OPEN GROUND IN UPLAND FORESTS: A REVIEW OF ITS POTENTIAL AS WILDLIFE HABITAT AND APPROPRIATE MANAGEMENT METHODS

RUSSELL ANDERSON
FOREST RESEARCH

November 2003

SUMMARY

This review deals with open ground in forests in Britain's uplands. Such ground includes integral open space (roads, rides, streams, deer glades and felled areas), larger open areas (high ground and bogs, etc. managed for conservation) and grazings. In the uplands, integral open space probably occupies 12.5 % of the woodland area while the combination of all three types occupies 34 % of the Forestry Commission's landholding. The integral open space is mainly managed for access, compartmentalisation, fire limitation, riparian buffering and deer management. Nature conservation could be incorporated as an objective.

The setting of conservation objectives is considered and the concept of managing for biodiversity is discussed. In theory, managing for biodiversity is ideal but in reality, it is impractical because total biodiversity is too complex to deal with. The requirements of various species and groups of plants and animals known to use forest open ground are reviewed. The importance of such ground for other, less well studied, groups needs to be assessed.

Methods of managing open ground for nature conservation are reviewed for the three broad vegetation types, heathland, grassland and mire. Some possible conservation objectives are selected for larger areas and for land in the network of integral open space. Methods appropriate for these objectives are reviewed. Management could involve prescribed grazing or carefully targeted cutting regimes.

Forest open ground is an important nature conservation resource whose full potential is not yet being achieved. Some general management principles that could benefit most, but not all species using forest open ground, are recognised. Methods are required for identifying and prioritising the various conservation interests of a site. Ungrazed ground vegetation tends to become less species-rich because tall, vigorous plant species out-compete others for light. Conservation grazing has great potential. The sustainable forestry standards require the management of open ground but practice seems to fall short of the requirements. Unless the standards are more strictly upheld or other incentives are provided, management of open ground for nature conservation objectives will not become normal practice.

CONTENTS

INTRODUCTION

Rationale

'Treatment of open spaces is the single most important factor in the success or failure of nature conservation in forests' – George Peterken (Peterken, 1996).

'The skill required to manage these sites in a species-specific way is immense….. The easiest decision is to do nothing but nothing succeeds like succession. Ponds will dry up, moorland will be colonised by natural regeneration, birchwoods will move on' – Donald McPhillimy (McPhillimy, 1989).

Open ground in forests takes many forms, from large areas unsuitable for planting and/or designated for nature conservation, to various types of small, interconnected areas: rides, roads, way-leaves, deer glades, stream-sides and quarries. There is usually also a shifting patchwork of temporary open ground – felled coupes at different stages of restocking. Sometimes there are also semi-open areas such as altitudinal treelines, windthrow gaps, failed or checked patches, sparsely wooded bogs and heaths, wood pastures and areas damaged by fire. Large areas designated for conservation – SSSIs, SACs, NNRs, etc. - should already be subject to a management plan and in many cases will be managed with nature conservation objectives foremost. Some large open areas are managed with mainly economic objectives, often as sheepwalk but sometimes as wind farms. There may be others that are not managed at all. In general, the network of small open areas is subject to minimal management geared towards fulfilling specific purposes including forest compartmentalisation, access, fire limitation, riparian buffering, deer management, etc. There is huge scope for improving the nature conservation value of forests by actively managing open ground.

Why isn't more forest open ground managed for nature conservation? Firstly, there is not the same pressure to enhance open habitats as there is to meet economic targets, achieve certification standards, provide social benefits or follow environmental guidelines. Secondly, managing land for nature conservation involves real costs but attracts little or no direct economic return. Thirdly, perhaps most importantly, stands of trees dominate forests. Other, minor components of forests or forested landscapes are less well understood and some basic principles are unclear, such as the relative merits of active management and minimum intervention. Lastly, while attention has been drawn to the potential of open ground in forests for nature conservation (Hill, 1983; McIntosh, 1988; McPhillimy, 1989; Peterken, 1996; Ratcliffe, 1986; Ratcliffe & Petty, 1986), management guidance on the subject has mainly focused on the lowlands, on southern Britain and on plants and butterflies (Anderson & Carter, 1988;

Ferris & Carter, 2000; Warren & Fuller, 1993). The quite different possibilities provided by open ground in upland forests have been largely overlooked.

This literature review aims to gather together and interpret existing knowledge on managing upland habitats, placing it in the context of forest open ground. It will evaluate the potential benefits for nature conservation of managing such ground and deals with the applicability and success of different methods of achieving these benefits.

In considering management methods, the range of open vegetation types potentially requiring management, the range of likely conservation objectives and the corresponding range of potential methods is too large to cover here. It has been necessary to focus on the three major broad vegetation types, heathland, grassland and mire. Together these cover the majority of open ground in upland forests. Other land covers, such as standing water, riparian and open water margins, crags, screes and rocky ground, treeline scrub and restocking areas are not comprehensively reviewed but some of their particular habitat values emerge under the accounts of the various species groups whose requirements are reviewed in the management objectives section.

Scope

Practical guidance on managing open ground for nature conservation has already been published for lowland forests (Anderson & Carter, 1988; Carter & Anderson, 1987; Ferris & Carter, 2000; Warren & Fuller, 1993). This review is the first stage towards providing similar guidance on managing open ground in upland forests. In keeping with the general nature of upland forests in Britain, the focus is mainly on planted conifer forests but often the management will also be relevant to broadleaved and mixed forests and to those of semi-natural origin.

Besides a focus on the uplands, particular attention is devoted in this review to the network of small or narrow areas of open ground in upland forests because, despite its distinctive environmental qualities, it is not specifically covered by existing conservation management guidance. Larger expanses of upland open ground on the forest estate are also dealt with but in less depth. Their management for conservation hardly differs from that of similar land outwith the forest estate for which sources of conservation guidance already exist (Backshall, 2001a; Fielding & Haworth, 1999; Kirby, 1992; Sutherland & Hill, 1995). Practicality dictates that there is a lower limit in the size of patch of open ground below which management is unlikely to be undertaken because it would not be cost-effective or because the patches are destined to close over quickly. Thus rides, streamsides and glades are within the scope of this review but windthrow gaps and thinning racks are not.

Most of the information gathered for review pertains to permanent open ground. However temporary open ground, in the form of felled coupes and young restocked areas, is also covered in the species group accounts in the section on management objectives.

The review itself is not presented in the form of guidance to forest managers; instead it provides a synthesis of relevant scientific and technical knowledge that can contribute to the formulation of guidance. Also included is some discussion of issues arising. A subsequent practical guidance document is planned.

Structure of the review

Information has been divided according to whether it pertains to forest open ground generally or to heathland, grassland or mire in particular. Introductory and methodological sections are followed by two sections dealing with forest open ground in general. The first covers what we already know about forest open ground and the second deals with setting management objectives, including a discussion of biodiversity as an objective and a look at a range of potential conservation targets.

The remaining sections deal with heathlands, grasslands and mires. They cover the reasons for conservation of these semi-natural habitats and possible management objectives before reviewing the literature on management methods for various conservation objectives. Management of extensive areas and small or linear areas are treated separately and habitat restoration is also covered.

METHODS

Search methods

Information was gathered by using Web of Science to search the scientific literature and building on the material found by using the ‘articles citing this paper’ and the ‘articles cited in this paper’ tools to work forward and backward in time, tracing developments in the most relevant research topics.

Wider searches took in my own and colleagues’ book shelves and literature collections amassed from general reading, often with the help of the Forestry Commission library’s ‘Assistance with Reading’ service.

Sources

A wide variety of types of information sources have been tapped. Scientific papers mostly came from journals in the conservation, applied biology and forestry sectors (Table 1).

Material published by Britain’s three national nature agencies provided most of the information on management methods. Forest industry guidance produced by the Forestry Commission and parter NGOs, notably RSPB and the Woodland Trust, yielded much relevant material on conservation practice.

A few papers from proceedings of symposia were used. Some relevant unpublished material was also available, mostly in the form of contract reports and student dissertations.

Table 1. Scientific journals containing articles used in this review.

Scientific sector	Journal
Conservation	Biodiversity and Conservation, Biological Conservation British Wildlife Conservation Land Management Ecos Enact Journal of Environmental Management National Trust Views Watsonia
Biology	Acta Oecologia – Oecologia Generalis Aspects of Applied Biology Botanical Journal of Scotland Grass and Forage Science Journal of Applied Ecology Journal of the British Grassland Society Journal of Ecology Journal of Range Management Journal of Zoology London Soil biology and biochemistry Vegetatio
Forestry	Australian Forestry Forest Ecology and Management Forestry Journal of Arboriculture Quarterly Journal of Forestry Scottish Forestry

ABOUT FOREST OPEN GROUND

Scale of the resource

There are important differences between extensive unplanted areas on the forest estate and the much smaller open ground areas that form networks within and on the edge of forests. The extensive areas lack the shelter that much of the open ground network benefits from. Usually, extensive areas are subject to grazing, whereas the open ground network is very rarely grazed other than by the indigenous deer population. Many extensive open areas on the forest estate are SSSIs and their management is constrained by an SSSI management plan. This is seldom the case for the forest open ground network.

Large areas of grazed open ground on the forest estate are no different to similar areas on the open hills and moors (i.e. the wider uplands). Management objectives and methods of achieving them will usually be the same as those adopted for the wider uplands although there may be scope for raising the standing of conservation objectives relative to that of economic ones. Contrastingly, in the forest open ground network, forest managers have the freedom to decide on management objectives and to come up with methods that will achieve these objectives. However, methods must be affordable and should not compromise other uses of this ground. This is a challenging opportunity for the forester.

The distinction between the two different scales of open ground is not always straightforward. There are plenty of extensive areas that are not SSSIs and don't have a management plan and some that are not grazed so are different from the wider uplands. Linearly distributed open ground - roads, rides, streams and way-leaves - is obviously part of the network, as are the associated quarries, timber stacking areas and turning bays. The forest edge (i.e. ground between the outermost trees and the fence or ownership boundary) is also included in the network because it is generally ungrazed and may be sheltered. Likewise, lake or loch sides are included. Deer glades may or may not be directly connected to the rest of the network but certainly count as part because they are small, sheltered and within the forest fence. Broad riparian open areas can be large in extent but are also part of the network because they are connected to it via streams or rivers and are generally sheltered and of limited width. Small areas that were left unplanted either because they were unplantable or because they were recognised as valuable natural habitats (e.g. springs, flushes, fens, basin mires, peat cuttings, crags, screes, limestone pavements) can be regarded as part of the network too but they may benefit from very specific, targeted management. Enclaved agricultural land in the forest, if still in use, can be managed as part of the wider uplands but if abandoned, becomes part of the open ground network within the forest.

Types and distribution

During the 1995-98 survey period for the National Inventory of Woodland and Trees, **integral** open space occupied 8 % of Great Britain's **woodland** area, with felled areas not yet restocked and windblown areas not yet cleared or regenerated occupying a further 2% (Smith & Gilbert, 2003). Corresponding figures of 10.5% and 2% for Scotland are probably more representative of the uplands.

Of Forestry Commission managed land in Scotland, 20% is ‘open land within the forest’ and a further 5% is ‘agricultural and grazing land’ (Forestry_Commission, 2002a) but these categories mostly comprise extensive open areas and exclude integral open space and felled areas awaiting restocking (Forestry_Commission, 2002b). If the National Inventory figures for all woodland in Scotland hold true for FC woodland in Scotland, then integral open space, including felled and windblown patches, occupies approximately 9% of the **landholding**. A total of 34% of all FC-managed land in the uplands might be termed forest open ground.

Information on the breakdown of forest open ground into open ground types and/or vegetation types is generally not available. There is one notable exception, that of Kielder Forest. In the late 1980s, 15% of the plantation area was occupied by roads and rides and a further 5 % occupied by open ground left unplanted for other reasons (McIntosh, 1988). These estimates exclude enclaves of agricultural land within the forest and other large areas of land remaining unplanted for conservation reasons. A more detailed estimated breakdown for Kielder (Good *et al.*, 1990) is summarised in Tables 2, 3 and 4. These show the total area, or for the linear open ground types the total length, broken down into vegetation types for two altitude classes. Data on the breakdown into drift geology types are also available. Some facts emerge which presumably also apply to other upland forests. Firstly, if the forest spans an appreciable altitude range, as it does at Kielder, open ground vegetation types vary with altitude. Secondly, the vegetation type varies with the type of open ground. For example, at higher elevations, M19 *Calluna-Eriophorum* blanket mire predominates on large unplanted areas and rides, while road and river sides predominantly support U4 *Agrostis-Festuca* acid grassland. Thirdly, restocks (i.e. clear-felled and replanted areas) support a more limited range of vegetation types than the other open ground types.

The breakdown of open ground in Forest Enterprise forests in Caithness and Sutherland into types (Pyatt, 1993) is shown in Table 5. The types which fall into the extensive unplanted areas category are far more important than the open ground network in area terms, making up more than 70 % of all forest open ground in these forests.

Table 2. Vegetation of linear habitats in Kielder Forest in the late 1980s (Good *et al.*, 1990). The total length of roads, rides and rivers above and below 300 m altitude are given and the breakdown into NVC plant communities (Rodwell, 1991a; Rodwell, 1991b; Rodwell, 1992) is expressed as the percentage of the total length of the linear habitat type within the altitude class. Key to NVC community types: H = heathland, M = mire or wet heath, U = acid grassland, MG = mesotrophic grassland, W = woodland. Full details in Rodwell texts.

	Total length (km)	H12	M19	M15	M15 /U2	U2	U4	M25	M23	M6	MG9	W10	W4	Unknown
>300 m asl														
Roads	274	-	8	6	4	-	40	6	6	-	20	-	-	9
Rides	560	7	55	7	11	5	-	4	-	5	3	-	3	-
Rivers	343	-	-	-	27	-	37	4	6	-	1	6	-	18
<300 m asl														
Roads	354	-	-	9	-	-	9	19	16	-	47	-	-	-
Rides	719	6	2	22	14	3	10	14	7	5	12	3	-	2
Rivers	326	-	-	-	3	-	13	23	25	-	21	18	-	-

Table 3. Vegetation of larger unplanted areas in Kielder Forest in the late 1980s (Good *et al.*, 1990). The total areas above and below 300 m altitude are given and the breakdown into NVC plant communities is expressed as the percentage of the total area of larger unplanted areas within the altitude class.

	Area (km^2)	H12	M18	M19	M15	M15 /U2	U2	M25	M23	M6	W10	U5	U20	MG5	MG9	Unknown
>300 m	71	14	14	47	1	1	10	0	2	1	1	-	-	-	3	2
<300 m	28	0	2	-	14	5	-	4	21	0	3	6	0	5	11	29

Table 4. Vegetation of restock areas in Kielder Forest in the late 1980s (Good *et al.*, 1990). The total areas above and below 300 m altitude are given and the breakdown into NVC plant communities is expressed as the percentage of the total area of restocks within the altitude class.

	Area (km^2)	M19	M15	M25	MG9	W10	Little or no Vegetation
>300 m	16	14	29	14	29	-	14
<300 m	42	5	47	11	32	-	5

Table 5. Areas of open ground in Forest Enterprise forests in Caithness and Sutherland broken down into different types of open ground (Pyatt, 1993).

	Very wet bog (km^2)	Hilltops and landscaping (km^2)	Rides and roads (km^2)	Streamsides (km^2)	Lochsides (km^2)	Unplanted ground as percentage of forest area
Caithness	7	1	2	1	0	14 %
Sutherland	6	24	5	3	2	12 %
TOTAL	13	25	7	5	2	12 %

Characteristics

Upland open ground incorporated into a new forest, even though it is to remain as open ground, will undergo a change in vegetation. Generally, events occur as follows. The forest is fenced to exclude domestic stock and/or deer. The former land use, which almost invariably will have involved grazing (and perhaps also periodic burning), ceases. The vegetation changes quickly at first because, in the first summer without grazing, the ground vegetation grows taller and denser than before. Over the next few years, without disturbance, competition reigns. Species with a competitive advantage in a particular situation come to dominate and the other, suppressed species may gradually disappear. After a few years, these relatively undisturbed ecosystems may contain few plant species.

This happens on some sites but not all. The main upland vegetation types are dominated by heather, grasses, rushes, bracken, sedges, shrubs or trees. The response of the different types to the cessation of grazing varies (Hope *et al.*, 1996), with soil fertility the major influence. A review of published exclosure studies (Marrs & Welch, 1991) revealed that vegetation response (i.e. changes in composition and structure) was usually greater in communities that had formerly been more heavily grazed. For example, on Rum, species-poor *Agrostis-Festuca* grasslands changed markedly (*Deschampsia cespitosa*, *Festuca rubra*, *Luzula sylvatica and Poa pratensis* increased their cover) but *Calluna-Molinia* wet heath hardly changed at all (Ball, 1974). In some situations, excluding sheep can result in increases in wild herbivores, (e.g. deer, rabbits, hares and voles) and this increased ‘natural’ grazing can partly cancel out the effects of removing sheep (Hope *et al.*, 1996; Marrs & Welch, 1991).

Increased vole numbers can increase the food supply for birds of prey and other predators.

Well-grazed vegetation on fertile, grassy sites, which would formerly have provided plenty of microsites suitable for germination and early seedling growth, gets taller and more tussocky when grazing is discontinued (Ball, 1974). Little foliage is being eaten off, so a larger amount of dead plant material (litter) is deposited in autumn (Humphrey & Patterson, 2000; Sykes *et al.*, 1989). The hooves of the grazing animals no longer trample down the litter so the bottom layer of the vegetation becomes matted and the ground surface heavily shaded. This extensive, unbroken litter layer provides few opportunities for seedling establishment so the opportunistic plants that would formerly have sprung up in the sheep's hoof-prints or dung patches or places where the grass was grazed short, become scarce or extinct. Any shrub and tree seedlings already established, or that manage to get established and hold their own in competition with the taller ground vegetation, are now less likely to be browsed and may develop into bushes or saplings. Forbs (non-grassy herbaceous species), especially herbs (non-woody small plants which die back annually) are generally unable to compete with tall grasses and are gradually lost (Ball, 1974).

On less fertile grassy sites - those dominated by mat grass (*Nardus stricta*), wavy hair grass (*Deschampsia flexuosa*) or purple moor grass (*Molinia caerulea*) - grazing would have had less effect on the vegetation and less of a change can be expected on removal of grazing. However these vegetation types are found on acid soils and may have originally developed from heath vegetation under the influence of grazing. They are sometimes termed grass heaths. Where heather is absent when grazing ceases, its reappearance can be impossible to predict (Marrs & Welch, 1991).

Bog and heath vegetation would formerly have supported a low density of grazing animals but may still change, albeit very slowly, after incorporation as forest open ground. Heathery vegetation formerly overgrazed or grazed during winter will have an increased cover of grass at the expense of dwarf shrubs. Here, the heather can be expected to increase its cover again when grazing is removed (Marrs & Welch, 1991). Where heather cover on blanket bog has become very low or even disappeared, heather can slowly recover as a result of removing grazing. In this situation species-richness can increase in the ungrazed vegetation (Adamson & Kahl, 2003).

Research on forest open ground

Research undertaken or supported by the Forestry Commission

In 1971 the Forestry Commission was not doing any in-house conservation-related research, although it was claimed that the combination of site improvement and tree breeding research would have conservation spin-offs (Holtam, 1971).

The first FC research related to conservation on open ground began around 1975 with a study of the use, for wildlife conservation management, of broadleaved and mixed woodlands interspersed with glades along watercourses and dry gullies (Rowe, 1976; Rowe, 1979). A comparison of bird communities of afforestation and restock sites began in 1979 (Rowe, 1980). This was followed by studies of raptors, particularly tawny owl and goshawk, in second rotation forests. This work highlighted the importance of restock sites as sources of prey in the form of field voles (Petty, 1983; Petty, 1984; Petty, 1985; Petty, 1990; Petty, 1994; Petty & Peace, 1992). The work led on to a study with Aberdeen and Durham Universities of the factors affecting synchronicity of vole population cycles among individual restock sites at Kielder (Petty *et al.*, 1997).

The investigation of forest management methods for conserving rare reptiles and amphibia also started in 1979 (Rowe, 1980). This included FC-commissioned research by Southampton University on habitat use by sand lizards in Wareham Forest. Ride verges and unplanted habitats with dry, heathery vegetation were the most important habitats in the forest (Dent & Spellerberg, 1986; Spellerberg & Wright, 1982; Spellerberg & Wright, 1983). Further studies of reptile ecology focused strongly on forest open ground because of its potential as an important habitat and as a refuge for reptiles displaced from former habitats by afforestation. Forest management guidance was produced as a consequence (Spellerberg, 1988a; Spellerberg, 1988b).

New FC research on cutting back and shaping ride-sides in lowland forests to benefit woodland plants and butterflies began in 1986 (Anderson & Carter, 1987; Carter & Anderson, 1987). It included the development of a method of calculating the light climate of rides in relation to season, width and orientation (Anderson, 1988; Anderson & Carter, 1988; Carter & Anderson, 1988). Experiments were conducted, in collaboration with Wye College, in which the benefits of widening rides were demonstrated (Buckley, 1989; Carter & Ferris-Kaan, 1989; Ferris-Kaan, 1992). A survey in 1989 revealed that, in practice, ride management for conservation was often not working, possibly because of incorrectly timed cutting and failure to remove the cut material (Ferris-Kaan, 1990b; Ferris-Kaan, 1994). Machines that could cut ride vegetation and remove the cuttings were compared at a demonstration site (Ferris-Kaan, 1991). Further vegetation management studies tested the effectiveness of herbicides and a growth regulator to suppress aggressive species and favour broadleaved herbs (Ferris-Kaan, 1990a), without much success (Ferris-Kaan, 1991). Another study showed that light scarification could increase species diversity in the short term but severe scarification only encouraged undesirable common species (Ferris-Kaan, 1991; Ferris-Kaan, 1994).

Following the devastating storm of 1987, a study was set up to assess whether windthrown areas on former heathland sites could revert to lowland heathland (Ferris-Kaan, 1991). Three years on, there was little indication of heath recovery (Ferris-Kaan, 1994). An FC-supported study by the University of East Anglia found that the floristic interest of restock sites was less than that of the original Breckland heaths and calcareous grasslands but suggested some possible improvement techniques (Prigmore, 1991).

With the burgeoning interest in biodiversity, the FC’s biodiversity research programme included a project on how forest structure influences insect diversity, focusing partly on canopy gaps, such as roads and rides (Carter & Winter, 1994; Evans, 1992; Evans, 1993). It also included a study of the impacts of deer and hare browsing on the vegetation composition of restock sites (Pepper, 1994).

The FC began studying the forest habitat requirements of bats by funding a studentship (Neville, 1986), followed by an in-house review (Mayle, 1987; Mayle, 1988). By 1990 this research had shown the importance of ponds and rides as feeding areas for bats (Mayle, 1990a; Mayle, 1992) and management guidance had been produced (Mayle, 1990b).

Attention was turned to upland forests in 1987. The FC commissioned ITE Bangor to study plants and invertebrates of open and planted ground at Kielder and to recommend how management could be modified to better conserve and enhance these communities (Good, 1988; Patterson, 1988). This study showed that forest open ground provides habitats that are scarce elsewhere in the uplands and that their management should be integrated with that of the forest. High altitude bogs were found to be particularly sensitive to afforestation (Good, 1991). The FC also supported a separate study comparing ground vegetation development in mature Sitka spruce stands with that in restocks up to six years old (Abdy, 1991).

The FC commissioned the RSPB to study demography, habitat use and the diet of black grouse in upland Wales (Hope-Jones, 1988). The importance of forest open ground and forest edges has been studied in several bird research projects (Bowden & Green, 1991; Parr, 1991; Patterson & Ollason, 1991; Patterson & Ollason, 1993).

New experimental research on the value of cattle grazing in maintaining the floristic diversity of riparian ground began in the late 1980s (Patterson, 1989; Ratcliffe, 1992). It has shown that seasonal cattle grazing can halt the decline in plant species richness of riparian grassland communities after afforestation, confirming the potential of cattle grazing as a conservation management tool in forests (Humphrey & Patterson, 2000). Experiments on methods of encouraging the establishment of heather, birch and juniper on forest open ground (Patterson, 1991) were also begun. A review of the potential for using grazing as a tool to manage forest habitats for wildlife conservation found little direct information to exist but literature on plant/animal interactions was used to derive conservation grazing regimes (Gordon & Fraser, 1991). A more recent collaborative venture with European partners led to an assessment of common research needs (Humphrey, 1998; Humphrey *et al.*, 1998).

Research by other organisations

The Nature Conservancy Council commissioned research that included conservation of forest open ground. In 1975, it contracted its offshoot, ITE Bangor, to begin a major investigation on the impact of afforestation on upland vegetation. Initially they used a chronosequence approach but changes with time since planting were confounded by a change in the predominant soil types afforested (Hill, 1978b). A second approach was to undertake a 1976 re-survey of Caeo Forest for comparison with a 1944 survey by Oxford University (Hill & Jones, 1978). Both these studies focused on planted ground. A survey of part of Clocaenog Forest and the adjacent, unafforested, Hiraethog Moors showed that a few small wetland plants and some grazing-dependent moorland plants had been lost from the afforested area while more new species had appeared, mostly lowland species of road verges (Hill, 1978a; Hill, 1983). A separate study within the same contract focused on forest roads as habitats for wild plants in coniferous forests (Evans, 1978).

NCC evidence to a 1980 House of Lords Committee inquiry into further predicted afforestation inspired the Ecology and Conservation Unit of University College London to undertake, as a useful academic exercise, a study of the botanical interest of areas left unplanted during upland afforestation (Goldsmith, 1981). Based in Galloway, it focused on lochs, streams, roads, rides, edges and the effects of fertiliser. For each situation, it recommended changes, mainly in forest design, that could improve the value of forests as plant habitats.

A study was set up at Stone Chest, Cumbria by ITE Merlewood in 1972, apparently to monitor the success of forestry design with game conservation as a major objective. It involved monitoring amphibians, reptiles, birds, mammals and vegetation in the newly planted forest, including the open ground (Sykes *et al.*, 1989).

A set of case studies of good conservation practice in Scotland’s forests was commisioned by the NCC and the Countryside Commission for Scotland and included cases focusing on conservation design and planning, watercourse management and open ground management (McPhillimy, 1989). It highlighted the importance of open ground and the enormity of the task of learning how to make the most of it in terms of conservation benefits.

A study of rides in lowland forests planted on ancient woodland sites was undertaken by ITE Monks Wood, partly funded by the NCC (Greatorex-Davies *et al.*, 1994; Sparks & Greatorex-Davies, 1992; Sparks *et al.*, 1996). It focused on the effects of increasing shade and aspect on the important plant and invertebrate communities of the rides, demonstrating the need for remedial action to conserve the species-richness of these communities as the trees grew up and increasingly shaded them. The findings contributed to JNCC guidance on the management of woodland rides and glades for wildlife (Warren & Fuller, 1993).

In Ireland, two university groups studied invertebrate habitats in different forest types but most of their research was focused on the tree stands, rather than the open ground (Day *et al.*, 1993; Fahy & Gormally, 1998). One group went on to study invertebrate communities of forest road edges (Mullen *et al.*, 2003). A new project on biodiversity and forestry, funded by COFORD and EPA is being led by University College Cork. It will include measurement of the effect on biodiversity of creating or enlarging open spaces in forests (COFORD, 2001).

Little has been published overseas, other than from Ireland, on research pertaining to forest open ground. Presumably in most countries the former, native vegetation was forest rather than an open type so nature conservation in plantation forests revolves around native forest remnants (Lindenmayer *et al.*, 2003). One unreplicated study in the USA compared methods of managing an electricity way-leave and indicated that a mowing plus herbicide treatment for the zone directly beneath the wire may be the most successful of those tested in maximising bird species diversity (Yahner *et al.*, 2003).

Open ground in the certification standards

The UK Forestry Standard (Forestry_Authority & Department_of_Agriculture_for_Northern_Ireland, 1998) includes some criteria and indicators of sustainability but relies strongly on previously published guidance to furnish the detail. It specifically requires that opportunities for nature conservation are considered and accommodated and that biodiversity is not unreasonably compromised by other management objectives. Designated sites and sensitive areas for rare or threatened species and genotypes must be recorded and protected. Semi-natural sites have to be identified and the principles of good management for such sites applied. There is also a requirement to avoid afforesting or irreversibly changing habitats subject to local Biodiversity Action Plans. An acceptable standard of forest design must be applied to water margins and opportunities must be taken to improve riparian zones during the course of forestry operations.

The Standard also recognises that some species and habitats, including those associated with open ground and water, require special management because normal forest management does not cater for them. Sites of high ecological value include those supporting Red Data Book or local Biodiversity Action Plan habitats or species, semi-natural open ground habitats (especially where extensive or of a diverse or rare type) and water bodies, streams and wetlands with a ‘natural’ character. Such sites should be identified and taken into account in planning. Cultivation and drainage operations should avoid damaging the hydrology of wetlands of conservation or heritage value. Opportunities should be taken to restore those previously drained but not successfully planted. The Standard also allows for the clearance of plantations to restore open ground habitat in places where it is rare, subject to consultation with FC and the appropriate national nature conservation agency (Forestry_Authority & Department_of_Agriculture_for_Northern_Ireland, 1998).

The Standard requires foresters to ensure that the management of rides, road edges and other open space promotes, or is sympathetic to, wildlife conservation. The design of new woodlands has to include 10-20 % of the area as open space and this should be used to encourage the development of wildlife habitat. Additional open space should be created in areas not naturally broken up by topographic features or natural woodland. The design of open ground is particularly important in new native woodland. It should be based on features of conservation potential and site diversity, should occupy at least 20 % of the area and should be linked to adjoining open ground habitat. When conifer forests are being restocked, the forest design should improve the network of open ground, streams and semi-natural habitats. Management plans for semi-natural woodlands should cover management of permanent and temporary open space, recognising that some open space can only be maintained by positive management. Riparian ground, wetlands, rock outcrops and parts of the ride network should be used as the bases for any extension or restoration of open areas (Forestry_Authority & Department_of_Agriculture_for_Northern_Ireland, 1998).

The UK Woodland Assurance Scheme (UKWAS) lists requirements for certification of woodlands as sustainable. Some of these affect forest open ground (Table 6).

Table 6. UK Woodland Assurance Scheme requirements related to design and management of forest open ground.

	Requirement
1.1.4	Commitment to protect and maintain the ecological integrity of the woodland.
2.1.1 2.2.2 2.3.2	Management planning to include ecological assessment and appropriate treatment. Authorised non-timber forest product harvesting to be on a sustainable basis only. Monitoring of progress towards management objectives.
3.1.1 3.1.2 3.2.1 3.2.2 3.3.2 3.5.1	Environmental impacts of new planting and other plans to be assessed before implementation. Impacts of plans must be considered at landscape level, particularly on flora, fauna, watercourses and other linear habitats, scale and pattern of open space and links with similar habitats outside the forest. New woodlands located and designed so as to maintain or enhance the visual, cultural and ecological value and character of the landscape. New planting designed so that it eventually creates a diverse woodland Planting or restocking to include at least 10% open space in woods over 10 ha. If native broadleaves are not suited to the site, a further 5% open space is required. Large scale deforestation for habitat restoration only where justified and agreed.
4.3.2	Forest roads designed and managed to minimise the environmental impact and promote the habitat value. Materials to be in keeping with the local ecology.
5.1.1 5.1.3 5.4.1 5.4.2	Planting and restructuring plans to consider diversity of open ground distribution. Management of wild mammals to prevent ecological damage (e.g. to areas with vulnerable flora) or, where not possible, protection from browsing for these areas. Wildlife management and control used instead of fencing, where possible. Fences aligned to minimise impacts on wildlife, especially woodland grouse.
6.1.1 6.1.2 6.1.3 6.3.1	Areas and features significant for biodiversity to be surveyed and mapped (e.g. valuable or diverse wildlife communities, rare and vulnerable species, Red Data Book or Biodiversity Action Plan species or habitats, wetlands, peatlands). Management to safeguard and where possible enhance these special areas. Conserve or restore valuable semi-natural habitats incorporated into plantations but still viable (e.g. widen rides, extend glades, clear trees to recreate bogs, heaths). Manage at least 15% of the woodland with conservation as a major objective, including the special areas identified at 6.1.1.
7.2.1	Sustain permissive or traditional uses of the woodland, such as footpaths and bridleways, berry picking and mushroom gathering, traditional Common rights.

These standards seem to put ample emphasis on managing forest open ground. Yet positive management of open ground still seems to be the exception, rather than the rule. Some questions arise. Are the standards really being met and, if so, how effective is the open ground management being practiced? Do the assessors need to be made more aware of the fact that non-intervention is generally less suitable than some form of positive management? Unless the standards are properly applied in respect of open ground, the necessary systems for funding and planning open ground management will not be put in place and the standards will be unsuccessful.

SETTING MANAGEMENT OBJECTIVES

Nature conservation objectives

Kielder Forest contains a network of open ground within the plantation area, plus some agricultural land and some larger areas of open ground that were retained for conservation reasons (McIntosh, 1988). The policy adopted for the open ground network has been one of encouraging habitat diversity rather than trying to provide any particular type of habitat or cater for any particular species (McIntosh, 1988). This complements the larger areas of open ground which are mostly managed to maintain or enhance the condition of specific habitat types.

Another approach not directed at particular habitats or species is that of increasing the 'naturalness' of wildlife communities in forests (Bradley, 1988). However it is not clear how to go about this or which of the recognised states of naturalness (i.e. original-naturalness, present-naturalness, past-naturalness, potential-naturalness or future-naturalness (Peterken, 1981; Peterken, 1996) should be the target.

McPhillimy (1989) recognised some 1980s problems related to the setting of conservation objectives for forest open space. Firstly, when new forests were being designed, foresters often had to identify and evaluate the conservation interests of the ground themselves and some did not have the skills to do this successfully. They needed support from experts or proper training. Secondly, at the design stage, ground was left unplanted for various conservation reasons but the future management of this ground had not always been thought through. Options included the maintenance of current populations of interesting species, the encouragement of succession to woodland by planting broadleaves or management for amenity more than conservation.

What to manage for? From wider biodiversity to rare and threatened species

Biodiversity is defined in the context of forests as "the variability among living organisms and the ecological processes of which they are part; this includes diversity within species, between species and of ecosystems and landscapes". In its strict sense, it is not a useful concept. In biodiversity terms we don't know what we want and even if we did we would have no way of knowing whether we had got it. The variety of life is too great for us to cope with. Botanical or zoological specialists - experts on mosses, ground beetles or slime moulds, for example - can manage reasonably well within their own specialism but biodiversity includes many such groups and a grand combined effort would be required to measure biodiversity in its strict sense.

We attempt to get around this problem by using indicator measures of biodiversity that are easier to use, usually species richness within indicator groups or species, such as plant species-richness, but sometimes habitat quality measures such as vertical structure of the vegetation (Ferris & Humphrey, 1999). The approach is seldom properly validated. The indicators may be derived through correlation with species-diversity in one or more taxonomic groups but this hardly justifies their use for all the rest.

It may be a mistake to equate plant species-richness with biodiversity. It is tempting for the biological surveyor to focus on plants because they are fixed. Some ecological principles do suggest that biodiversity should be related to plant species-richness. Many animals are adapted to using one or a few particular plant species. The more plant species present, the more of these specialists there are likely to be. Diversity of micro-habitats, reflecting variable soil conditions, light and microclimate, makes for diversity of both plant and animal species.

However, biodiversity and plant species-richness are not infallibly linked. At the landscape scale, biodiversity is greatest in landscapes with a variety of different vegetation types and these can include types with low plant species-richness. Also, many species are not directly dependent on plants as host or habitat. For example, wood-decaying fungi are strongly linked to the abundance and quality of deadwood (Humphrey *et al.*, 2000).

Another problem with biodiversity in its strict sense is the difficulty of dealing with the different scales of variation. The definition mentions within-species, between-species, between-ecosystem and between-landscape but few, if any studies actually cover all these scales. Most studies measure biodiversity in the context of one of these scales and ignore the others. Diversity of ecosystems at the landscape scale is relatively easy to measure but factors such as habitat condition or quality, which also influence biodiversity, need to be taken into account.

Given the complexity of biodiversity in totality we have to adopt some simple rules to help us decide what we want. We want species-richness, the more species the better. And we want evenness, equal densities of all species rather than an abundance of one or two and few of any other.

We also talk about 'appropriate biodiversity', recognising that, if saving all species from extinction is a priority, we need habitat diversity and that some habitats are inherently species-poor. We must also recognise that strict evenness is not desirable for combinations of large and small species. Sometimes we want abundance (of birds, orchids or butterflies, say) but this is more a reflection of our preference for some species over others and cannot be generally applied. Even when we are sure we want lots of something, like red squirrels, for example, we would not want an infinite abundance of them and would not like some of the unforeseen consequences of having them in great abundance (e.g. less food available for birds and invertebrates).

Encouraging a wide variety of habitat types in the landscape and as wide as possible a variety of vegetation structures and appropriate species in any individual habitat is a reasonable strategy for most sites. However, on sites that support a threatened, rare species, this approach may improve the site's overall biodiversity but result in the extinction of its most precious entity. Single species management may be required to safeguard the rarity. Some sites may have several such jewels, each requiring specific management of its habitats. If these overlap, very careful planning could be required to avoid harming one to benefit the other. Occasionally, conflicts of interest may be unavoidable and tough decisions required on which species to favour.

Single species management is not necessarily straightforward. The requirements of many species are hardly known and the variety of species for which such management might be required is enormous. Even when the requirements of the species are known, it may not be clear how to provide them (McPhillimy, 1989). It will often come down to vegetation management, a complex science due to the infinite variety of starting conditions and multiplicity of factors that influence its effects.

What wildlife can open ground in upland forests provide for and what are the requirements of individual groups and species?

The characteristics that make forest open ground different from other open ground probably make it inherently more suitable for certain groups of plants and animals than for others. This can help us to decide the conservation objectives. It is important that if we narrow down the scope of our objectives to favour particular groups we do it with valid justification. In principle it would be wrong to ignore other groups just because we hadn't considered the value of open ground for them, because nobody was pressing for their conservation or because little is known about their habitat requirements. In practice this will happen until a review of the importance of forest open ground as habitat for the full range of taxonomic groups is undertaken and made available.

Open ground in planted conifer forests may have the potential to provide similar habitats to those in openings in natural forests. These would have included glades and sparsely wooded areas maintained by grazing by large herbivores, burnt areas in the early stages of succession back to woodland and floodplain meadows created by shifting river channels (Svenning, 2002).

Small fragments in forests will make little difference to the overall national or regional resource of a particular type of habitat, such as heathland or unimproved grassland. Where cattle and sheep are fenced out of the forest, there is scope for setting different conservation objectives to those for equivalent open habitats outside the forest. Conditions in the forest are different from those on the open hill (more shelter, higher humidity, lower grazing pressure, grazing mainly by deer, smaller but interconnected patches with a greater proportion shaded). In the forest open ground network there are opportunities to encourage more uncommon biological communities, something different from the norm.

The rest of this section deals with a selection of species and groups that are either recognised as being associated with forest open ground or that use it and deserve to be considered because of their high conservation value. This selection is not exhaustive - it does not cover deer, for example – but it does include most of the obvious potential conservation targets and a few less obvious ones.

Bryophytes and lichens

A study of bryophytes and their habitats in Kielder Forest (Hill, 1990) recorded 198 species, considered poor for an upland area and due to inherent qualities of the land, rather than land use. Some species declines and a few losses from the area had probably occurred as a result of afforestation, the lost species most likely small liverworts of bogs and marshes. These detrimental impacts will have been compensated for by species inhabiting new habitats such as roads and quarries.

The open ground provided a greater variety of bryophyte habitats than the tree stands, but was generally species-poor, with very common species most abundant (Hill, 1990). A lack of disturbance since the cessation of grazing and burning seemed to be responsible for the lack of liverwort habitats and species on bogs. The best permanent bryophyte habitats were a large gritstone crag in relict broadleaved woodland, steep-sided stream gulleys with rock outcrops and rocky streams. Hard rock quarries and forest roads, especially those made of calcareous roadstone, were valuable man-made habitats. Hill (1990) recommended preserving the good natural bryophyte habitats by cutting trees if necessary to prevent good rocks being overshadowed and by not planting close to these areas so that whole stream gulleys are left unplanted. Increasing disturbance on unplanted bogs was also recommended but no specific method was suggested. Hill (1990) also advocated keeping quarries clear of rubbish and continuing to use calcareous roadstone.

Thus, for Kielder at any rate, management for bryophytes would be simple, confined mainly to a few existing unplanted habitat areas (large crags, steep-sided stream gulleys and bogs) and would hardly constrain normal silvicultural practice. Few conflicts with other conservation management practices would arise.

Woods in the western Scottish Highlands can have particularly valuable assemblages of bryophytes and lichens favoured by the highly oceanic climate and clean air. This group of plants is vulnerable to dessication and so requires maintenance of microclimate conditions, particularly shelter and adequate humidity (Averis, 2001). They grow on shaded rocks and banks and on the trunks and branches of trees and shrubs. Opening up the woods by felling, coppicing or heavy grazing would harm these plants so these should be avoided in areas with special lower plant interest (Averis, 2001). Some shading of rocks and tree bases by bracken can be beneficial.

Plants colonising forest roads

The road surface habitat suffers environmental extremes and frequent crushing disturbance and occasional devastating regrading (Evans, 1978). Nevertheless, forest roads are sometimes colonised by plants that are relatively scarce in other habitats in the vicinity. Well-known examples include stagshorn clubmoss (*Lycopodium clavatum*) and orange peel fungus (*Peziza aurantia*). Hill (1983) reported finding stagshorn clubmoss on a forest road in Clocaenog Forest but not on the adjacent Hiraethog Moors. Presumably it either was present in both but more conspicuous on the forest road or had colonised the forest via vehicles, other road users or imported roadstone. Hill (1983) also cited a report (Lousley, 1976) that forest roads formed the only remaining habitat for this species in Surrey. The liverwort *Solenostoma* *crenolata* was reported as being characteristic of forest road edges in Fleet Forest, while those in Laurieston supported four locally rare vascular species (*Medicago lupulina*, *Myosotis arvensis*, *Lathyrus pratensis* and *Sagina procumbens*) (Goldsmith, 1981).

A study of forest roads in Wales, southern Scotland and northern England identified two mosses, redshank (*Ceratodon purpureus*) and Hercynian haircap (*Oligotrichum hercynicum*), that were particularly characteristic of forest roads. A further ten vascular species were much more common on forest road surfaces than in other habitats in the forest (Evans, 1978). These vascular plants were low-growing or prostrate and adapted to withstand a limited amount of crushing.

The construction of forest roads using locally quarried stone creates a new habitat because the stone would not normally be found on the surface (Evans, 1978). While not natural, this can be beneficial in increasing floral (Forestry_Commission, 1978; Good *et al.*, 1990) and faunal (Good *et al.*, 1990) diversity. In forests with acid soils in which calcareous roadstone had been imported, the road surface and verges had a distinctive plant assemblage including many calcicolous species (Evans, 1978). Maintaining the natural integrity of a forest by using locally quarried roadstone was considered preferable to diversifying the flora artificially by introducing calcareous stone (Peterken, 1996).

Vascular plants

Cessation of sheep grazing on upland pasture can cause coarse grasses or heather to increase rapidly, leading to the loss of smaller and choicier plants (Hill, 1983). In a study at Clocaenog, most of the few moorland species that did not survive in the forest were low-growing marsh or bog plants (*Anagallis tennella*, *Pinguicula vulgaris*, *Achillea ptarmica*, *Pedicularis palustris* and *Drosera rotundifolia*) or interesting mosses. These are not species that can be conserved by leaving marshes unplanted within forests. Without sheep grazing to keep the turf short the distinctive species will be smothered by their larger neighbours and will die out (Hill, 1983).

Rides during the first rotation are a rather poor habitat, lacking sufficient grazing to keep the grass or heather short, so that the vegetation becomes rank and matted (Hill, 1983). The vegetation was found to be much less species rich than the vegetation of road corridors, with, on average, 15 vascular, 11 bryophyte and 1 lichen species per sample (Evans, 1978). Swiping rides could probably increase their floristic diversity. Draining of rides is detrimental as the drying of the ground encourages overwhelming Molinia or Calluna dominance (Goldsmith, 1981). This study failed to show any improvement in botanical diversity with increasing ride width, although rides orientated north-south were botanically richer than other orientations, with NW-SE rides poorest (Goldsmith, 1981).

Forest roadsides are generally the most interesting new habitats for plants. They are much more disturbed than rides and their verges are sometimes grazed sufficiently or mown so that the grass is kept short (Hill, 1983). Road corridor vegetation was more species-rich and not similar in composition to that of clear-felled areas (Evans, 1978).

Road corridors were found to be relatively species-rich, with 34 vascular, 17 bryophyte and 2 lichen species per sample (Evans, 1978). Roads in forests were more important botanically than roads in open country (Evans, 1978). Of 68 vascular species that were preferential to forests (i.e. their frequency of occurrence in forested OS 1 km^2 grid squares at Clocaenog was more than twice that in non-forested squares), 34 were more or less confined to road corridors (Evans, 1978). Maintenance of road corridor plant diversity probably depends on a limited amount of disturbance and on the suppression of woody vegetation (Evans, 1978).

Common non-preferential species made up the bulk of road corridor vegetation, mostly species with some tolerance of low light levels, many being species of open ground which normally grow better in the open (Evans, 1978).

Unlike most rides, streamsides and lakesides can have a rich flora without grazing because they are disturbed by water, allowing small species to survive (Hill, 1983). Low-growing marsh and bog plants which can be largely displaced by afforestation may find haven in wet areas disturbed by streams (Goldsmith, 1981). Rocky bluffs and ravines are often the most botanically interesting places before afforestation and should remain so afterwards, provided they are left unplanted (Hill, 1983).

Scrub

Scrub communities can form good habitats, particularly for birds and for plants sensitive to grazing. They can also have high conservation value in their own right and as components of landscapes but are often overlooked, even in conservation circles (King, 2001). Some types are very rare and some of the component shrub species are only found in these scrub communities (Mortimer *et al.*, 2000). The main upland types are listed in Table 7.

Most upland scrub communities below the timberline in Britain are either stages of successions to woodland or are prevented from succeeding to woodland by grazing. Because sheep are usually excluded from forest open ground, scrub may develop (if browsing pressure by deer allows) in suitable situations such as around lake or loch shores, on river banks or on drier ground where some hawthorn, blackthorn or juniper is already present. There will, however, be a long-term tendency for the succession to proceed and for the scrub to develop into woodland.

Table 7. Conservation value of the different types of upland scrub (information from Mortimer *et al.* (2000)).

Upland scrub type	Conservation value in Britain
Scrub on wet soils in the forest zone Willow carr Salix aurita willow scrub Salix phyllicifolia willow scrub Salix myrsinifolia willow scrub Bog myrtle scrub	 Important component of lake-side vegetation mosaic. Component of Wet Woodland. Important habitat for rare, grazing-intolerant plant species such as globeflower, wood crane's-bill and shrubby cinquefoil.
Scrub on dry soils in the forest zone Hawthorn or upland thorn scrub	 Important addition to structural complexity of landscape and important habitat for birds such as stonechat, whinchat and tree pipit.
Tree-line scrub and scrub woodland Tree-line scrub woodland or Scots pine scrub	 Very rare. Important component of native pine forest.
Upland juniper scrub Common juniper scrub (W19) Prostrate juniper heath (H15)	Juniper threatened (Species Action Plan). Component of EU Habitats Directive Annex I habitat, Juniper Formations. Sub-alpine stands extremely rare (100 ha total). Restricted distribution (610 ha total).
Dwarf birch scrub Dwarf birch scrub (M19ci)	Dwarf birch nationally scarce. Component of EU Habitats Directive Annex I priority habitat, Active Blanket Bog.
Sub-arctic willow scrub Sub-arctic willow scrub (W20)	One of UK's rarest habitats. Many of the dominant shrubs Nationally Scarce or in Red Data Book. Woolly willow (*Salix lanata*) subject of a Species Action Plan.

Scrub communities above the timberline represent climatic climax vegetation. The main factors contributing to their decline are browsing by sheep and red deer (Gilbert & Di Cosmo, 2003; Scott, 2000) and possibly burning (Sullivan, 2001). Many surviving patches of montane willow and juniper scrub are too small to hold viable populations of the component species and will be lost without successful intervention to restore them (Mardon, 2003). Where forestry-owned land above the timberline is not grazed by sheep, there are opportunities to restore montane scrub. Planting may be required (Mardon, 2003). Deer and mountain hares can also suppress scrub regeneration so might need to be excluded (Scott, 2000).

Research on scrub conservation has concentrated on montane scrub because of its rarity in Britain. Management for juniper is also receiving renewed attention (Dearnley & Duckett, 1999) and guidelines have been issued for identifying appropriate juniper re-introduction sites, emphasising the importance of sites from where it has recently been lost (Wilson & King, 2001). Efforts to conserve or restore scrub communities may raise issues of conflicting conservation priorities because other valuable vegetation may be replaced when scrub develops and the tendency for scrub to succeed to valuable woodland types may have to be countered.

Butterflies and moths

Much research and conservation management guidance for open ground in lowland forests has focused on butterflies. Upland forest open ground can also provide good habitats for them but will support a different suite of species, including both woodland edge species and species of upland open habitats. These include pearl-bordered fritillary (*Boloria euphrosyne*), small pearl-bordered fritillary (*Boloria selene*), marsh fritillary (*Euphydryas aurinia*), chequered skipper (*Carterocephalus palaemon*) and large heath (*Coenonympha tullia*).

The ecology of most British butterfly species has been well researched and in general their habitat requirements are known. However these requirements differ among species and site management should be carefully targeted towards species already present or those present in the vicinity and capable of colonising suitable habitat patches.

For many species, conservation needs to be geared towards protecting or expanding existing colonies or improving the suitability of habitat patches nearby. For some species, such as marsh fritillary, grazing is essential to maintain habitat suitability but deer grazing can be effective (Gaywood, 1996). For others, including pearl-bordered fritillary, early successional vegetation is needed, so areas need to be clearfelled every year to maintain the supply (Brereton, 1999).

Upland heathland can support large and diverse moth communities (MacDonald & Haysom, 1997). Species diversity can be maximised by cutting or burning rotationally to produce a mosaic of heather patches of different ages, maintaining some tall heather, encouraging other dwarf shrubs, such as blaeberry, and herbs and controlling browsing pressure so that unbrowsed heather and blaeberry shoots are available (MacDonald & Haysom, 1997).

Other invertebrates

Fragments of forest open ground may have the potential to provide valuable habitats for invertebrates (Kirby, 1992), which are affected less by the limited space than larger animals. Flying insects which can forage or hunt more successfully in sheltered but open conditions may find forest open ground ideal. The large variation in shade may make for a great diversity of ground-dwelling invertebrates. Tall, well-sheltered ground vegetation may form good quality habitat for spiders. Sunny, sheltered edges may be perfect basking places for hoverflies and other thermophilic insects. Disturbance of the vegetation and soil surface by deer will provide habitat for some invertebrates and deer dung will encourage dung flies and beetles.

Forest open ground supports invertebrates that are adapted to woodland edges, often with the larvae using tree stands and the adults using adjacent open ground (Kirby, 1992). Their key open ground requirement is for warmth and they find it in sheltered, sunny places in the open ground network. Many species feed on nectar as adults so they need suitable flowers. Species richness of plant bugs (Hemiptera) and flies

(Diptera) on forest road edges correlate positively with both plant species richness and light level (Mullen *et al.*, 2003). Plants with open-structured flowers, such as hawthorn, sallow and blackthorn, the umbellifers and the composites, are particularly useful (Key, 1995; Kirby, 1992). Tree and shrub foliage at forest/open ground edges may provide foodplants and perches (Key, 1995). Structurally diverse forest/open ground transitions, with high forest bordered by shrubs, then tall herbs, then low grassy vegetation, are valuable because they can support a wide range of specialist invertebrates adapted to particular growth forms of their host plants (Kirby, 1992). Sunlit bare soil can be used for nesting by solitary bee and wasp species and for basking by thermophilic species (Key, 1995; Key & Gent, 1993). On clay soils, puddles, especially in the sun, provide habitat for temporary pool fauna (Key, 1995).

Forest open ground can also support communities of wholly open-ground invertebrate species, such as grassland, heathland and wetland communities (Kirby, 1992). To favour these, their habitat patches need to be managed for the same characteristics as their open country equivalents with one exception. A gradual woodland edge transition should be encouraged as this can add greatly to their value as invertebrate habitats (Kirby, 1992) but the trees must not be allowed to shade sunny habitats or dry out damp or wet ones (Key, 1995).

Forest edges, including internal open ground edges, can support the most species-rich communities of ground beetles in the forest because they are used by woodland species, open ground species of the adjacent habitat and by edge specialist species (Magura, 2002). Open ground carabid species can also colonise clear-felled and restocked areas although their diversity tends to decrease as the new stand grows (Magura *et al.*, 2003).

In new woodlands it is far better to incorporate existing semi-natural habitats than to convert them to tree stands because this increases structural diversity and the extent of woodland edge (Key, 1995). However unplanted buffer areas may be needed, especially to the south, east and west of semi-natural habitat areas, to prevent them becoming shaded when the trees grow tall. If possible, semi-natural habitat areas should be linked by rides or other types of corridor, preferably of similar habitat. The forest design should allow road or ride access to open heathland and grassland areas to allow easy access for stock grazing and/or mechanical management operations. Once incorporated into a woodland, semi-natural habitat areas should be specifically managed as woodland open space, aiming to maintain a varied vegetation structure and provide nectar plants of appropriate species. Rotational mowing and raking of the vegetation can help provide a varied vegetation structure (Key, 1995). In all woods except very wet alder or willow woods, some unvegetated ground open to the sun should be provided. Eroded vehicle or pedestrian tracks can provide this niche but it may be necessary to introduce rotational scraping of surface vegetation, particularly on sunny open ground sloping towards the sun (Key, 1995).

The extremely rare narrow-headed wood ant lives in nest mounds in open glades or moorland edges adjacent to old Scots pine woods (Hughes *et al.*, 2003). It needs the relatively sunny conditions of the open ground to warm the nest sufficiently for brood-rearing. Open ground occupied by this species or with the potential to be occupied by it needs to be protected against gradual shading by trees. Designing open space into new woodlands near those it occupies may help its conservation but great care is needed to avoid planting up ground it already uses or that it might potentially use under the current land use.

Bats

Most British bat species use woodland habitats for foraging and roosting (Mayle, 1990b). They roost in trees, caves, buildings and mines but are vulnerable to disturbance, particularly when hibernating. They are insectivorous, foraging in sheltered, insect-rich airspace at woodland edges, around native broadleaved trees and shrubs, over open grasslands and particularly above ponds and streams. Ponds of at least 0.5 ha spaced at 2 km intervals give optimum foraging conditions.

Mayle (1990b) provided guidance on forest management to maintain or improve habitats for bats. Known roost sites need protection from disturbance, potential roost sites can be improved and boxes can be provided. Insect prey can be encouraged by maintaining or providing corridors of broadleaved trees and shrubs, such as birch, willow and cherry. In conifer forests, planting broadleaved trees and shrubs around ponds and beside streams will improve foraging conditions. Waterside foraging habitats, if absent from a forest, can be provided by constructing ponds of half a hectare or more, to an appropriate design (Springthorpe & Myhill, 1985). Deer glades and bays in road and ride edges can provide the necessary sheltered airspace and mown grassy areas open to direct sunlight support the seasonally important craneflies and ground beetles.

Other small mammals

Small mammals, particularly short-tailed or field voles, are very common but are regarded as ‘keystone’ species because they form the staple diet of many predators at the top of their food chains, including fox, pine marten, weasel, adder, tawny owl, long-eared owl, barn owl, short-eared owl and kestrel . Because of the strong influence it has on local densities of top predators, the population density of field voles could be used as an indicator of ecosystem health, although a good understanding of vole population cycling (Petty *et al.*, 1997) would be needed to interpret its meaning.

The cessation of sheep grazing in the uplands has been shown to increase vole population densities on some sites (Hope *et al.*, 1996). Grassy open areas, including restock sites, can support dense populations of voles, shrews and mice, making them important hunting areas for predator. Managing these areas to maximise vole densities would increase the total resource of this food but could result in hunting habitat more suitable for some predators than others. A better understanding of the different hunting methods and habitat preferences of the various predators that feed mainly on voles (Petty, 1994) would allow more carefully targeted management.

Reptiles

Open ground in Kielder Forest supports common lizard (*Lacerta vivipara)*, adder (*Vipera berus*) and possibly slow-worm (*Anguis fragilis*) (Thomson, 1990). Some upland forests in England and Wales may also support the grass snake (*Natrix natrix*). Reptiles need structural variation in the ground cover and unshaded conditions

(Backshall, 2001a). Dry and sufficiently sunny rides and road-sides can support adders, lizards and slow-worms, especially when south-facing and well vegetated. Drier unplanted areas with bracken, heather or grassland can support large populations, particularly around major rock outcrops. Stands of tall heather provide better habitats for reptiles on moorland than a more varied heather/cottongrass/grassland mosaic. Some reptile species are sensitive to habitat change and are therefore indicators of naturalness (lack of anthropogenic alteration of habitats or communities) and biological richness of the habitat (Spellerberg, 1988b).

Information on the ecology of the adder comes from a detailed study of populations in Dorset (Prestt, 1971). It is reasonable to assume that the broad findings will also apply to upland sites. They use dry, sunny, south-facing banks with old rabbit or small mammal burrows for communal hibernation. In spring they lie out on top of the hibernation bank, using hollows under stumps or tall vegetation such as grass tussocks, rushes, reeds or heather to form surface dens. They migrate up to 2 km to damp grassy habitats in summer to feed, mainly on field voles and other small mammals but with common lizards the staple food of the young. They travel between these areas using banks, ditches or hedges.

Management for reptiles at Kielder would entail maintaining and possibly expanding dry unplanted well-vegetated ground and encouraging stands of dense, mature heather on moorland (Thomson, 1990). Maintaining and enhancing rides (the wider and more sunlit the better) and roadsides (sunlit, south-facing and with bracken, heather or tussocky grassland is best) will benefit reptiles. Moorland management for reptiles should aim to maintain unshaded and structurally variable vegetation, sometimes achievable without any management on poor soils or where grazing is light (Backshall, 2001a). An understanding of the different summer and winter habitats used by adder populations may help to ensure that both are safeguarded and that routes between them are maintained.

Most of the reptile conservation measures will not affect silvicultural operations but adders should not be encouraged on ground adjoining public picnic sites or car parks. Widening rides will take up formerly productive ground but should give good benefits for a small sacrifice. Encouraging dense, mature heather may conflict with other moorland interests, such as red grouse and golden plover conservation, which benefits from a mosaic of different ages of heather. Management for reptiles will also benefit other animals, such as butterflies, spiders, amphibians and small mammals (Spellerberg, 1988a).

Amphibians

Open ground in Kielder Forest supports populations of common frog (*Rana temporaria*), common toad (*Bufo bufo*) and palmate newt (*Triturus helveticus*) (Thomson, 1990). Many other upland forests will support these and some may also support smooth newts (*Triturus vulgaris*), great crested newts (*Triturus cristatus*) or natterjack toads (*Bufo calamita*). Amphibians need suitable aquatic sites to breed in and terrestrial habitats that stay damp in dry summer weather (Thomson, 1990). Water quality, particularly pH and ionic concentrations, affects breeding success so needs to be maintained (Spellerberg, 1988b). Acidification of pools has led to population declines and fertilizer runoff can also be detrimental (Spellerberg, 1988b).

Amphibians also need an adequate food supply, heat, protection from predators and bad weather (Spellerberg, 1988b). Damp rides can form good terrestrial habitats. Small, shallow water bodies, such as wet Sphagnum hollows in heathery vegetation and stagnant ditches, are important for breeding. Wet heaths and mires should also support good amphibian populations but at Kielder they failed to do so because they lacked the pools or ponds needed as breeding sites (Thomson, 1990). On moorland, stands of tall heather are better for amphibians than a heather/cottongrass/grassland mosaic.

Management for amphibians in Kielder Forest would include maintaining the area of damp heathlands and mires, improving them by digging shallow amphibian breeding pools and encouraging stands of dense, mature heather on unplanted moorlands (Thomson, 1990). Maintaining and enhancing rides (the wider and more sunlit the better), roadsides (ones with bracken, heather or tussocky grassland are best) and small aquatic sites (shallow ones fringed with dense vegetation are best; marshy areas with pools are good) will benefit amphibians. Large fireponds can probably become useful amphibian breeding habitats if one end is extended as a shallow area, 50 cm deep, with an edge made to slope gently instead of sheer (Thomson, 1990). On moorland areas, amphibians can be helped by maintaining structurally diverse conditions and one way to achieve this is to lightly graze the vegetation to give it an uneven structure (Backshall, 2001a). Heavy grazing and frequent burning are both detrimental.

Amphibian conservation measures should not hinder other forestry operations. Widening rides will involve sacrificing formerly productive ground but should be worthwhile. Encouraging dense, mature heather on moorlands will benefit both amphibians and reptiles but, if undertaken too extensively, will conflict with moorland interests favoured by heather/cottongrass/grassland mosaics.

Black grouse

The black grouse is threatened and declining in Britain. Management of the upland forests of southern Scotland, England and Wales will be important in determining its fate (Currie & Elliot, 1997). It is essentially a species of open forests and forest edges but can live on moorland, in conifer plantations and in native woodland. In our highly man-altered uplands it needs a mosaic of habitats (RSPB, 2002) because no single habitat can cater for all its needs. A forest can provide some elements of the mosaic with the other elements being provided by neighbouring land. Low-intensity or traditional agriculture provides particularly valuable habitats, such as herb- and sedge-rich meadows. In upland conifer forests the open ground accounts for much of the potentially suitable habitat. The forest habitat requirements of black grouse have been reviewed and appropriate forest management measures recommended (Cayford, 1993). Guidance on managing the components of the crucial forest/moorland/hill farm mosaics they inhabit has also been issued (RSPB, 2002).

The requirements of the black grouse are fairly well understood. It can use forest open ground for sheltering and roosting, feeding, nesting, chick-rearing and lekking. Its diet varies seasonally, including heather shoots, blaeberry shoots and berries, cottongrass buds, rush and sedge seeds, larch and birch buds, rowan and hawthorn berries, caterpillars and spiders (RSPB, 2002). Boggy areas are particularly valuable sources of invertebrates for chicks. It needs tall ground vegetation as cover for nesting, often using heather more than 40 cm tall or tall patches in grazed grass/sedge/rush mosaics. For lek sites, which it re-uses year upon year, it may use forest open ground, such as clearings or tracks. They need to be open (no planting within 50 m), with short vegetation for good visibility (RSPB, 2002). They also need to be kept free of disturbance between March and May (Currie & Elliot, 1997). Any vegetation management should be undertaken between late summer and the end of January (Currie & Elliot, 1997).

Deer fences in and around forests, especially near lek sites, can be lethal to black grouse (they fly into them). If possible, their use should be avoided in black grouse country (Currie & Elliot, 1997; RSPB, 2002), otherwise they should be designed to be highly visible. High-visibility fences designed to reduce the danger to grouse are being tested (Summers & Dugan, 2001; Trout *et al.*, 2001). The upper half of the fence is made more conspicuous using one of several methods recently developed, such as attaching coloured plastic netting, chestnut paling or extra droppers (Andrews & MacDonald, 1996). Controlling foxes and crows will reduce predation on grouse chicks. Herbicides can harm grouse so their use should be minimised (Currie & Elliot, 1997).

Owls

The four owl species found in upland forests all feed mainly on field voles during late winter and the early part of their breeding season (Petty, 1994). Short-eared owls are diurnal whereas tawny, long-eared and barn owls are largely nocturnal. At Kielder, grassy restock sites support good vole numbers and it is only since restructuring of the forest began, with a resultant increase in the area of grassy restock sites, that long-eared owls, formerly confined to the forest edge, have colonised the interior (Petty, 1994).

Besides voles and other prey, owls need suitable nesting sites. In forests where nest site availability limits owl population density, the placement of artificial nest boxes can increase numbers. However the desirability of doing so must be established before taking this course, as must the feasibility of committing the resources necessary to maintain the boxes over a long term.

Other birds

The in-forest ecology of birds has probably been studied more fully than that of any other taxonomic group. The subject has been reviewed (Petty & Avery, 1990) and guidance has been issued on managing forests for rare birds (Currie & Elliot, 1997).

There is good evidence that some bird species are more abundant at woodland edges than in the interior. One lowland study (Fuller & Whittington, 1987) failed to find an edge effect in areas of forest adjoining rides. It was found that the vegetation did not increase in density beside the ride as much as it did beside the forest's outer edge, possibly because the rides were too narrow to allow sufficient light in to boost vegetation growth (Petty & Avery, 1990).

Petty and Avery (1990) gave guidance on aspects of the design of new forests that affect birds. They consider watercourses, forest road corridors and wayleaves to be valuable forms of open space for birds but rides to be of little value. They are too narrow to remain unshaded as the adjacent trees grow and they stand out as artificial in the landscape. They suggest that occasional contour rides are needed as future road or extraction lines but otherwise rides are not needed. Watercourses or roads can be used as management boundaries and are more effective as conservation areas than rides (Petty & Avery, 1990).

The soil biological community

Soil hosts a diversity of life forms far greater than that of any other environment on earth (Campbell & Puri, 2002). The functions performed by this community sustain all life above ground. Yet it is poorly understood. Of the estimated 95 % of all microorganisms still awaiting discovery, a large proportion live below ground. Scientific study of the soil biota is still at the stage of developing methods of identification, quantification and detection of functions performed.

The way we manage habitats affects soil biodiversity (Campbell & Puri, 2002; Neilson *et al.*, 2002). In woodlands, although fungal fruiting bodies represent only a small fraction of the fungi present in the soil, we know that soil fungal diversity is influenced by dead wood and leaf litter and therefore by forest management. Grassland management intensity influences soil bacterial, fungal and faunal diversity.

Further research on soil biodiversity is needed. We can speculate that forest open ground may be important in sustaining more fully functioning soil biological communities than those under dense conifer stands. It may have a role as a soil organisms bank that can act as a source for colonisation of temporary open ground, similar to its role as a bank of vascular plants, invertebrates and field voles.

MANAGING HEATHLAND

What is heathland?

In most terrestrial situations the climax vegetation will be woodland of some kind. However above the altitudinal tree-line, trees cannot survive because the conditions are too severe. There, they are replaced by dwarf shrubs adapted to tolerate these conditions. In Britain these include common or ling heather (*Calluna vulgaris*), bell heather (*Erica cinerea*), cross-leaved heath (*Erica tetralix*), blaeberry or bilberry (*Vaccinium myrtilus*) and crowberry (*Empetrum nigrum*). These dwarf shrub communities are termed montane heaths. Heath communities can form the climax vegetation at very windy sites at lower altitude, such as immediately above sea cliffs (Thompson *et al.*, 1995). They can also occur in the lowlands as a successional stage on land with acid, nutrient-poor soil, such as dune slacks, where trees are suppressed by a deficiency of nitrogen and sometimes phosphorus. These are lowland heaths.

Many of the hills and moors of Britain's uplands support dwarf-shrub heath, or have done in the past, on land that has long been deforested and that has been prevented from undergoing succession to woodland by management involving burning and grazing (Thompson *et al.*, 1995; Thompson & Miles, 1995). These are 'cultural landscapes', unnatural in the sense that they would not exist were it not for the agency of man. Heathland in the uplands below the tree line is termed upland heathland. Thompson *et al.* (1995) defined this as occurring in the sub-montane zone, i.e. between the original climax upper treeline (600-700 m asl but much lower towards the north and west) and the upper edge of enclosed agricultural land (300-400 m asl but also lower towards the north and west). In conserving upland heathland, we are taking a strongly interventionist stance. It would neither have been there without deforestation and subsequent land management in the first place, nor would it continue to exist there without land management in future. A strong argument could be made, on grounds of unnaturalness and unsustainability, for allowing Britain's upland heaths to succeed to woods but others argue that the distictive biological communities associated with heathlands should be conserved, despite being 'unnatural'.

A few of the heathland communities recognised in the National Vegetation Classification (Rodwell, 1991b) make up the bulk of heathland in upland forests. In the climatically more oceanic parts of north-western Britain, *Calluna-Erica cinerea* heath (H10), or Atlantic heather moor, is common on dry soils. In the same regions, in shady, sheltered situations and on ground not burned, *Calluna-Vaccinium-Sphagnum capillifolium* (H21) heath is found. On wetter soils, especially shallow peat and artificially dry deep peat, *Scirpus cespitosus-Erica tetralix* wet heath (M15) predominates. Further east where the climate is less oceanic, and at higher altitudes, *Calluna-Vaccinium myrtillus* heath (H12), regarded as Boreal heather moor, is more common. In our most climatically continental region, the east-central Highlands, *Calluna-Arctostaphyllos uva-ursi* heath (H16), a community similar to that of Scandinavian heaths, is found (Rodwell, 1991b).

Why conserve heathland in general?

Plant and animal communities

Heathlands support unique plant and animal communities. Their flora is rather species-poor but rich in dwarf shrub species. They include a surprisingly wide range of distinct vegetation types. Some types support outstanding bryophyte and lichen understorey communities (Thompson *et al.*, 1995). *Calluna-Vaccinium-Sphagnum capillifolium* (H21) heath, for example, is highly valued for its diverse assemblage of liverworts, including many rarities, while *Calluna-Arctostaphyllos uva-ursi* heath (H16) is valued for a rich and distinctive assemblage of uncommon herb species (Rodwell, 1991b). They are also important for their animal assemblages, particularly for invertebrates and birds. They provide habitats and food for invertebrates, supporting unusually rich assemblages because they include representatives of three biogeographic groups - arctic-alpine, alpine and boreal-British (Thompson *et al.*, 1995). Their richness is particularly notable in terms of species of flies, spiders, beetles and moths but population densities of springtails, mites and bugs are also remarkable (Coulson *et al.*, 1992; MacDonald & Haysom, 1997).

Characteristic bird communities are an important feature of upland heathlands (Thompson *et al.*, 1995). Red grouse (*Lagopus lagopus scoticus*) are heather moorland specialists and cannot live anywhere else. Golden plover (*Pluvialis apricaria*), merlin (*Falco columbarius*) and hen harrier (*Circus cyaneus*) breed mainly on heather moorland. These four species all declined during the 1970s and 1980s due to a combination of habitat loss, increased predation and persecution. Upland heather moorland provides a major breeding habitat for a further 16 species: whinchat (*Saxicola rubetra*), stonechat (*Saxicola torquata*), greenshank (*Tringa nebularia*), short-eared owl (*Asio flammeus*), black grouse (*Tetrao tetrix*), dunlin (*Calidris alpina*), ring ouzel (*Turdus torquata*), great skua (*Stercorarius skua*), arctic skua (*Stercorarius parasiticus*), skylark (*Alauda arvensis*), teal (*Anas crecca*), whimbrel (*Numenius phaeopus*), common gull (*Larus canus*), curlew (*Numenius arquata*) meadow pipit (*Anthus pratensis*) and cuckoo (*Cuculus canorus*) (Thompson *et al.*, 1995). For another 11 species upland heather moorland provides locally important breeding habitat. It also provides important feeding habitat for another 9 species: Greenland white-fronted goose (*Anser albifrons*), golden eagle (*Aquila chrysaetos*), peregrine (*Falco peregrinus*), raven (*Corvus corax*), buzzard (*Buteo buteo*), kestrel (*Falco tinnunculus*), red kite (*Milvus milvus*), common/hooded crow (*Corvus corone*) and goshawk (*Accipiter gentilis*).

Upland heather moorland bird assemblages are outstanding in four respects (Thompson *et al.*, 1995):
1. A unique mixture of low and high arctic, boreal, temperate and continental nesting species, species-richness increasing northwards.
2. Internationally important populations/dense concentrations of moorland-breeding and/or -feeding birds
3. Zoogeographical aspects which may reflect novel adaptations to changing environmental conditions. Racial differentiation in breeding red grouse, golden plover and twite. Unexplained disjunct global distributions in twite and great skua.

4. Exceptionally high densities of red grouse and golden plover maintained by heather burning and predator control.

Habitat loss

Over-grazing, agricultural improvement and afforestation have caused the loss of a significant proportion of our upland heathland. Overgrazing is an ongoing problem, resulting in its conversion to acid grassland. Scotland's Southern Uplands is a good example of an upland area partly transformed by a long period of heavy sheep grazing. In the English and Welsh uplands there are estimated to be 440,000 ha of grassland containing suppressed dwarf shrubs (JNCC, 2001), probably mostly in the process of changing from heathland to acid grassland but capable of reverting to heathland if grazing pressure were to be reduced. The significance of this problem is clear when the area is compared with the total of 350,000 ha classed as upland heathland in the two countries (JNCC, 2001).

A tendency, over large parts of the uplands, for less frequent muirburning than was practised before 1945, has reduced the structural diversity of much of the vegetation (MacDonald, 1996b). On these areas a much greater proportion of heather moorland now consists of heather stands in the late building, mature and degenerate phases (*sensu* Gimingham (1972)). These moors provide a reduced range of wildlife habitats compared with the former, more structurally varied, vegetation.

Conservation commitments

The UK Biodiversity Action Plan process has generated a Habitat Action Plan for Upland Heathland (JNCC, 2001). It refers to afforestation as leading to loss of the habitat but points out that areas of heathland are also being created in some forests by restructuring after the first rotation. The objectives of the plan include maintaining the heathlands already in good condition, getting heathland in SSSIs into good condition by 2010, improving the condition of at least half of the heathland outside SSSIs by 2010, restoring at least 25 % dwarf shrub cover where it has been reduced below this on 50,000-100,000 ha by 2010 and starting to restore at least 5,000 ha of the heathland lost to agricultural improvement or afforestation, by 2005.

The Forestry Commission has undertaken to participate in many of the actions proposed under this UK Habitat Action Plan (JNCC, 2001). It should be able to make a positive contribution in the areas of encouraging and managing moorland mosaics (of heathland, marginal hill ground, woodland and scrub and other farmed land), providing best practice demonstration sites and assigning sites for upland heathland restoration and expansion, including sites in forests.

What can heathland in upland forests offer that is special?

Heathland will normally have undergone a vegetation change since incorporation into the forest. The change depends on its initial composition, which in turn depends on the former management regime. Overgrazed heaths would probably have been grass-dominated with or without some surviving dwarf shrubs. Where dwarf shrubs were still present they are likely to have increased their cover rapidly after grazing ceased (Marrs & Welch, 1991). Where they had been eliminated there may have been a viable seedbank but in the absence of grazing and other disturbance, the grass sward may have prevented its activation.

Studies of vegetation change at upland sites where grazing had been excluded experimentally showed that plant species richness is usually reduced as a result (Marrs & Welch, 1991) but can increase on species-poor blanket bog (Adamson & Kahl, 2003).

Many of the carabid beetle species characteristic of upland heathland require some tall heather and a few require shorter, more open stands. Thus for greatest carabid diversity a structurally diverse heath vegetation is needed (Gardner *et al.*, 1997).

Forest managers may have some control on sheep stocking densities on large heathland areas, either through stipulations in grazing leases or by having the option not to lease out grazing at all. These areas may differ from those off the forest estate by having a wider range of objectives than the narrow economic ones commonly held by sheep farming and grouse shooting enterprises.

Heathland in the forest open ground network is mostly more sheltered than on exposed hills and moors. It may be partly shaded by adjacent trees, may have a more humid micro-climate and is usually not grazed by domestic stock. Grazing pressure by wild herbivores is to some degree controllable by managing deer numbers (although rabbits, hares, voles, etc. are less easy to control).

Management objectives for heathland in upland forests

Management objectives will vary, depending on the scale of the heathland in question. Large expanses have the potential to contribute to Habitat Action Plan targets. These areas are often situated at the edge of the forest, adjoining similar habitat ‘outside the fence’. The objectives for these large expanses may mirror those for heathland on open hills and moors.

UKBAP Habitat Action Plans take account of past habitat loss and future threats when setting objectives. Heathlands have been lost to afforestation, natural succession, mineral extraction, development and many other causes but mostly to overgrazing. High grazing pressure, particularly from sheep during winter, has brought about a widespread change from heathery to grassy vegetation. The primary objective of the Upland Heathland HAP is the maintenance and restoration of dwarf shrub dominated heaths. The potential benefits include improved landscapes in the form of heather-clad hills and moors and increased numbers of red and black grouse, merlin and hen harrier.

Heathland in upland forests can provide excellent habitat for the threatened black grouse. It would be easy to set black grouse conservation as the main management priority for all such ground but this is not recommended in areas more than 15 km from existing populations (Cayford, 1993). Single-species management is not usually appropriate for a habitat that supports other threatened species as well, and upland heathland is the primary habitat for seven species listed as priorities under the UK Biodiversity Action Plan (Simonson & Thomas, 1999). These are: the liverwort Lindenberg's featherwort (*Adelanthus lindenbergianus*), black grouse (*Tetrao tetrix*), the moths argent and sable (*Rheumaptera hastata*), netted mountain moth (*Semiothisa carbonaria*), Ashworth's rustic (*Xestia ashworthii*) and sword-grass (*Xylena exsoleta*) and the cranefly *Thereva serrulifera*.

Thompson *et al.* (1995) recommended that the internationally important upland heather moorland plant communities they listed should be developed to the full range of their distribution, towards what would have been found in the 1940s. They provided a map (their Fig. 5a) showing the heather moorland conservation priorities for the upland regions of Britain, with the various important plant communities assigned high, medium or low priority. Forest open ground might potentially contribute to this cause and in some cases may already be doing so, since overgrazing was the main cause of losses in many regions.

Thompson *et al.* (1995) also recommended that improved habitat management be implemented to enhance populations of characteristic heather moorland birds. They named 6 'flagship' bird species, the status of which could easily be monitored by land owners and managers and which would generate strong public interest: hen harrier, merlin, golden eagle, golden plover, red grouse and black grouse. They presented a map (their Fig. 5b) showing, by region, with high, medium or low priority indicated, the heather moorland bird species for which habitat enhancement should be undertaken. Besides the six flagship species, the list also includes ring ouzel, peregrine, raven, buzzard and teal. Large heathland areas in forests could contribute to this effort. Smaller fragments of heathland in forests can contribute to a lesser extent. Most ground-nesting moorland birds, such as golden plover and hen harrier, need large open areas to breed successfully. Merlin, however, will use the forest open ground network to hunt and may nest in the trees. Black grouse will also use forest open ground and edges if the vegetation and forest structure suit their needs.

Thompson *et al.* (1995) set out six core objectives for restoring and maintaining heather moorland but they were devised for the open hills and moors, where overgrazing has degraded much heather moorland, and are not applicable to ungrazed heathland in forests. The objectives may be useful for large heathlands outside forests but on forest land, where past or present overgrazing has degraded the vegetation. They are:

- Restore dwarf shrubs and bryophytes on sub-montane moorlands
- Restore dwarf shrubs and bryophytes (particularly Sphagnum spp.) on blanket bog
- Restore the breeding range of key moorland birds
- Encourage management to sustain heather moorland in 'good' condition
- Improve heather moorland in 'poor' condition
- Restore 'suppressed' heather

Thompson *et al.* (1995) recommend changes in grouse moor management that favour nature conservation interests, including one action relevant to forest open ground. They recommend allowing vegetation to succeed towards scrub in suitable places, especially at higher altitude and along the edges of sheltered gorges where there may already be some remnant woodland.

Managing heathland – extensive areas

Encouraging botanical diversity

On dry heath of NVC community H12 (Calluna vulgaris-Vaccinium myrtillus heath), a species-poor community at Kielder, management is essential to maintain at least some botanical diversity (Good *et al.*, 1990). Grazing and burning are the traditional practices but where these are impractical, mowing can be used instead (MacDonald, 1996a). Wet heath is not usually heavily grazed but, even so, its plant species-richness can decrease as a result of reducing grazing pressure and ceasing burning (Ball, 1974).

Sheep drains or grips are common on hills and moorlands, particularly on areas of wet heath and blanket mire. They were dug to improve the vegetation for sheep and grouse but now they are damaging moorland communities, having adverse hydrological impacts on streams and providing very few benefits (Backshall, 2001a). Consideration should be given to blocking them with the objectives of encouraging revegetation of the bog surface, reducing erosion, restoring natural drainage patterns and minimising the downstream hydrological impacts (Murphy, 2001).

Practical guidance on grip blocking has been compiled (Murphy, 2001). Blocking is done with vegetated peat taken from the sides of the ditches to form wider ponded sections above the dams. Tracked excavators are best for this but manual work may be appropriate for a small number of dams or on steep or eroded ground. Wooden posts or boards can be used to reinforce peat dams in wide or eroded ditches. The dams should be one to two ditch widths long and the original vegetation from the ditch-sides should be kept upper-most to knit with the adjacent vegetation. The peat should be compacted down into the ditch and the top should finish level with, or slightly above, the adjacent vegetation.

Dams should be installed at intervals so that the water ponds back to the base of the next dam upslope. On level or very gently sloping ground, use 10-20 m intervals. Avoid creating water more than 60 cm deep where livestock are present because it creates a potential hazard for them. On steeper ground, if these specifications are not practical, block high feeder grips to slow down the water flow. Try to install dams where the grips join natural drainage runnels to restore the former natural flow pattern. Install dams in autumn so that they start to revegetate the following spring. This timing reflects a compromise between the need for the peat to be wet enough to compact down well when forming the dams and the easier and less damaging machine accessibility at drier seasons (Murphy, 2001).

Maintaining dwarf shrub dominance

High grazing pressure on moorland can cause grasses to increase in cover at the expense of dwarf shrubs (Backshall, 2001a). The grazing pressure is usually predominantly from sheep but other herbivores often contribute. Heavy grazing and trampling by red deer can reduce Calluna cover in dry heaths (McConnell_Associates, 2001). Reducing the grazing intensity sufficiently will stop this trend. Increasing

Molinia dominance may be controlled, in the very long term, by selective grazing and complementary burning may not help (Grant *et al.*, 1963; Todd *et al.*, 2000).

Diversifying the structure of dwarf-shrub heaths

Maintaining a varied age structure in H12 heather communities is necessary to provide suitable feeding and breeding habitats for many moorland birds (Good *et al.*, 1990). Heavy grazing by red deer can cause a loss of structural diversity on heaths (McConnell_Associates, 2001).

Restoring dwarf shrubs to dominance where they are still present

Re-introducing burning, followed by grazing, may restore heather to dominance in Molinia dominated M15 wet heaths on abandoned or neglected farmland at low altitudes in Kielder (Good *et al.*, 1990).

Sod removal was very successful in restoring dwarf shrub cover to Deschampsia flexuosa- and Molinia-dominated heathlands in Holland, restoring 100% dwarf shrub cover within 6-12 years (Diemont & Linthorst Homan, 1989). Complete ploughing and surface milling (rotovating) treatments were less successful. It was thought that grazing at some stage after sod-cutting could be beneficial in controlling Deschampsia regrowth. Machinery has been developed to apply the superficial sod-cutting treatment mechanically and hundreds of hectares had been successfully treated by 1986. Presumably the sod-cutting treatment is extremely destructive of the existing fauna so should not be applied uniformly over large areas. Optimal spatial patterns of restoration treatment need to be determined.

Controlling bracken to prevent loss of dwarf-shrub heath

Bracken can form good habitats for birds, notably whinchat and twite, invertebrates, some species of which are entirely dependent on bracken, reptiles (Spellerberg, 1988b; Thomson, 1990) and some rare butterflies (Abbot, 2002; Warren & Oates, 1994). However it can invade heath and other vegetation, eventually replacing it (Backshall, 2001b; Heal *et al.*, 1978; Roberts *et al.*, 1996). It can also invade grazing land and thus increase grazing pressure on valued heathland nearby. These adverse impacts can be avoided by controlling bracken where it is threatening valued heathlands. Thomson (1990) recommended that, to conserve reptiles in Kielder Forest, areas of bracken, particularly those on sunny, south-facing slopes and around major rock outcrops but also on forest road verges, should be maintained or, if possible, expanded.

The decline in bracken use for stock bedding and thatch and as a source of potash for glass and soap making, combined with climate change and less trampling by cattle and horses, has allowed bracken to spread over large areas (Green, 2003). Its replacement of heathland vegetation on well-drained soils is regarded as a natural succession. Lowland heaths which have undergone this succession can have increased soil nitrogen concentrations (Mitchell *et al.*, 1997). If grazing pressure allows, the succession will continue with very gradual development of woodland (Heal *et al.*, 1978), possibly via gorse scrub (Sydes & Miller, 1988). Le Duc *et al.* (2003) suggest that bracken may increase under the drier conditions expected as global warming progresses. Detailed guidance on bracken management in a nature conservation context is available (Backshall, 2001b; Roberts *et al.*, 1996). Bracken management can range from preventing bracken encroachment onto heathland (i.e. arresting the progress of the advancing front) to restoring areas already succeeded to dense bracken back to heath vegetation.

Physical bracken control methods involve starving the plants to death (Roberts *et al.*, 1996) by preventing the above-ground fronds from feeding the storage rhizomes that the plant lives off in winter. These rhizomes, deep in the soil, need to be starved for at least three years to exhaust their carbohydrate reserves, so control treatments are not instant. Breaking up the layer of bracken litter beneath the stand can also help by allowing frost to penetrate into the soil and weaken the bracken rhizomes. Removing the litter layer completely can help reduce the site nutrient capital where soil nutrient concentrations are higher than the low levels typically found under heaths (Snow & Marrs, 1997).

Asulam is the most commonly used herbicide for bracken control. It is sprayed onto the fronds and is translocated by the plant from the fronds to the rhizomes, where it kills frond-producing buds. This appears effective by greatly reducing frond density the following year but it hardly effects carbohydrate reserves in the storage rhizomes. Without follow-up treatments, the bracken can recover rapidly. If follow-up treatments can maintain a low frond density for long enough, the carbohydrate reserves will gradually become depleted (Le Duc *et al.*, 2003).

Physical control methods include cutting the mature fronds twice each summer, crushing the fronds using an agricultural roller in spring when they are brittle, using cattle to trample the litter and buds in winter or spring and ploughing or rotovating to remove the litter layer and physically damage the rhizomes. Cut fronds left lying can smother regenerating vegetation so should be either chopped up using a flail or removed, in which case baled material may be saleable for composting (Hunt, 2003).

Chemical methods involve spraying the fronds with asulam, or in some cicumstances spraying or weed-wiping with glyphosate during summer. Care is needed to avoid harming non-target plant species (Backshall, 2001b), such as rare bryophytes or lichens (Averis, 2001).

Snow and Marrs (1997) found that once-only ploughing and herbicide treatments did not have a lasting effect. Treatment regimes considered appropriate for a national bracken control strategy were, where possible, cutting twice yearly and elsewhere, applying herbicide (Le Duc *et al.*, 2003). On bracken-infested lowland heaths, bulldozing to remove fronds, litter and some rhizomes has proven more successful than some other restoration methods (Mitchell *et al.*, 1999).

Intensive control measures need to be continued for at least three years and less intensive ones for at least five (Roberts *et al.*, 1996) but, for best effect, efforts probably need to be continued for much longer (Marrs *et al.*, 1998). Follow-up treatments are needed after this to maintain control. Marrs *et al.* (1998) suggested a two-phase control strategy, with the first phase lasting 12, 12-18 or >18 years depending on whether control was by cutting twice yearly, cutting once yearly or spraying with asulam. This phase of treatment depletes the bracken rhizome system as much as is possible. The second phase involves a less intensive treatment regime to maintain a low rhizome biomass, preventing bracken recovery. Even when control regimes were continued for 18 years they did not eradicate bracken altogether because it eventually reaches a low level at which it stops responding to further treatment (Marrs *et al.*, 1998).

Burning can be a useful pre-treatment in bracken control programmes, easing access and use of machinery, removing the litter layer to expose rhizomes and allow frost to penetrate and encouraging heather seed to germinate (Roberts *et al.*, 1996). It is not a useful control measure on its own because it favours bracken in competition with heather, the bracken recovering far more quickly and shading out the heather (Heal *et al.*, 1978).

Encouraging adders

Heaths are used for hibernation and lying-out areas by adders. They need thickly vegetated, dry, elevated ground below which to hibernate communally (Prestt, 1971). Summer feeding grounds are the edges of ditches in damp grassy, rushy or reedy ground such as river meadows, usually within a mile of the hibernating area. When managing land to conserve or enhance adder populations, both the winter and summer habitats must be conserved, together with suitable migration routes between them, such as ditches, banks or hedges.

Unplanted areas of dry heathland on south-facing slopes, especially around major rock outcrops, were considered to provide the best habitats for adders in Kielder Forest (Thomson, 1990). Adder conservation would entail maintaining or enhancing these and encouraging dense stands of mature heather, rather than a more varied mosaic of *Calluna*, *Eriophorum* and grassland. Thomson (1990) also recommended enhancing reptile habitats in Kielder by maintaining or widening sunlit rides and roadsides, especially those with bracken, heather or tussocky grasses. However Prestt (1971) showed that in Dorset adders are site-faithful colony dwellers, so it may only be worth managing for adders where they already exist.

Measures that benefit reptiles will also benefit small mammals (Spellerberg, 1988a; Thomson, 1990), butterflies, spiders and amphibians (Spellerberg, 1988a) but discouraging a vegetation mosaic on heathland conflicts with plant, bird and invertebrate conservation requirements for structural variety.

Situations where nature conservation is not worthwhile

M15 communities (*Scirpus cespitosus – Erica tetralix* wet heaths) at Kielder were overwhelmingly dominated by *Molinia* and, apart from those on abandoned or neglected farmland at low altitudes, were considered unsuitable for positive management to enhance wildlife because this would probably be neither practical nor successful (Good *et al.*, 1990).

Managing heathland - small or linear fragments

Encouraging the development of old heather communities

Tall heather (>20 cm) usually shows above snow cover, providing food for herbivores during hard weather. However at other times it is a much poorer quality food than shorter heather. Heather layering (i.e. rejuvenation by the establishment of new adventitious roots) may be favoured by the sheltered conditions prevailing on some forest open ground. Stable layering heather stands that have gone for long periods (40 years plus) without burning or other disturbance can provide habitats for uncommon liverworts and invertebrates requiring humid, sheltered conditions (MacDonald, 1996b). Possible indicator species for such communities include juniper and mixtures of the liverworts *Anastrepta orcadensis*, *Bazzania tricrenata*, *Mylia taylorii* and *Scapania gracilis*. These stands should be maintained undisturbed.

Encouraging the development of scrub communities

A no-management policy on low-altitude areas of H12 dry heath at Kielder would allow birch scrub to develop in some places, enhancing wildlife habitat diversity of the forest (Good *et al.*, 1990).

Encouraging black grouse

Because their dispersal ability is limited and to make the most effective use of conservation effort, management for black grouse should be targeted within a 1.5 km radius of existing leks (Currie & Elliot, 1997). Forest edges bordering moorland and unplanted moorland remnants within forests were among the forest site types recommended for targeting management measures within areas designated as Black Grouse Management Areas (Cayford, 1993). In many cases these areas will support heath vegetation.

Management in young plantations should be aimed at maintaining a network of heather and blaeberry, boggy patches and natural edges (Currie & Elliot, 1997). Heather moorland and heathery vegetation in and around the forest can provide nesting sites. Heather should be managed to provide a mosaic of all age classes (Currie & Elliot, 1997). Patches of heather at least 40 cm tall are needed (RSPB, 2002) but these must be interspersed with shorter heather to allow the chicks to move easily to wetter areas with a good supply of the invertebrates they require as food. This could be achieved by using carefully controlled grazing or burning but in the forest situation mechanical methods such as swiping or cutting will usually be the most practical. Cutting should be done in autumn or early spring and the cut material should be removed to improve regeneration (Cayford, 1993). The regenerating heather will be more nutritious than the older growth. Heathland is particularly important in winter, when it provides shelter and a supply of the staple winter foods, heather and blaeberry shoots. It is important that heaths used by black grouse are at most only lightly grazed so that plenty of current year shoots are still available in winter.

Stands become less valuable when the canopy closes, although they still offer shelter and sometimes food in the form of larch buds, Scots pine pollen and caterpillars. Particularly good areas of transitional heathland/forest habitat can be kept open by respacing (Currie & Elliot, 1997). It is worth taking opportunities to widen rides and roadsides, scallop edges where appropriate, create more open ground and thin stands at the compartment edge (Currie & Elliot, 1997; RSPB, 2002). Establishing areas of broadleaves and enhancing wet open areas are also beneficial. Clearfelling provides a good opportunity to improve the habitat (Currie & Elliot, 1997).

Forest edges adjoining moorland can be improved by creating a wide graded transition between the two vegetation types (Cayford, 1993; Currie & Elliot, 1997) and by leaving unplanted heathland, including bogs, heather and blaeberry patches (Currie & Elliot, 1997). This can also provide many other conservation benefits. Within the forest fence, the planting spacing should be varied so that the trees are far apart at the outer edge and gradually close to normal spacing up to 200 m inside. Management should be aimed at creating, by the end of the rotation, a mixture of trees interspersed with open patches of heath vegetation (Cayford, 1993). Planting Scots pine, larch and broadleaves that provide food in winter, such as birch, rowan, hawthorn and willow can also help to improve this habitat (Cayford, 1993; Currie & Elliot, 1997; RSPB, 2002). Water-courses and associated forest bogs and wet areas are valuable sources of invertebrate food for chicks so should be protected (Currie & Elliot, 1997).

Restock areas where heather regenerates will provide good feeding areas for adult black grouse until the canopy closes (Cayford, 1993). Coupe size seems to be unimportant. Pre-thicket stage stands with a good cover of ground vegetation can provide suitable sheltered nest sites. Their years of suitability could be extended by either planting at wide spacing or thinning them out to delay canopy closure.

Heathland restoration by deforestation

Clearfelled coupes on Kielder Forest's peat, peaty gley and non-peaty gley soils revegetate quite densely before canopy closure, with *Calluna*, *Vaccinium myrtillus* and all the other characteristic species of the pre-afforestation plant communities reaching flowering size (Good *et al.*, 1990). *Calluna* regenerated more densely where the needle litter layer had been disturbed during felling operations, exposing bare peat. *Calluna* recovery during restoration might therefore be hastened by deliberately scraping peaty areas free of litter (Good *et al.*, 1990).

Experiments in restoring improved pasture back to heathland are giving promising early results, with two treatments, sulphur ammendment and soil-stripping, already showing signs of success and a cheaper treatment, deep ploughing also under trial (Peters, 2003). The trials also test the necessity for applying heather cuttings as a source of seed. This does seem necessary with the sulphur amendment treatment but might be avoided if the deep ploughing treatment successfully re-activates buried heather seed (Peters, 2003).

The need for re-introducing heather seed on some sites is clearly established and techniques for collecting suitable seed are being developed (Robinson, 2002).

MANAGING GRASSLANDS

About grasslands

The existence of most grasslands is dependent on land use rather than soil or other site properties. They include a very wide range of site types and reflect this in their wide range of species composition. Our focus on upland Britain narrows down the range of types we need to consider but we need to be careful to include those defined as lowland but occurring at the lower altitudes in the forests we think of as upland. Nevertheless, the National Vegetation Classification (Rodwell, 1992) includes 27 types of upland grassland (Fielding & Haworth, 1999). A primary division of types is that based on soil chemistry, pH in particular, into acid grasslands, mesotrophic grasslands and calcareous grasslands. The topsoil of Britain's uplands is mostly acidic and, as a result, acid grasslands are by far the most extensive types.

The most important acid grassland types are bent/fescue (*Agrostis canina*, *A.capillaris*, *Festuca ovina*) grasslands (NVC communities U1, U3, U4, U6, U13 and U15), mat grass (*Nardus stricta*) grasslands (U5, U7) and heath rush (*Juncus squarrosus*) grassland (U6). Purple moor grass (*Molinia caerulea*) mire (M25) is grass-dominated and can be considered an additional major acid grassland type (Fielding & Haworth, 1999).

Mesotrophic grasslands are mostly found in the lowlands (Rodwell, 1992) but *Cynosurus-Centaurea* grassland (MG5) and its more improved equivalent, *Lolium-Cynosurus* pasture (MG6) can extend into the upland fringes. On cessation of grazing, they can succeed to *Holcus lanatus-Deschampsia cespitosa* grassland (MG9), also found in upland forests on abandoned pastures, restock sites and as strips of disturbed ground beside roads (Good *et al.*, 1990). Upland limestone grassland (*Festuca-Agrostis-Thymus* grassland, CG10) is the only widely-distributed upland calcareous type.

Why conserve grasslands?

Plant and animal communities

Grasslands include a wide range of site types varying in climate, soil properties (wetness, nutrient status, reaction), and intensity of management. This ecological diversity supports a diverse range of plant communities and species. For example, a French study reported 77 nationally or regionally protected grassland species in a single region (Muller, 2002). MacKintosh *et al.* (2001) described the wildlife values of grasslands on Scottish farmland using a simple classification based on species composition. Table 8 summarises this information for the three types commonly found in the uplands.

Unimproved grasslands are key habitats for grassland fungi, particularly those in the genera *Camarophyllopsis*, *Dermoloma*, *Entoloma*, *Hygrocybe* and *Porpoloma* and in the families *Clavariaceae* and *Geoglossaceae* (Newton *et al.*, 2003). Across Europe as a whole, 286 species of grassland fungi appear in Red Data Lists. Many species are thought to be scarce in Britain. The soil biological community under grassland is affected by changes in management that alter the composition of the vegetation, such as removal of grazing (Neilson *et al.*, 2002).

Table 8. Summary of wildlife values of upland grassland types (information from MacKintosh *et al.* (2001)).

Grassland type	Wildlife values
Poorly-drained marshy grassland with prominent tussocks of rushes and/or purple moor grass. (Rush pasture)	Can be rich in plant species if dominated by *Juncus acutiflorus*. An important habitat for invertebrates. Supports large-bodied beetles, scarce in other types of grassland and a valuable food source for waders. Supports rarities, such as the slender-striped rufous moth and the marsh fritillary butterfly where its larval foodplant, devil's-bit scabious, is present. Provides shelter, cover and a range of prey for birds. Main habitat for snipe and other soil-probing waders. Provides shelter, hibernation sites and sometimes breeding ponds for frogs and toads.
Short grassland on lime-rich soils containing bents and fescues, at least moderately species-rich and with lime-loving species, such as wild thyme, and species that are more indifferent to soil type.	Important habitat for a large number of plants, including lime-loving species uncommon in the uplands. Important for many invertebrates. Warm sunny slopes support a range of solitary bees, butterflies, grasshoppers and snails. Flushes and springs support specialists, such as soldier flies, craneflies and snails. Rockrose growing here supports caterpillars of the rare northern brown argus butterfly, adults taking nectar from wild thyme and bird's-foot trefoil. Support breeding and feeding snipe, lapwing and curlew when close to moorland. Can be important for moorland species, such as twite and golden plover while awaiting snowmelt on higher ground and as summer feeding ground.
Species-poor grassland on acid soils typically containing several of: mat-grass, wavy hair-grass, heath bedstraw, common bent and sheep's fescue.	Supports a few specialist plant species. Bracken in small patches provides cover for birds, food for some invertebrates and can support woodland plants. A combination of different heather and grass sward structures in close proximity can provide good habitats for invertebrates. Important breeding habitat for waders, such as golden plover and curlew. Damp areas and flushes are important as sources of invertebrate food for their chicks. An abundance of small mammals and birds make these grasslands good hunting grounds for raptors, such as peregrine, hen harrier and merlin.

Habitat loss

Unimproved grassland is an endangered habitat in much of northern Europe. The major threat is from agricultural improvement but reduced grazing intensity, atmospheric nitrogen deposition and afforestation may also contribute to loss of the habitat. In the lowlands of Britain, 95 % of semi-natural grasslands have been lost (Hopkins & Tallowin, 2002). Losses have also been severe, but less so, in the uplands, where most of the surviving unimproved grassland is found. Newton *et al.* (2003) found examples in Scotland of sites known for grassland fungi that have been lost in the last 20-40 years due to agricultural improvement and road or building developments.

Conservation commitments

Species-rich grasslands can be restored but lost species may have to be re-introduced and increased soil nutrient fertility can limit success (Hopkins & Tallowin, 2002). It is therefore important that we attempt to conserve remaining areas of the habitat. Three species of fungi associated with unimproved grasslands are the subject of UKBAP Species Action Plans (*Hygrocybe calyptriformis, H. spadicea* and *Microglossum olivaceum*). The plans aim to maintain populations of the species at all known sites and to increase the extent of the populations where possible.

Agri-environment schemes have targeted unimproved grassland for management to encourage their habitat quality.

What can grasslands in upland forests offer?

Refugia

Many upland forests were partly planted on former unimproved grassland. The surrounding land still in agricultural use may subsequently have been improved so that the only remaining patches of unimproved grassland are the open areas in the forest. These will have been subject to varying rates of succession and may have deteriorated, at least in terms of plant species richness. However, in areas where there is no other unimproved grassland remaining, they may be the last refugia for grassland species lost from the improved land. They may act as sources for dispersal of species onto more extensive adjacent areas brought into management as grassland habitats for wildlife under agri-environment schemes. They may also serve as stepping-stones for wider dispersal of grassland species.

Pasture

There is growing interest in keeping livestock, especially cattle, in forests. They are now widely used as a means of vegetation management on nature reserves and may have the potential for similar use on forest open ground. They are also recognised as a possible means of managing woodland vegetation to increase overall biodiversity and for specific tasks such as encouraging natural regeneration.

Grasslands provide the best grazing ground within forests. Where a sufficient area of grassland exists, forest grazing may be a viable proposition, with the potential to benefit local economies. Because such grazing would be fulfilling conservation objectives, the products would be suitable for eco-branding, thus increasing their market value. There will, of course be practical constraints and these may affect feasibility, but there are enough potential benefits to justify trials.

Management objectives for grasslands in upland forests

In the absence of grazing, succession will tend to occur and grassland will become heath or scrub. It is important, when setting conservation management objectives for grassland sites, to consider what level of management it will be possible to sustain in the long term. Mowing regimes may be straightforward if the ground is not too rough but will commit the manager to an annual expenditure in perpetuity. Grazing is more complicated to instigate but could become a long-term source of income or at least be self-financing.

Muller (2002) demonstrated that, to conserve all the protected grassland plant species of a region, a wide variety of management practices – combinations of grazing, mowing and non-intervention – is required. This highlighted the inadequacy of using too limited a range of management regimes over a large area and showed that conservation of the full range of grassland habitat types is needed to conserve all the protected plant species.

Managing grassland – extensive areas

Restoration of botanical diversity to species-poor grassland

Hopkins & Tallowin (2002) provided guidelines for restoring the botanical diversity of grasslands that have become species-poor through agricultural improvement. Restoration is most likely to succeed at sites where the soil phosphate concentration is still low or where the sward has a moderately diverse composition and is not dominated by white clover or vigorous grasses, such as Yorkshire fog or perennial ryegrass. Restoration involves reducing the competitiveness of the existing sward (e.g. by mowing followed by hard grazing), disturbing the ground (e.g. by turf removal or partial rotovating) and oversowing with native wildflower and grass seed. The site will then require ongoing management, involving mowing and/or grazing, to maintain its renewed species diversity and develop other habitat qualities.

Controlling rushes to prevent loss of species diversity

There are good and bad sides to rushes (Wolton & Burke, 2003). Scattered clumps in grassland can provide good feeding and nesting habitat for wildfowl and waders. They can support strong populations of short-tailed field voles and other small mammals, providing good hunting grounds for raptors and owls. They provide food for some invertebrates, such as the rufous minor moth, and shelter for many others. On the down-side, they are invasive and dense patches smother low-growing plants and reduce plant species richness. Rush pasture and fen meadow must have less than 50% rush cover (<80% cover for Juncus articulatus or Juncus acutiflorus)to be in favourable condition. For wetland birds (except snipe) 33% cover is the maximum acceptable.

MANAGING MIRES

About mires

Mires are peat-producing ecosystems. They occur in places where persistently wet ground conditions limit soil biological activity. They accumulate organic matter as peat because the rate of organic matter deposition is greater than its rate of decay. They include the two main peatland types, bogs (nutrient-poor and strongly acidic) and fens (richer in nutrients and mildly acidic, neutral or basic). Strictly speaking, they also include sites with peaty mineral soils, usually supporting wet heaths or Molinia or Juncus grasslands. The National Vegetation Classification includes 38 mire communities but 10 of these are of very limited extent, growing only around springs and flushes (Rodwell, 1991b).

Of the 31 or so mire types found in the uplands, only a few are important in terms of their extent in upland forests. Blanket bog communities (M17-M20) cover huge areas, especially in the wetter north and west of Britain and at higher altitudes further south and east. The wetter areas of these bogs often support bog pool communities (M1-M3). Where the peat blanket thins out around the fringes of blanket mires, wet heath communities (M15-M16) and Molinia mire (M25) are common. Also on shallower peat, rush-pasture (M23) is common on poorer agricultural ground. Other fen communities tend to occupy only small areas in the uplands because the topography limits them mainly to flushed areas. M6 and M10 are the most common on acidic and calcareous soils, respectively. The vegetation communities of springs and flushes, though less extensive, are also important and can, in some cases, have higher conservation value than the more extensive types mentioned.

Bogs are by far the most extensive types of mire in the uplands. Where the peat thins out and the bog adjoins mineral soil ground, either around the edges of a raised bog or around mineral soil islands or incised streams within blanket bogs, there is usually a permanently wet seepage zone of fen vegetation, known as the lagg. Here, nutrients are relatively freely available so that it supports a completely different plant community and provides good habitats for invertebrates and birds. For some invertebrates, and perhaps for adders too, this close juxtaposition of bog and fen provides habitats suitable for their diverse needs or for different stages of their life-cycle.

Why conserve mires?

Plant and animal communities

Mires support a range of flora and fauna tolerant of the exposed, wet and sometimes nutrient-poor and acidic conditions. Some have evolved special adaptations. The bog mosses (*Sphagnum spp.*) include a range of species, from the almost completely aquatic to those with special mechanisms for retaining moisture, enabling them to survive in a sometimes strongly dessicating environment. Insectivorous plants obtain nitrogen by digesting invertebrates. The sundews (*Drosera spp.*) and butterworts (*Pinguicula spp.*) trap small insects on their sticky leaves and the bladderworts (*Utricularia spp.*) catch aquatic invertebrates by underwater suction trapping. The cottongrasses (*Eriophorum spp.*) develop cavities in their roots, carrying air down to support root tissue growing in an otherwise oxygen-free environment (lodgepole pine does this too!). These and many other specialist plants grow only in mires.

Mires support some specialist fauna of their own besides sharing some species with heathlands. Blanket mires are important breeding habitats for waders, including snipe, golden plover, greenshank, dunlin and curlew. The bleak, open landscape is an inhospitable environment for most mammalian and avian predators and is therefore a safe place for these ground-nesting waders. However they also provide hunting grounds for merlin and hen harrier. Dragonflies and damselflies live in mire pools during their aquatic larval stage. In common with heathlands, mires support diverse moth communities, as well as the large heath butterfly.

Small-scale mires, the spring and flush communities, are valued for their naturalness and the fact that they are permanent and unchanging (Averis, 2003). They support small flowering plants not found elsewhere, including such rarities as starwort mouse-ear chickweed (*Cerastium cerastoides*), brown bog-rush (*Schoenus ferrugineus*), false sedge (*Kobresia simpliciuscula*), creeping forget-me-not (*Myosotis secunda*) and Iceland purslane (*Koenigia islandica*) and many less rare but strongly asociated with these habitats. They tend to be rich in invertebrate species, especially protozoa, craneflies and other flies, spiders and aquatic beetles. Springs can also have cultural value, e.g. as healing or clootie wells and social or economic value as water supplies or spring water sources for bottling.

What can mires in upland forests offer?

Mires in any setting are valuable sites for nature conservation. Besides providing areas of habitats for the many mire-dependent specialist species, they act as stepping stones for the movement of these and other species through the landscape.

Mires in upland forests are generally more sheltered than those surrounded by land in other uses. Increased shelter can be beneficial for flying insects, including the odonata (dragonflies and damselflies) and lepidoptera (butterflies and moths). The juxtaposition of this prey-rich habitat with a coniferous forest edge seems well-suited to the merlin, which feeds on small birds and odonata and can adapt from its habit of nesting on the ground among tall heather to nesting in old crow’s nests in trees at the forest edge.

The ecological integrity of mires on farmland is often compromised by encroachment of agricultural improvement onto the shallower peat of the mire edge and consequent loss of the natural lagg fen. This may also have happened at the edges of unplanted bogs in forests. However, forestry objectives often include the provision of wildlife habitats, making it easier for the forester than the farmer to re-instate the lagg fen. This could be achieved by cutting back the forest to a new boundary part-way up the adjacent mineral soil slope, leaving space for a lagg fen to develop in its natural context (i.e. in the low-lying ground between the bog edge and the adjacent slope).

Management objectives for mires in upland forests

Bogs are the most common and extensive types of mire in upland forests and many are protected by conservation designations. Because of their inherent low productivity, they are not, in their natural state, subject to succession in the same way as heathlands and grasslands. However most mires have been altered by past attempts at improvement, usually drained to some degree and often burned. Many have also been cut away around the edges. These disturbances will have caused a drying of the surface and often the loss of the natural fen vegetation of the lagg. As a result their flora and fauna will be impoverished by the loss of fire-sensitive species, some of the more hydrophilic mire specialist species and the fen species of the margins. Often the drying will have led to a change in vegetation from bog towards species-poor dry heath communities. Many will have developed a tendency to succeed to woodland by the establishment of naturally regenerated birch, pine or other trees.

Mires still in something like their natural condition need to be kept that way. They are not eligible for afforestation (Patterson & Anderson, 2000). Avoiding damaging them by drainage, fertiliser application or drift may be the main objectives of management. But there is often scope for pro-active management, such as the blocking of drains or the clearing of forest further back from the edge to encourage re-naturalisation of the lagg.

Grazing, including ‘natural grazing’ (i.e. grazing and browsing by deer and other wild animals), has probably been the main force keeping Britain’s mires open and free of scrub or tree cover in recent centuries(Chambers, 2001). The cessation of traditional grazing and burning practices can have adverse impacts on some bog plants (Chapman & Rose, 1987). Grazing may have been a factor in maintaining the species richness of bogs and it may be desirable to re-introduce a light grazing regime designed for conservation (Brooks & Stoneman, 1997). The objective of such management must be clear; is the aim solely to prevent the establishment of trees or is it to encourage the development of a particular vegetation composition or structure? Burning of blanket bog or wet heath can be damaging to the flora and fauna and is not generally recommended as a conservation management tool (Shaw *et al.*, 1996). However, where fire-sensitive species such as Sphagnum austinii are absent, burning may be a practical solution to the problem of tree regeneration.

Dried or otherwise degraded mires with a tendency for scrub or woodland development will require a decision on whether to restore them, so that the successional tendency is reduced, or allow them to succeed to wet woodland, itself a valuable habitat (Wilkinson, 2001) and the subject of a UKBAP Habitat Action Plan. The decision will hinge on the feasibility of rewetting the mire by raising its water table (Anderson, 2001a) and will be influenced by the standing of both mires and wet woodlands among local conservation priorities.

Mires that have already been planted over may be suitable for deforestation and restoration. Forestry Commission policy on the subject (Patterson & Anderson, 2000) and a review of the evidence concerning its feasibility and cost-effectiveness (Anderson, 2001a) can help inform the decision. Principles for wise use of mires and peatlands have been compiled for global use by countries and include a framework for decision-making (Joosten & Clarke, 2002). The framework is intended to be used to help resolve conflicts between different uses, such as forestry and nature conservation. It may be helpful in justifying mire conservation during the design of new forests or in deciding whether to attempt to deforest and restore mires that have already been afforested.

Managing mires – extensive areas

Keeping mires wet

There are few, if any, scientific studies of management to keep mires wet, perhaps because it is obvious what is required. If a mire has not been affected by drainage, afforestation, peat cutting or in the case of fens, by diversion of their water source, it will already be wet. Keeping it wet is simply a matter of preventing any of these from happening.

Mires that are artificially dry, probably because they have been drained, afforested or cut about, will need to be rewet by reversing the effects of these. Tree stands can be removed (Anderson, 2001a; Bacon & Lord, 1996) and drains infilled or blocked (Anderson, 2001a; Brooks & Stoneman, 1997; Hutt, 2002). Peat cutting commonly impinges on the edges of bogs and its hydrological influence usually extends much further over the bog surface. Reversing the drying effects of peat cutting is problematic. Unless the hydrological effect is very minor, the options for intervention (Wheeler & Shaw, 1995) are expensive and their long-term efficacy unknown. An alternative is to accept that the site is artificially dry and that woodland is likely to develop on it naturally. In the long term, the wooded or partly wooded bog might eventually subside sufficiently for the surface to become wet again.

Encouraging a natural lagg at the edge of a bog

The lagg at the edge of a bog is an area of wet ground with a layer of peat perhaps 15-75 cm thick and a much better supply of nutrients than on the bog itself due to the influence of mineral soil water. In its natural state the lagg supports fen plants, most typically marsh cinquefoil (*Potentilla palustris*), marsh violet (*Viola palustris*) and marsh pennywort (*Hydrocotyle vulgaris*) and, in an ungrazed situation, willows.

The most basic requirement for a naturalistic lagg is sufficient open space at the boundary between bog peat and mineral soil. If this ground has been planted with conifers, they will need to be removed before a lagg can develop. The former lagg will usually have been a natural drainage route for water running off the bog and the adjacent mineral soil ground. The drainage will almost invariably have been improved by the digging of ditches. These need to be blocked or, preferably, filled in to allow the lagg to retain water again.

Grazing bogs to maintain or increase plant species richness

There is little in the way of published results of grazing trials. Grant *et al.* (1985) found that stocking rates of 2.2 sheep ha^{-1} under a year-round grazing system and 1.4 sheep ha^{-1} under an off-wintering system were too high for M17 blanket bog. Besides causing reductions in the productivity of the vegetation and the cover of heather and cottongrass, these grazing regimes increased the proportion of ground bare of vascular plants. A lower stocking rate also began to adversely affect the vegetation during wet years. An upper limit stocking rate of 1 sheep ha^{-1} is suggested for avoiding overgrazing. Brooks and Stoneman (1997) suggest appropriate sheep stocking rates for bogs of <0.25 sheep ha^{-1} for wet bog, 0.25-0.37 sheep ha^{-1} for degraded bog and 1.0-1.5 sheep ha^{-1} for wet heath.

Grazing to discourage tree establishment on dried bogs

Some degree of tree cover on bogs is now increasingly accepted as part of the natural scene (Chambers, 2001; Wilkinson, 2001). It is also a commonly expressed view that tree growth on Britain's bogs, particularly the blanket mires, has been suppressed by grazing and burning and limited regeneration due to the deforested state of the uplands (Chambers, 2001). Light grazing may be a useful practice where it is desired to continue to suppress trees. Roe deer can suppress tree regeneration but management of forest deer populations usually seeks to limit the population, possibly limiting their efficacy in this role.

Mechanical and chemical methods of discouraging tree establishment on dried bogs

On many raised bog nature reserves, scrub, especially regenerating birch, is managed by cutting it and applying glyphosate to the stumps. This generally doesn't work because the scrub regrows from stumps, seedlings or both (Meade, 2001). A range of treatments combining mechanical and chemical methods was trialled at Fenns and Whixall Mosses (Daniels, 2001).

In general, attempting to deal with tree regeneration or scrub development is not worthwhile on degraded sites that are artificially dry, nutrient enriched or both. The drying or nutrient enrichment need to be reversed. Unless this is achieved, efforts to keep the bog free of trees might as well be abandoned. Scrub or tree removal treatments may improve the scene temporarily but would need repeated at regular intervals and much expense. Grazing may be a solution but trials are only just beginning.

Managing mires – small or linear fragments

Conserving springs

The short vegetation characteristic of springs is vulnerable to damage if excessively trampled by cattle, sheep or deer. However, where there is a suitable seed source and little or no grazing to suppress regeneration, they can develop low willow scrub communities, which may replace valued short vegetation (Averis, 2003). Where this conflict arises, the practicality of maintaining a light grazing pressure and the relative conservation value, locally, of the vying spring and willow scrub communities should all be taken into consideration in deciding whether to try to conserve the short vegetation or allow succession to scrub to occur.

Conserving flushes

Flushes, like springs, are vulnerable to trampling damage by red deer (Averis, 2003). They can also be adversely affected by cultivation or drainage further up-slope that changes the pattern of water flow, reducing the degree of flushing and perhaps allowing the former flush to dry out in summer. A lack of grazing, if not compensated for by natural grazing by wild herbivores, can allow succession to occur so that the bryophytes, sedges, rushes and herbs are replaced by willow scrub (Averis, 2003). As in the case of springs, the relative value of the flush and scrub communities should be considered when deciding the management objectives. Flush vegetation dominated by tall rushes or bottle sedge (*Carex rostrata*) usually represents wet woodland vegetation that has survived since the site was deforested (Averis, 2003). On these sites, it would seem appropriate to tolerate or even encourage succession towards new wet woodland, provided there is no good reason for conserving the open vegetation.

Managing rides, road verges and forest edges in forests on deep peat

Rides and other unplanted areas in forests on former mires act as refuges for many of the mire plant species (Anderson, 1998; Anderson, 2000; Anderson, 2001b) and for some of the associated invertebrates, amphibians and reptiles. There will usually be a tendency for these areas to be drier than their-pre-forestry condition due to the edge-effect of the cultivation and drainage of the adjoining compartments. On raised bogs and blanket bogs, however, some rides can remain surprisingly wet and retain most of the bog species. These areas are also vulnerable to nutrient enrichment caused by direct application or drift of fertilizer applied aerially. This will encourage dominance of the vegetation by purple moor grass (*Molinia caerulea*) and bog myrtle (*Myrica gale*) where these are present as components of the former vegetation and will encourage natural regeneration of birch and conifers. The changes may lead to the loss of smaller mire species.

Management planning on these sites needs to consider their long term future. If it is assumed that the forests will undergo many planting and felling cycles then the refugia are of little value because they will become progressively drier until all the bog species are lost. However if there is a possibility that future management of the forest will aim to conserve part or all of the bog by deforestation and restoration then the refugia are immensely valuable as potential sources of the species which will one day be expected to recolonise the site.

Conserving rides as species refugia entails protecting them as far as is possible against drying and nutrient enrichment. Blocking ride-side drains will often be incompatible with continued timber production from the adjoining compartments. Enlarging these areas as part of forest restructuring can allow some drain blocking and help to reduce the hydrological edge effects that tend to dry them. Careful planning and implementation of aerial fertilizing programmes may help to avoid fertilizing the unplanted ground, although it is not known whether the precision needed to protect rides is achievable in practice.

Red deer presence is often concentrated onto rides and unplanted areas. The stags use pools, flushes and wet hollows to wallow in, churning up the peaty surface and damaging the vegetation. Despite the obvious damage, such disturbance is probably beneficial for the mire ecosystem because it creates bare patches for small and pioneering plant species to regenerate and creates bare ground habitats for specialist invertebrates. Provided the deer population density is low enough for some of these wallows to revegetate, the benefits will outweigh the harm. If all the wallows are in such continuous use as to never revegetate then deer numbers need to be reduced if the rides are to continue to act as mire species refugia. Moderate densities of deer probably also help to suppress shrub and tree regeneration, keeping the vegetation open.

Restoring mires by deforestation

There is little in the way of published evidence for successful restoration of mires by deforestation (Anderson, 2001a). However there are now many sites, mostly bogs, where it has been attempted and there are some indications that it can be successful in achieving the re-establishment of bog vegetation. It remains to be seen whether the new vegetation will endure or be replaced by succession to other types.

Forestry policy for Great Britain in relation to deforestation for peatland restoration was set out recently (Patterson & Anderson, 2000). Now that forestry policy has been devolved to Wales, England and Scotland, they will have their own policies on deforestation, which may affect attitudes to bog restoration.

CONCLUSIONS

Some conclusions have emerged, both directly from the material reviewed and indirectly through the reviewing process.

- Forest open ground is a largely untapped nature conservation resource.

- Non-intervention leads to deterioration of habitat quality in terms of decreased vegetation structural diversity. Positive management is better than non-intervention in most cases.

- Management for nature conservation need not conflict with, and can sometimes complement, management for other objectives, such as compartmentalisation, access, fire limitation, riparian buffering and deer management.

- Many different groups of plants and animals use forest open ground but few species are entirely or mostly dependent on it.

- The requirements of a minority of the species that use forest open ground are well understood.

- Methods of managing forest open ground to conserve or favour particular species or groups have only been considered for a few.

- Management based on some general principles may benefit most, but not all the species using forest open ground: encouraging the development of ecotones at forest/open ground edges, positive management of special habitats (lakes, streams, ponds, wetlands, bogs, heaths, rock outcrops, etc.), planting or encouraging certain broadleaf species, encouraging some scrub development, encouraging habitats intermediate between woodland and open vegetation.

- Aiming to manage for biodiversity is not feasible because biodiversity is too difficult to measure and the appropriateness of different management methods is not known.

- Attempts to manage forest open ground for particular known conservation interests will inevitably meet with situations where the interests of different species or groups conflict.

- Management aimed at enhancing habitat quality faces the same problem because habitat quality is only meaningful when the identity of the species using the habitat is explicitly stated.

- Methods are required for identifying and prioritising the various open ground conservation interests of a site.

- Vegetation management methods to achieve conservation aims on forest open ground need to be developed and their cost-effectiveness maximised.

- Conservation grazing has enormous potential as a means of making better use of forest open ground but concerns about viability, access, road use conflicts, herding requirements, animal welfare, supplementary feeding and water supply protection, may need to be overcome.

- Prescribed burning has little potential because of the risk of forest fires. It may be feasible on some areas but the cost of precautions against forest fire will be high.

- At present the UK Forestry and UKWAS standards include a requirement to manage open ground but there are, as yet, few obvious efforts to do so.

- Outside the forestry standards, there is little incentive for forest managers to manage open ground in forests for nature conservation objectives.

- Mechanisms for obtaining funds for managing forest open ground need to be developed.

- More detailed standards for forest open ground management need to be incorporated into the forestry standards used in certification schemes.

- The sustainability of open ground management involving manipulation of natural succession needs to be considered.

ACKNOWLEDGEMENTS

I am grateful to Jonathan Humphrey, Chris Quine, Liz Poulsom, Kirsten Hutchison, Helen Armstrong, Duncan Ray and Alice Broome for helping in various ways. Steve Gregory commented helpfully on a partial draft.

REFERENCES

Abbot, E. (2002) British butterflies - a review of their current status and conservation. Unpublished review paper. Napier University, Edinburgh.

Abdy, E. (1991) Ground flora dynamics of Sitka spruce plantations. Forestry Commission Report on Forest Research 1991. 70. HMSO, London.

Adamson, J.K. and Kahl, J. (2003) Changes in vegetation at Moor House within sheep exclosure plots established between 1953 and 1972. CEH Project C00162. Report to English Nature, March 2003. Centre for Ecology and Hydrology, Grange over Sands.

Anderson, A.R. (1998) Botanical surveys of Racks and Ironhirst Mosses. Forestry Commission internal report (unpublished). Forest Research, Roslin.

Anderson, A.R. (2000) Report on the suitability of Flanders Moss Forest for bog restoration. Forestry Commission internal report, unpublished. Forest Research, Roslin.

Anderson, A.R. (2001a). *Deforesting and restoring peat bogs: a review*. Forestry Commission Technical Paper 32. Forestry Commission, Edinburgh, 28 pp.

Anderson, A.R. (2001b) FE Dornoch northern forests peatland SAC boundaries survey. Forestry Commission internal report, unpublished. Forest Research, Roslin.

Anderson, M.A. (1988) Vegetation management. Forestry Commission Report on Forest Research 1988. 50. HMSO, London.

Anderson, M.A. and Carter, C.I. (1987) Vegetation management. Forestry Commission Report on Forest Research 1987. 57. HMSO, London.

Anderson, M.A. and Carter, C.I. (1988) Shaping ride sides to benefit wild plants and butterflies. In: Jardine, D.C. (Ed.) *Wildlife management in forests. Proceedings of a discussion meeting. University of Lancaster 3-5 April 1987*. Institute of Chartered Foresters, Edinburgh.

Andrews, J. and MacDonald, A. (1996) Fences and upland conservation management. SNH Information and Advisory Note No. 59. Scottish Natural Heritage, Battleby.

Averis, A. (2003). *Springs and flushes*. Scotland's living landscapes. Scottish Natural Heritage, Battleby.

Averis, A.B.G. (2001) The effects of woodland management on bryophytes and lichens in the western Highlands. SNH Information and Advisory Note No. 121. Scottish Natural Heritage, Battleby.

Backshall, J. (2001a) Chapter 6 Moorland. In: Backshall, J., Manley, J. and Rebane, M. (Eds.) *The upland management handbook*. English Nature, Peterborough pp. 6:1-6:130.

Backshall, J. (2001b) Information Note 6 Managing bracken. In: Backshall, J., Manley, J. and Rebane, M. (Eds.) *The upland management handbook*. English Nature.

Bacon, J. and Lord, R. (1996) Troublesome trees. Taking trees off bogs. *Enact*, **4**(3): 12-16.

Ball, M.E. (1974) Floristic changes on grasslands and heaths on the Isle of Rhum after a reduction or exclusion of grazing. *J. envir. mgmt.*, **2**: 299-318.

Bowden, C.G.R. and Green, R.E. (1991) The ecology of nightjars in pine plantations. Forestry Commission Report on Forest Research 1991. 70. HMSO, London.

Bradley, R.T. (1988) The established forest: maximising the cost:benefit of wildlife management planning. In: Jardine, D.C. (Ed.) *Wildlife management in forests. Proceedings of a discussion meeting. University of Lancaster, 3-5 April 1987.* Institute of Chartered Foresters, Edinburgh.

Brereton, T. (1999) The distribution, ecology and conservation of the pearl-bordered fritillary butterfly Boloria euphrosyne in Scotland. SNH Information and Advisory Note No. 114. Scottish Natural Heritage, Battleby.

Brooks, S.J. and Stoneman, R.E. (1997). *Conserving bogs: the management handbook*. The Stationery Office, Edinburgh, 280 pp.

Buckley, G.P. (1989) Forest edge management to conserve wild plants. Forestry Commission Report on Forest Research 1989. 76. HMSO, London.

Campbell, C. and Puri, G. (2002) Soil biodiversity. SNH Information and Advisory Note No. 151. Scottish Natural Heritage, Battleby.

Carter, C. and Winter, T.G. (1994) The influence of forest structure on insect diversity in broadleaved woodland. Forestry Commission Report on Forest Research 1994. 9. HMSO, London.

Carter, C.I. and Anderson, M.A. (1987) Enhancement of lowland forest ridesides and roadsides to benefit wild plants and butterflies. Research Information Note 126. Forestry Commission, Farnham.

Carter, C.I. and Anderson, M.A. (1988) Duration of daylight and levels of energy input to sunlit ridesides. Forestry Commission Report on Forest Research 1988. 48-49. HMSO, London.

Carter, C.I. and Ferris-Kaan, R. (1989) Responses of insects to newly widened rides. Forestry Commission Report on Forest Research 1989. 54-55. HMSO, London.

Cayford, J.T. (1993) Black grouse and forestry: habitat requirements and management. Forestry Commission Technical Paper No. 1. Edinburgh. Forestry Commission, Edinburgh.

Chambers, F.M. (2001) When are trees natural on bogs? In: Whild, S., Meade, R. and Daniels, J. (Eds.) *English Nature Research Report No. 407. Management of water and trees on raised bogs. Papers and transcripts from a lowland peatland workshop held at Hanmer, 10-12 June 1997.* English Nature, Peterborough.

Chapman, S.B. and Rose, R.J. (1987) Vegetation change at Coom Rigg Moss NNR. *The NERC Institute of Terrestrial Ecology Report for 1986-87*. Natural Environment Research Council, Swindon pp. 100-101.

COFORD (2001). *COFORD annual report*. COFORD, Dublin.

Coulson, J.C., Goodyer, A. and Fielding, S. (1992) The management of moorland areas to enhance their nature conservation interest. JNCC Report No. 134. Joint Nature Conservation Committee, Peterborough.

Currie, F. and Elliot, G. (1997). *Forests and birds. A guide to managing forests for rare birds*. Royal Society for the Protection of Birds, Sandy.

Daniels, J. (2001) Scrob control on Whixall Moss and Bettisfield Moss. In: Whild, S., Meade, R. and Daniels, J. (Eds.) *English Nature Research Report No. 407. Management of water and trees on raised bogs. Papers and transcripts from a lowland peatland workshop held at Hanmer, 10-12 June 1997.* English Nature, Peterborough.

Day, K.R., Marshall, S. and Heaney, C. (1993) Associations between forest type and invertebrates: ground beetle community patterns in a natural oakwood and juxtaposed conifer plantations. *Forestry*, **66**(1): 37-50.

Dearnley, T.C. and Duckett, J.G. (1999) Juniper in the Lake District National Park. A review of condition and regeneration. *Watsonia*, **22**: 261-267.

Dent, S. and Spellerberg, I.F. (1986) The behaviour of sand lizards in relation to forest management. Forestry Commission Report on Forest Research 1986. 73-74. HMSO, London.

Diemont, W.H. and Linthorst Homan, H.D.M. (1989) Re-establishment of dominance by dwarf shrubs on grass heaths. *Vegetatio*, **85**: 13-19.

Evans, D.F. (1978). *Roads as a habitat for wild plants in coniferous plantations. ITE NERC/NCC Contract No. F3/03/78 unpublished report*. ITE, Bangor.

Evans, H. (1992) Entomology. Forestry Commission Report on Forest Research 1992. 35. HMSO, London.

Evans, H. (1993) Entomology. Forestry Commission Report on Forest Research 1993. 1. HMSO, London.

Fahy, O. and Gormally, M. (1998) A comparison of plant and carabid beetle communities in an Irish oak woodland with a nearby conifer plantation and clearfelled site. *For. Ecol. Mgmt.*, **110**: 263-273.

Ferris, R. and Carter, C. (2000). *Managing rides, roadsides and edge habitats in lowland forests.* Forestry Commission Bulletin 123. Forestry Commission, Edinburgh.

Ferris, R. and Humphrey, J.W. (1999) A review of potential biodiversity indicators for application in British forests. *Forestry*, **72**(4): 313-328.

Ferris-Kaan, R. (1990a) Studies of the use of herbicides and growth regulators to manipulate ground vegetation for conservation. Forestry Commission Report on Forest Research 1990. 65-66. HMSO, London.

Ferris-Kaan, R. (1990b) Survey of ride management practices in England and Wales. Forestry Commission Report on Forest Research 1990. 65. HMSO, London.

Ferris-Kaan, R. (1991) Vegetation management (lowlands). Forestry Commission Report on Forest Research 1991. 48-49. HMSO, London.

Ferris-Kaan, R. (1992) Ride management in lowland woods - vegetation succession and invertebrate responses. Forestry Commission Report on Forest Research 1992. 39-40. HMSO, London.

Ferris-Kaan, R. (1994) Vegetation management (lowlands). Forestry Commission Report on Forest Research 1994. 51-52. HMSO, London.

Fielding, A.H. and Haworth, P.F. (Editors), (1999) Upland habitats. Routledge, London.

Forestry_Authority and Department_of_Agriculture_for_Northern_Ireland (1998). *The UK Forestry Standard - the government's approach to sustainable forestry*. Forestry Commission, Edinburgh.

Forestry_Commission (1978) South Scotland Conservancy Technical Instruction. Unpublished internal document. Forestry Commission.

Forestry_Commission (2002a) Forestry facts and figures 2002. Forestry Commission, Edinburgh.

Forestry_Commission (2002b) Forestry Statistics 2002. A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom. Forestry Commission, Edinburgh.

Fuller, R.J. and Whittington, P.A. (1987) Breeding bird distribution within Lincolnshire ash-lime woodlands: the influence of rides and the woodland edge. *Acta Oecologia - Oecologia Generalis*, **8**: 259-268.

Gardner, S.M., Hartley, S.E., Davies, A. and Palmer, S.C.F. (1997) Carabid communities on heather moorlands in northeast Scotland: the consequences of grazing pressure for community diversity. *Biol. Conserv.*, **81**: 275-286.
Gaywood, M. (1996) The distribution, ecology and conservation of the marsh fritillary butterfly (Eurodryas aurinia). SNH Information and Advisory Note No. 9. Scottish Natural Heritage, Battleby.
Gilbert, D. and Di Cosmo, L. (2003) Towards restoration of treeline woodland and montane scrub. *Bot. J. Scotl.*, **55**(1): 177-187.
Gimingham, C.H. (1972). *Ecology of heathlands*. Chapman and Hall, London.
Goldsmith, B. (1981) The afforestation of the uplands: the botanical interest of areas left unplanted. University College London Discussion Papers in Conservation No. 35. University College London.
Good, J.E.G. (1988) Nature conservation in upland conifer forests. Forestry Commission Report on Forest Research 1988. 75. HMSO, London.
Good, J.E.G. (1991) Nature conservation in upland conifer forests. Forestry Commission Report on Forest Research 1991. 69. HMSO, London.
Good, J.E.G., Williams, T.G., Wallace, H.L., Buse, A. and Norris, D.A. (1990) Nature conservation in upland conifer forests. A report to the Forestry Commission and the Nature Conservancy Council. Unpublished contract report. Institute of Terrestrial Ecology, Bangor.
Gordon, I. and Fraser, J. (1991) Review of the potential for domestic stock grazing for wildlife conservation in forests. Forestry Commission Report on Forest Research 1991. 71. HMSO, London.
Grant, S.A., Bolton, G.R. and Torvell, L. (1985) The responses of blanket bog vegetation to controlled grazing by sheep. *J. appl. Ecol.*, **22**: 739-751.
Grant, S.A., Hunter, R.F. and Cross, C. (1963) The effects of muirburning Molinia-dominant communities. *Journal of the British Grassland Society*, **18**(3): 249-257.
Greatorex-Davies, J.N., Sparks, T.H. and Hall, M.L. (1994) The response of Heteroptera and Coleoptera species to shade and aspect in rides of coniferised lowland woods in southern England. *Biol. Conserv.*, **67**: 255-273.
Green, M. (2003) The Welsh uplands - past, present and future. *British Wildlife*, **August 2003**: 403-412.
Heal, O.W., Adamson, J.K., Ball, D.F., Benefield, C.B., Bocock, K.L., Bunce, R.G.H., Chapman, S.B., Miles, J., Millar, A., Satchell, J.E., Smith, I.R., Thomas, D.I., Welch, D. and Williams, W.M. (1978) Upland land use in England and Wales. CCP 111. CCP 111. Countryside Commission.
Hill, M.O. (1978a) Comparison of the flora of forested and unafforested kilometre squares on the Hiraethog Moors, Clwyd. ITE report to the Nature Conservancy Council. Institute of Terrestrial Ecology, Bangor.
Hill, M.O. (1978b) Notes on plant species and their habitats in British upland forests. ITE report to the Nature Conservancy Council. Institute of Terrestrial Ecology, Bangor.
Hill, M.O. (1983). *Plants in woodlands. Session 3. Centenary Conference on Forestry and Conservation*. Royal Forestry Society, Tring.
Hill, M.O. (1990) Appendix 3.5 Bryophytes of Kielder Forest. In: Good, J.E.G., Williams, T.G., Wallace, H.L., Buse, A. and Norris, D.A. (Eds.) *Nature conservation in upland conifer forests. A report to the Forestry Commission and the Nature Conservancy Council*. Institute of Terrestrial Ecology, Bangor.

Hill, M.O. and Jones, E.W. (1978) Vegetation changes resulting from afforestation of rough grazings in Caeo Forest, South Wales. *J. Ecol.*, **66**: 433-456.

Holtam, B. (1971) Research on conservation in the Forestry Commission. *Forestry*, **Supplement: wildlife conservation in forest management.**: 49-54.

Hope, D., Picozzi, N., Catt, D.C. and Moss, R. (1996) Effects of reducing sheep grazing in the Scottish Highlands. *Journal of Range Management*, **49**(4): 301-310.

Hope-Jones, P. (1988) Blackgrouse ecology. Forestry Commission Report on Forest Research 1988. 76. HMSO, London.

Hopkins, A. and Tallowin, J. (2002) Enhancing the biodiversity and landscape value of grasslands. IGER Innovations 2002. Institute of Grassland and Environmental Research, Aberystwyth.

Hughes, J., Jones, A. and Gallagher, P. (2003). *Wood ants in Scotland. An information and management guidance note*. FC/SNH/WTS/SWT, Edinburgh.

Humphrey, J.W. (1998) Grazing as a management tool: a synthesis of common research needs. In: Humphrey, J.W., Gill, R.M.A. and Claridge, J. (Eds.) *Grazing as a management tool in European forest ecosystems*. Forestry Commission, Edinburgh.

Humphrey, J.W., Gill, R.M.A. and Claridge, J. (1998) Grazing as a management tool in European forest ecosystems. Forestry Commission Technical Paper 25. Forestry Commission, Edinburgh.

Humphrey, J.W., Newton, A.C., Peace, A.J. and Holden, E. (2000) The importance of conifer plantations in northern Britain as a habitat for native fungi. *Biol. Conserv.*, **96**(2): 241-252.

Humphrey, J.W. and Patterson, G.S. (2000) Effects of late summer cattle grazing on the diversity of riparian pasture vegetation in an upland conifer forest. *J. appl. Ecol.*, **37**: 986-996.

Hunt, J. (2003) Cashing in on bracken. Interview with Simon Bland., Farmers Weekly.

Hutt, D. (2002) Damming ditches in peat bogs. (Unpublished report, copies available from author). Northumberland Wildlife Trust, Newcastle-upon-Tyne.

JNCC (2001) Upland heathland Habitat Action Plan. Joint Nature Conservation Committee, Peterborough.

Joosten, H. and Clarke, D. (2002). *Wise use of mires and peatlands - background and principles including a framework for decision-making*. International Mire Conservation Group and International Peat Society.

Key, R.S. (1995) Chapter 10. Invertebrate conservation and new woodland in Britain. In: Ferris-Kaan, R. (Ed.) *The ecology of woodland creation*. John Wiley & Son, Chichester.

Key, R.S. and Gent, A. (1993) Bare but not barren. *Enact - Managing land for wildlife*, **1**: 15-16.

King, M. (2001) Any room for scrub? *Ecos*, **22**(2): 21-24.

Kirby, P. (1992). *Habitat management for invertebrates: a practical handbook*. Royal Society for the Protection of Birds, Sandy.

Le Duc, M.G., Pakeman, R.J. and Marrs, R.H. (2003) Changes in the rhizome system of bracken subjected to long-term experimental treatment. *J. appl. Ecol.*, **40**: 508-522.

Lindenmayer, D.B., Hobbs, R.J. and Salt, D. (2003) Plantation forests and biodiversity conservation. *Aust. For.*, **66**(1): 62-66.

Lousley, J.E. (1976). *Flora of Surrey*. David and Charles, Newton Abbot.

MacDonald, A. (1996a) Cutting of heather as an alternative to muirburn. SNH Information and Advisory Note No. 58. Scottish Natural Heritage, Battleby.
MacDonald, A. (1996b) Heather layering and its management implications. SNH Information and Advisory Note No. 35. Scottish Natural Heritage, Battleby.
MacDonald, A. and Haysom, K. (1997) Heather moorland management for Lepidoptera. SNH Information and Advisory Note No. 78. Scottish Natural Heritage, Battleby.
MacKintosh, J., McCracken, D., Ford, M. and Phillips, D. (2001). *Managing grasslands for wildlife on Scottish farms*. Natural Heritage Management Series. Scottish Natural Heritage, Battleby.
Magura, T. (2002) Carabids and forest edge: spatial pattern and edge effect. *For. Ecol. Mgmt.*, **157**: 23-37.
Magura, T., Tothmeresz, B. and Elek, Z. (2003) Diversity and composition of carabids during a forestry cycle. *Biodiversity and Conservation*, **12**: 73-85.
Mardon, D.K. (2003) Conserving montane willow scrub on Ben Lawers NNR. *Bot. J. Scotl.*, **55**(1): 189-203.
Marrs, R.H., Johnson, S.W. and Le Duc, M.G. (1998) Control of bracken and restoration of heathland. VII. The response of bracken rhizomes to 18 years of continued bracken control or 6 years of control followed by recovery. *J. appl. Ecol.*, **35**: 748-757.
Marrs, R.H. and Welch, D. (1991) Moorland wilderness: the potential effects of removing domestic livestock, particularly sheep. Unpublished report to the Department of the Environment. Institute of Terrestrial Ecology, Huntingdon.
Mayle, B. (1987) Bats. Forestry Commission Report on Forest Research 1987. 56-57. HMSO, London.
Mayle, B. (1988) Bats. Forestry Commission Report on Forest Research 1988. 51. HMSO, London.
Mayle, B. (1990a) Bats. Forestry Commission Report on Forest Research 1990. 63. HMSO, London.
Mayle, B.A. (1990b) Habitat management for woodland bats. Forestry Commission Research Information Note No. 165. Forestry Commission, Farnham.
Mayle, B. (1992) Bat activity in a mixed lowland woodland in relation to insect prey availability. Forestry Commission Report on Forest Research 1992. 42. HMSO, London.
McConnell_Associates (2001) Damaging impacts of red deer on the natural heritage of Inverpolly and Inchnadamph. Scottish Natural Heritage Commissioned Report F01AC211. Scottish Natural Heritage Commissioned Report F01AC211.
McIntosh, R. (1988) Integrating management objectives in an upland forest. In: Jardine, D.C. (Ed.) *Wildife management in forests. Proceedings of a discussion meeting, University of Lancaster, April 1987*. Institute of Chartered Foresters, Edinburgh.
McPhillimy, D. (1989). *Conservation in forests: case studies of good practice in Scotland*. Countryside Commission for Scotland, Battleby.
Meade, R. (2001) Paper 2.1. Trees and scrub on raised bogs. In: Whild, S., Meade, R. and Daniels, J. (Eds.) *English Nature Research Report No. 407. Management of water and trees on raised bogs. Papers and transcripts from a lowland peatland workshop held at Hanmer, 10-12 June 1997*. English Nature, Peterborough.

Mitchell, R.J., Marrs, R.H., Le Duc, M.G. and Auld, M.H.D. (1997) A study of succession on lowland heaths in Dorset, southern England: changes in vegetation and soil chemical properties. *J. appl. Ecol.*, **34**: 1426-1444.

Mitchell, R.J., Marrs, R.H., LeDuc, M.G. and Auld, M.H.D. (1999) A study of the restoration of heathland on successional sites: changes in vegetation and soil chemical properties. *J. appl. Ecol.*, **36**: 770-783.

Mortimer, S.R., Turner, A.J., Brown, V.K., Fuller, R.J., Good, J.E.G., Bell, S.A., Stevens, P.A., Norris, D., Bayfield, N. and Ward, L.K. (2000) The nature conservation value of scrub in Britain. JNCC Report No. 308. Joint Nature Conservation Committee, Peterborough.

Mullen, K., Fahy, O. and Gormally, M. (2003) Ground flora and associated arthropod communities of forest road edges in Connemara, Ireland. *Biodiversity and Conservation*, **12**: 87-101.

Muller, S. (2002) Diversity of management practices required to ensure conservation of rare and locally threatened plant species in grasslands: a case study at a regional scale (Lorraine, France). *Biodiversity and Conservation*, **11**(7): 1173-1184.

Murphy, J. (2001) Information note 9. Moorland grip blocking. In: Backshall, J., Manley, J. and Rebane, M. (Eds.) *The upland management handbook*. English Nature, Peterborough.

Neilson, R., Robinson, D., Marriot, C.A., Scrimgeour, C.M., Hamilton, D., Wishart, J., Boag, B. and Handley, L.L. (2002) Above-ground grazing affects floristic composition and modifies soil trophic interactions. *Soil Biology and Biochemistry*, **34**(10): 1507-1512.

Neville, P.A. (1986) Factors affecting the distribution and feeding ecology of bats in Grampian forests. Forestry Commission Report on Forest Research 1986. 72-73. HMSO, London.

Newton, A.C., Davy, L.M., Holden, E., Silverside, A., Watling, R. and Ward, S.D. (2003) Status, distribution and definition of mycologically important grasslands in Scotland. *Biol. Conserv.*, **111**: 11-23.

Parr, S. (1991) Merlin ecology. Forestry Commission Report on Forest Research 1991. 69. HMSO, London.

Patterson, G.S. (1988) Vegetation management. Forestry Commission Report on Forest Research 1988. 50. HMSO, London.

Patterson, G.S. (1989) Vegetation management in upland forests. Forestry Commission Report on Forest Research 1989. 55-56. HMSO, London.

Patterson, G.S. (1991) Vegetation management (uplands). Forestry Commission Report on Forest Research 1991. 47-48. HMSO, London.

Patterson, G.S. and Anderson, A.R. (2000). *Forestry Commission Guideline Note1. Forests and peatland habitats*. Forestry Commission, Edinburgh, 16 pp.

Patterson, I.J. and Ollason, J.G. (1991) Modelling bird/habitat relationships in northern upland spruce forest. Forestry Commission Report on Forest Research 1991. 70. HMSO, London.

Patterson, I.J. and Ollason, J.G. (1993) Modelling songbird-habitat relationships in northern upland spruce forests. Forestry Commission Report on Forest Research 1993. 42. HMSO, London.

Pepper, H. (1994) Wildife and Conservation Research. Forestry Commission Report on Forest Research 1994. 50. HMSO, London.

Peterken, G.F. (1981). *Woodland conservation and management*. Chapman and Hall, London.

Peterken, G.F. (1996) Chapter 17 Design and management of upland conifer plantations *Natural woodland - ecology and conservation in northern temperate regions*. Cambridge University Press, Cambridge pp. 456-459.

Peters, A. (2003) Heathland restoration projects in Purbeck. *The National Trust. Views*, **38**: 30-32.

Petty, S.J. (1983) Bird studies. Forestry Commission Report on Forest Research 1983. 41. HMSO, London.

Petty, S.J. (1984) Bird studies. Forestry Commission Report on Forest Research 1984. 42. HMSO, London.

Petty, S.J. (1985) Birds. Forestry Commission Report on Forest Research 1985. 41. HMSO, London.

Petty, S.J. (1990) Birds. Forestry Commission Report on Forest Research 1990. 63-64. HMSO, London.

Petty, S.J. (1994) Ecology of long-eared owls in coniferous forests. Forestry Commission Report on Forest Research 1994. 56. HMSO, London.

Petty, S.J. and Avery, M.I. (1990). *Forest bird communities.A review of the ecology and management of forest bird communities in relation to silvicultural practices in the British uplands*. Forestry Commission Occasional Paper 26. Forestry Commission, Edinburgh.

Petty, S.J., Coles, C.F., Lambin, X.J.F., MacKinnon, J.L., Thomas, C.J. and Sherratt, T.N. (1997) A new GIS-based study on predator-prey relationships in an upland forest. Forestry Commission Report on Forest Research 1997. 45-48. Forestry Commission, Edinburgh.

Petty, S.J. and Peace, A. (1992) Temporal and spatial fluctuation in field vole abundance in a predator/prey study. Forestry Commission Report on Forest Research 1992. 40-42. HMSO, London.

Prestt, I. (1971) An ecological study of the viper Vipera berus in southern Britain. *J. zool. Lond.*, **164**: 373-418.

Prigmore, D. (1991) The effects of coniferous afforestation on the ground flora and conservation potential of Thetford Forest. Forestry Commission Report on Forest Research 1991. 71. HMSO, London.

Pyatt, D.G. (1993) Multi-purpose forests on peatland. *Biodiversity and Conservation*, **2**: 548-555.

Ratcliffe, D.A. (1986) The effects of afforestation on the wildlife of open habitats. In: Jenkins, D. (Ed.) *Trees and wildlife in the Scottish uplands*. Institute of Terrestrial Ecology, Abbots Ripton pp. 46-54.

Ratcliffe, P.R. (1992) Wildlife and conservation. Forestry Commission Report on Forest Research 1992. 39. HMSO, London.

Ratcliffe, P.R. and Petty, S.J. (1986) The management of commercial forests for wildlife. In: Jenkins, D. (Ed.) *Trees and wildlife in the Scottish uplands*. Institute of Terrestrial Ecology, Abbots Ripton pp. 177-187.

Roberts, J., MacDonald, A.J. and Wood-Gee, V. (1996) Bracken control. SNH Information and Advisory Note No. 24. Scottish Natural Heritage, Battleby.

Robinson, T. (2002) Options for seed-harvesting techniques, part two. *Enact*, **10**(1): 4-8.

Rodwell, J.S. (1991a). *British plant communities. Volume 1: Woodlands and scrub*. Cambridge University Press, Cambridge.

Rodwell, J.S. (1991b). *British plant communities. Volume 2: Mires and heaths*. Cambridge University Press, Cambridge.

Rodwell, J.S. (1992). *British plant communities. Volume 3: Grasslands and montane communities.* Cambridge University Press, Cambridge.
Rowe, J.J. (1976) Wildlife management. Forestry Commission Report on Forest Research 1976. 40-41. HMSO, London.
Rowe, J.J. (1979) Wildlife Management. Forestry Commission Report on Forest Research 1979. 38-39. HMSO, London.
Rowe, J.J. (1980) Wildlife Management. Forestry Commission Report on Forest Research 1980. 40-42. HMSO, London.
RSPB (2002). *Black grouse: habitats and land management*. Royal Society for the Protection of Birds, Sandy.
Scott, M. (2000). *Montane scrub*. Natural Heritage Management. Scottish Natural Heritage, Battleby.
Shaw, S.C., Wheeler, B.D., Kirby, P., Philipson, P. and Edmunds, R. (1996) Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath. English Nature Research Reports No. 172. English Nature, Peterborough.
Simonson, W. and Thomas, R. (1999). *Biodiversity. Making the links*. English Nature, Peterborough.
Smith, S. and Gilbert, J. (2003) National inventory of woodland and trees. Great Britain. Forestry Commission Inventory Report. Forestry Commission, Edinburgh.
Snow, C.S.R. and Marrs, R.H. (1997) Restoration of Calluna heathland on a bracken Pteridium-infested site in north west England. *Biol. Conserv.*, **81**: 35-42.
Sparks, T.H. and Greatorex-Davies, J.N. (1992) The effect of shade in plantation woodland on invertebrate abundance and diversity. *Aspects of Applied Biology*, **29**: 89-96.
Sparks, T.H., Greatorex-Davies, J.N., Mountford, J.O., Hall, M.L. and Marrs, R.H. (1996) The effects of shade on the plant communities of rides in plantation woodland and implications for butterfly conservation. *For. Ecol. Mgmt.*, **80**: 197-207.
Spellerberg, I.F. (1988a) Ecology and management of reptile populations in forests. *Q. Jl For.*, **82**: 99-109.
Spellerberg, I.F. (1988b) Management of forest habitats for reptiles. In: Jardine, D.C. (Ed.) *Wildlife management in forests. Proceedings of a discussion meeting. University of Lancaster 3-5 April 1987*. Institute of Chartered Foresters, Edinburgh.
Spellerberg, I.F. and Wright, S. (1982) Behaviour of rare reptiles in relation to forest management. Forestry Commission Report on Forest Research 1982. 56-57. HMSO, London.
Spellerberg, I.F. and Wright, S. (1983) Behaviour of sand lizards in relation to forest management. Forestry Commission Report on Forest Research 1983. 66-67. HMSO, London.
Springthorpe, G.D. and Myhill, N.G. (1985). *Wildlife rangers handbook*. Forestry Commission, Edinburgh.
Sullivan, G. (2001) Prostrate juniper heath in North-west Scotland: historical, ecological and taxonomic issues. PhD Thesis. University of Aberdeen, Aberdeen.
Summers, R.W. and Dugan, D. (2001) An assessment of methods to mark fences to reduce bird collisions in pinewoods. *Scott. For.*, **55**: 23-29.

Sutherland, W.J. and Hill, D.A. (Editors), (1995) Managing habitats for conservation. Cambridge University Press, Cambridge.
Svenning, J.-C. (2002) A review of natural vegetation openness in north-western Europe. *Biol. Conserv.*, **104**(2002): 133-148.
Sydes, C. and Miller, G.R. (1988) Range management and nature conservation in the British uplands. In: Usher, M.B. and Thompson, D.B.A. (Eds.) *Ecological change in the uplands.* Blackwell Scientific Publications, Oxford pp. 323-337.
Sykes, J.M., Lowe, V.P.W. and Briggs, D.R. (1989) Some effects of afforestation on the flora and fauna of an upland sheepwalk during 12 years after planting. *J. appl. Ecol.*, **26**: 299-320.
Thompson, D.B.A., MacDonald, A.J., Marsden, J.H. and Galbraith, C.A. (1995) Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation. *Biol. Conserv.*, **71**: 163-178.
Thompson, D.B.A. and Miles, J. (1995) Heaths and moorlands: some conclusions and questions about environmental change. In: Thompson, D.B.A., Hester, A.J. and Usher, M.B. (Eds.) *Heaths and Moorlands: Cultural Landscapes*. HMSO.
Thomson, A. (1990) Appendix 3.5 Reptiles and amphibians in Kielder Forest. In: Good, J.E.G., Williams, T.G., Wallace, H.L., Buse, A. and Norris, D.A. (Eds.) *Nature conservation in upland conifer forests. A report to the Forestry Commission and the Nature Conservancy Council*. Institute of Terrestrial Ecology, Bangor.
Todd, P.A., Phillips, J.D.P., Putwain, P.D. and Marrs, R.H. (2000) Control of Molinia caerulea on moorland. *Grass and Forage Science*, **55**: 181-191.
Trout, R.C., Quine, C.P., Dugan, D. and Summers, R.W. (2001) Alternative deer fences in core capercaillie and black grouse habitats. Forest Research/RSPB Guidance Note. Forestry Commission Highland Conservancy, Dornoch.
Warren, M.S. and Fuller, R.J. (1993). *Woodland rides and glades: their management for wildlife. Second edition*. JNCC, Peterborough.
Warren, M.S. and Oates, M.R. (1994) The importance of bracken habitats to fritillary butterflies and their management for conservation. In: Thornton, Smith, R. and Taylor, J.A. (Eds.) *Bracken: an environmental issue. International Bracken Group Special Publication No.2*. International Bracken Group pp. 178-181.
Wheeler, B.D. and Shaw, S.C. (1995). *Restoration of damaged peatlands*. HMSO, London.
Wilkinson, D.M. (Editor), (2001) An open place? A contribution to the discussion on trees on British mires. English Nature Research Report No.407. Management of water and trees on raised bogs. Papers and transcripts from a lowland peatland workshop held at Hanmer, 10-12 June 1997. English Nature, Peterborough.
Wilson, P.J. and King, M. (2001) A report on progress with implementation of the Species Action Plan for juniper Juniperus Communis during 2000-2001. Plantlife.
Wolton, R. and Burke, C. (2003) Controlling rushes. *Conserv. Land Mgmt.*(Spring 2003): 10-13.
Yahner, R.H., Hutnik, R.J. and Liscinsky, S.A. (2003) Long-term trends in bird populations on an electric transmission right-of-way. *J. Arbor.*, **29**(3): 156-164.