nutrient leaching. The effect of the chips on tree seedling regeneration and weed growth will depend in part on the density of material over the surface, and research is in progress to examine these aspects.

Placement in spoil trenches

The use of brash to infill ditches created by soil excavation for mound construction (Figure 12) has become a common practice in some areas where mounding is used in restock operations. This practice will exacerbate the risk of acidification and nutrient leaching and is best avoided in Nitrate Vulnerable Zones (NVZs) (DEFRA, 2002) and areas sited on critical load exceedance squares (Forestry Commission, 2003).

Figure 12

Infilling a spoil trench with brash.

BRASH MANAGEMENT AND THE LAW

A Waste Management Licence may be required for brash burning operations or, alternatively, exemption from licensing will need to be obtained according to Paragraph 30, Schedule 3, Waste Management Licensing (WML) Regulations 1994. It is an offence to burn brash in the open except in accordance with these regulations. Burning brash may qualify for exemption from the regulations provided that all the following conditions are met:

- The material to be burned consists of wood, bark or other plant matter.
- The material is produced on land which is a forest, woodland, park garden, verge, landscaped area, sports ground, recreation ground, churchyard or cemetery, or it is produced on land as a result of demolition work.
- The quantity of brash burnt does not exceed 10 tonnes in any 24-hour period.
- Burning takes place on the site where it is produced.
- The material destined for burning is produced by the establishment carrying out the burning (and is not therefore disposed of on behalf of a third party).

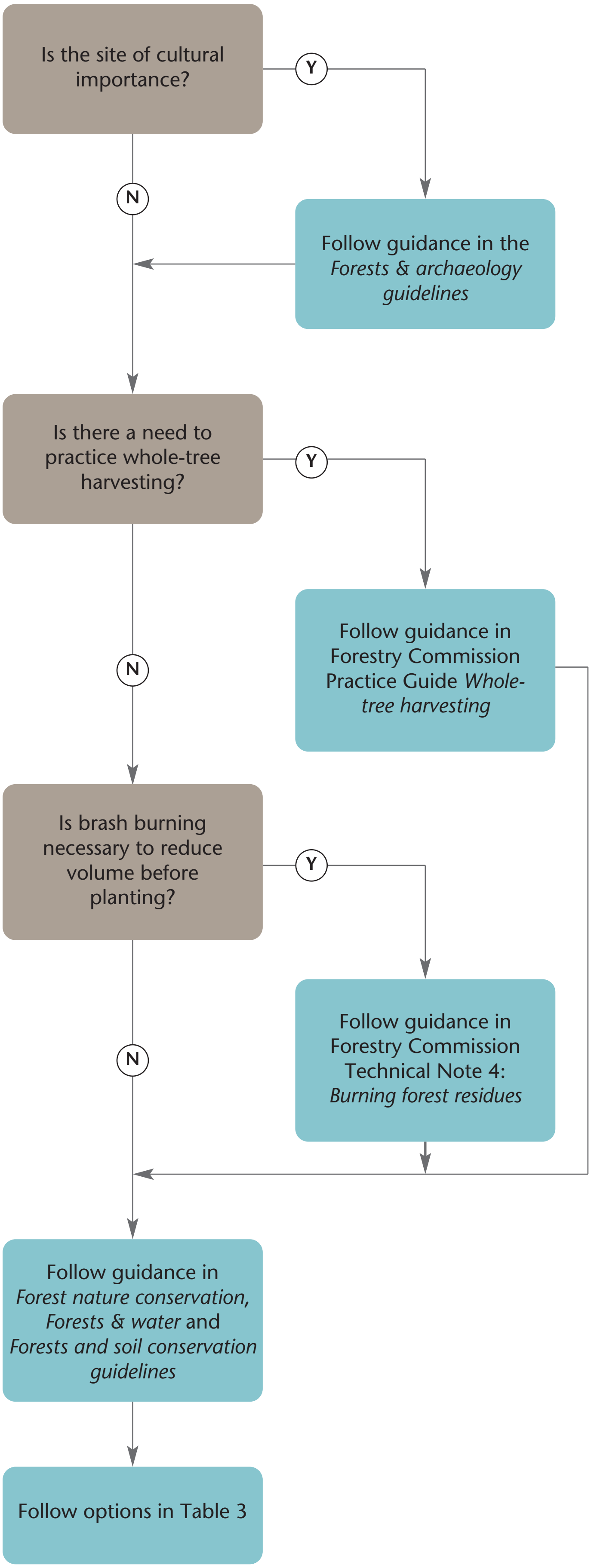
Brash can be stored *in situ* on the land where it is to be burned for a period prior to burning. Exemption from the WML Regulations must be applied for from the Environment Agency (EA) or the Scottish Environment Protection Agency (SEPA) in advance.

HIGH-LEVEL GUIDANCE

Figure 13 is a simple flow diagram which indicates how various important pieces of Forestry Commission guidance should be used in brash management decision making. It makes clear that environmental considerations, especially during harvesting and extraction, should be given priority. Considerations relating to possible biofuel marketing should not compromise the safeguarding of the forest site during harvesting, or the maintenance of fertility for successive rotations. Short-term gain, e.g. brash removal to facilitate restocking operations, may not be commensurate with attainment of full stocking, long-term tree growth or other aspects of sustainable forestry. A long-term, holistic view should be taken.

Figure 13

Decision tree for brash management.



CHECKLIST

Table 4 sets out the information that should be sought before effective decisions on brash management can be made. It is not an exhaustive list, but it can be used to ensure that pertinent information is obtained. It is strongly encouraged that information be supplemented by expert opinion where appropriate.

Table 4

Brash checklist.

Location
• Consider site in relation to critical load exceedance maps and Nitrate Vulnerable Zones (NVZs). • Consider location in relation to surface water features.
Site type
• Consider soil type and its sensitivity to physical damage during harvesting and restocking operations. Obtain soil information from maps, or surveys where maps are absent. • Establish current and past fertiliser requirements for site. Consider possible risk of inducing nutrient deficiency by brash removal.
Harvesting methodology
• Follow guidance in *Forests & water guidelines* regarding minimising site damage using brash. • Consider harvesting methodology and the appropriate flotation and ground protection needs. • Consider opportunities for woodfuel recovery.
Brash management
• Consider legal requirements under the Waste Management Licensing Regulations. • Consider browsing pressure from ungulates and rodents. • Consider restock policy, whether by replanting or natural regeneration. • Consider if *Heterobasidion* infection is a risk. • Consider proximity of brash windrows or heaps in relation to surface water features. • Consider nuisance value of burning brash, and risk of secondary fires.

TECHNICAL GUIDANCE

Forest Research Technical Development have produced a number of useful guides that refer to brash and its management, including costings for important operations. Those referred to in this Practice Note are given below.

REFERENCES AND USEFUL SOURCES OF INFORMATION

ALEXANDER, A.C. (1996).
Integrated residue harvesting: desk study.
Technical Development Branch Report 8/95.
Forestry Commission, Ae.

BERGQUIST, J. and ÖRLANDER, G. (1998).
Browsing damage by roe deer on Norway spruce seedlings planted on clearcuts of different ages. 2. Effect of seedling vigour. *Forest Ecology and Management* **105**, 295–302.

BERGQUIST, J., ÖRLANDER, G. and NILSSON, U. (1999).
Deer browsing and slash removal affect field vegetation on south Swedish clearcuts. *Forest Ecology and Management* **115**, 171–182.

DEFRA (2002).
Guidelines for Farmers in NVZs – England.
PB 5055, London.
www.defra.gov.uk/corporate/regulat/forms/agri_env/nvz/nvz4.pdf

DEPARTMENT OF TRADE AND INDUSTRY (1999).
New and Renewable Energy. Prospects for the 21st Century.
www.dti.gov.uk/renew/condoc/

DRAKE-BROCKMAN, G.R. (1996).
Residue production from clearfell at Kielder.
Technical Development Branch Technical Note 17/95.
Forestry Commission, Ae.

EBERMAYER, E. (1876).
Die gesamte Lehre von Waldsteu. Springer, Berlin.

FORESTRY COMMISSION (1990).
Forest nature conservation guidelines.
Forestry Commission, Edinburgh.

FORESTRY COMMISSION (1995).
Forests & archaeology guidelines.
Forestry Commission, Edinburgh.

FORESTRY COMMISSION (1998).
Forests and soil conservation guidelines.
Forestry Commission, Edinburgh.

FORESTRY COMMISSION (2002).
UK indicators of sustainable forestry.
Forestry Commission, Edinburgh.

FORESTRY COMMISSION (2003).
Forests & water guidelines 4th edn.
Forestry Commission, Edinburgh.

FORESTRY COMMISSION (2004).
The UK forestry standard.
Forestry Commission, Edinburgh.

HERITAGE, S. 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.

HIBBERD, B.G., ed. (1991).
Forestry practice.
Forestry Commission Handbook 6.
HMSO, London.

HUTCHINGS, T.R., MOFFAT, A.J. and FRENCH, C.J. (2002).
Soil compaction under timber harvesting machinery: a preliminary report on the role of brash mats in its prevention. *Soil Use and Management* **18**, 34–38.

HYVÖNEN, R., OLSSON, B.A., LUNDKVIST, H. and STAAF, H. (2000).
Decomposition and nutrient release from *Picea abies* (L.) Karst. and *Pinus sylvestris* (L.) logging residues. *Forest Ecology and Management* **126**, 97–112.

JONES, B.J. (2002).
Burning forest residues.
Forestry Commission Technical Note 4.
Forestry Commission, Edinburgh.

KARLSSON, M., NILSSON, U. and ÖRLANDER, G. (2002).
Natural regeneration in clear-cuts: effects of scarification, slash removal and clear-cut age. *Scandinavian Journal of Forest Research* **17**, 131–138.

LANGVALL, O., NILSSON, U. and ÖRLANDER, G. (2001).
Frost damage to planted Norway spruce seedlings – influence of site preparation and seedling type. *Forest Ecology and Management* **141**, 223–235.

MASON, B., KERR, G. and SIMPSON, J. (1999).
What is continuous cover forestry?
Forestry Commission Information Note 29.
Forestry Commission, Edinburgh.

MORGAN, S. (2001).
Excavator ground preparation method development.
Forestry Commission Technical Development Branch Internal Report. Forestry Commission, Ae.

MORGAN, S. (2002a).
Excavator ground preparation method development III.
Forestry Commission Technical Development Branch Internal Report. Forestry Commission, Ae.

MORGAN, S. (2002b).
Excavator ground preparation method development II.
Forestry Commission Technical Development Branch Internal Report, Ae.

MORGAN, S. and IRELAND, D. (2004).
Excavator mound spacing on restocking sites.
Forestry Commission Technical Note 8.
Forestry Commission, Edinburgh.

MURGATROYD, I.R., MORGAN, S. and JONES, W.M. (2000).
Excavator ground preparation.
Forestry Commission Technical Development Branch Internal Project Information Note.
Forestry Commission, Ae.

NISBET, T., DUTCH, J. and MOFFAT, A. (1997).
Whole-tree harvesting: a guide to good practice.
Forestry Commission Practice Guide.
Forestry Commission, Edinburgh.

OLSSON, B.A., BENGTSSON, J. and LUNDKVIST, H. (1996).
Effects of different forest harvest intensities on the pools of exchangeable cations in coniferous forest soils. *Forest Ecology and Management* **84**, 135–147.

PROE, M.F., CRAIG, J., DUTCH, J. and GRIFFITHS, J. (1999).
Use of vector analysis to determine the effects of harvest residues on early growth of second-rotation Sitka spruce. *Forest Ecology and Management* **122**, 87–105.

PROE, M.F., GRIFFITHS, J.H. and McKAY, H.M. (2001).
Effect of whole-tree harvesting on microclimate during establishment of second rotation forestry. *Agricultural and Forest Meteorology* **110**, 141–154.

SAUNDERS, C. (2002).
Brashmat construction trials.
Forestry Commission Technical Development Branch Internal Report. Forestry Commission, Ae.

STEVENS, P.A., NORRIS, D.A., WILLIAMS, T.G., HUGHES, S., DURRANT, D.W.H., ANDERSON, M.A., WEATHERLEY, N.S., HORNUNG, M. and WOODS, C. (1995).
Nutrient losses after clearfelling in Beddgelert Forest: a comparison of the effects of conventional and whole-tree harvest on soil water chemistry. *Forestry* **68**, 115–131.

TAYLOR, C.M.A. (1991).
Forest fertilisation in Britain.
Forestry Commission Bulletin 95.
HMSO, London.

TITUS, B.D. and MALCOLM, D.C. (1991).
Nutrient changes in peaty gley soils after clearfelling of Sitka spruce stands. *Forestry* **64**, 251–270.

WOOD, M.J., CARLING, P.A. and MOFFAT, A.J. (2003a).
Reduced ground disturbance during mechanized forest harvesting on sensitive forest soils in the UK. *Forestry* **76**, 345–361.

WOOD, M.J., MOFFAT, A.J. and CARLING, P.A. (2003b).
Improving the design of slash roads used to reduce soil disturbance during mechanised forest harvesting of coniferous forest plantations in the UK. *International Journal of Forest Engineering* **14**, 11–23.

ZABOWSKI, D., JAVA, B., SCHERER, G., EVERETT, R.L. and OTTMAR, R. (2000).
Timber harvesting residue treatment: Part 1. Responses of conifer seedlings, soils and microclimate. *Forest Ecology and Management* **126**, 25–34.

Website

Ministerial Conference on the Protection of Forests in Europe (MCPFE): www.mcpfe.org

Please note that all the guidance published by Forestry Commission, Ae is available from:

Forest Research
Technical Development
Forest Management Division
Ae Village
Dumfries
DG1 1QB

T: 01387 860264
F: 01387 860386
E: tdb.ae@forestry.gsi.gov.uk

Enquiries relating to this publication should be addressed to:

Andy Moffat
Environmental and Human Sciences Division
Forest Research
Alice Holt Lodge
Farnham
Surrey
GU10 4LH

T: 01420 526202
F: 01420 23653
E: andy.moffat@forestry.gsi.gov.uk

ISSN 1460-3810
ISBN 0-85538-686-X

FCPN013/FC(GB-ECD)/IA-2K/FEB06