Peatland Biodiversity

Nick Littlewood[1*], Penny Anderson[2], Rebekka Artz[1], Olivia Bragg[3], Paul Lunt[5], Rob Marrs[5]

Draft Scientific Review
August 2010

1. Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB15 8QH
2. Penny Anderson Associates Ltd., Park Lea, 60 Park Road, Buxton, Derbyshire, SK17 6SN
3. Geography, School of Social and Environmental Sciences, University of Dundee, Perth Road, Dundee, DD1 4HN
4. University of Plymouth, A504 Portland Square, Drake Circus, Plymouth, Devon, PL4 8AA
5. Applied Vegetation Dynamics Laboratory, University of Liverpool, PO Box 147, Liverpool, L69 7ZB

This is a draft scientific review, commissioned by the IUCN UK Peatland Programme's Commission of Inquiry into Peatland Restoration. The IUCN UK Peatland Programme is not responsible for the content of this review and does not necessarily endorse the views contained within.

Contents

Summary

Land covered in accumulated peat is known as peatland. It is active peatland if peat is being formed now or it supports vegetation capable of forming peat. Estimates of the extent of peatland in the UK vary widely but most are between 1.5 and 2.5 million ha. The UK may host between 8.8 and 14.8% of Europe's peatland area and about 13% of the world resource of one peatland type, namely blanket bog. Indeed blanket bog forms the largest expanse of semi-natural habitat in the UK.

Biodiversity Features

Peatland biodiversity includes a range of rare, threatened or declining habitats, plants and animals. The bird assemblage is highly valued in a European context, and some plant assemblages are better represented in the UK than anywhere else in the world. However, peatland biodiversity is sensitive to changes in land management and to a range of other external drivers.

Active bog is characterised by an abundance of bryophytes, especially the bog moss, *Sphagnum*. Different *Sphagnum* species, with different preferences for degree of ground wetness, form the characteristic hummock and pool systems and thus create topographical variation. The plant assemblage also includes a range of sedges and dwarf-shrubs and grades into associated habitats such as wet and dry heathland. The peatland vegetation assemblage, alongside high water levels, provides the key ecosystem service of laying down new peat accumulations and maintaining the peat store.

UK peatlands have a rich and unique breeding bird assemblage. It is a species-poor assemblage though contains an exceptionally high proportion of species with legal protection under UK and European conservation law. The Flow Country blanket bog of Caithness and Sutherland is an extraordinarily rich area for birds. The red grouse is an iconic bird of peatlands and related habitats. Many upland areas are managed primarily to maximise its numbers for commercial shooting. However conflicts over predator control on grouse estates can be a barrier to biodiversity conservation initiatives.

Invertebrate assemblages on peatlands can be very species rich, especially for families that respond to small scale structural variation in vegetation and topography. Invertebrates on blanket bog play a key role in fragmenting plant litter as part of the peat accumulation process. Below-ground biodiversity is much less studied and the role that it plays in influencing vegetation change is little understood.

Challenges

There have been significant challenges to peatlands over the last 300 years in particular. A number of drivers cause peatland degradation. Peatlands close to industrial centres have previously suffered from SO_2 and N-deposition, both of which adversely impact on *Sphagnum* in particular. Drain construction was carried out extensively through much of the 20^{th} century and though it has now largely ceased, its legacies of peat shrinkage and erosion remain.

Over-grazing and burning are currently the most significant ongoing activities that pose threats to blanket bog. Peatlands have a low carrying capacity for livestock and high grazing levels can suppress typical peatland vegetation. Burning impacts are poorly understood but may include adverse impacts on *Sphagnum*. In lowland raised bogs, hydrological change is the most significant threat with drainage of the bog or adjacent land lowering the water table and causing loss of vegetation and other biodiversity that depends on waterlogged conditions.

Climate change may exacerbate some of the negative drivers. Wildfire will become a greater threat in a drier landscape and increased storminess may cause greater erosion. Additionally there is already evidence of mismatches occurring in the timing of seasonal activity between predator and prey populations.

Impacts

Only 18% of blanket mire is currently in a natural or near-natural condition. Of the remainder, 16% is eroded, 16% is afforested and 40% is modified. The impacts are not uniform. Blanket bog in Scotland is in better condition than further south. Lowland raised bog also tends to be in a better condition further north though the picture is more mixed. Available evidence suggests that habitats on SSSI-designated peatland sites are in better condition that on non-designated sites. Peatland species show mixed trends but a majority of those designated as part of the UK Biodiversity Action Plan have declining populations.

Peatland management

Effective peatland management for biodiversity requires a good understanding of existing environmental and hydrological conditions. Under ideal circumstances hydrology and grazing livestock can be controlled. However this is often difficult. Burning is generally discouraged. Peatland restoration is a realistic option in most situations and the best results for returning peatland biodiversity will occcur where the hydrology can be controlled over a wide area in order to achieve well functioning bogs. However restoration may not always achieve a natural peatland and benefits may only be seen only in the long-term

Co-ordination and dissemination of management information is important for maximizing the biodiversity potential of peatland management. Management for other benefits (e.g. carbon sequestration) if undertaken correctly could promote typical peatland species and bring assemblage-level benefits at least in the long-term. The conservation of some species, though, may require further actions within and beyond peatland sites.

Peatland management requires long-term commitment and can be costly to the practitioner. However society must recognise that it is good value compared to the overall costs of continued peat loss. Stakeholders should input to development of funding schemes to ensure that they can be implemented to the maximum benefit of peatland habitats.

Key Points

1. Blanket bog forms the largest area of semi-natural habitat in the UK. It often occurs in a matrix with related habitats.

2. Peatland biodiversity is characterised by specialized species adapted to thriving in a waterlogged, acidic, nutrient-poor environment.

3. The value of peatland habitats is recognised through UK and European legal obligations for their protection and restoration.

4. The peatland bird assemblages is recognised as internationally important. Many species breeding on peatlands have UK or European conservation designations and legal protection.

5. Peatlands have been subject to significant multiple negative drivers including burning, pollution, over-grazing and draining.

6. Only 18% of UK's blanket mire is now in a natural or near-natural state. The remainder is eroded, modified or has undergone land-use change (e.g. to forestry or peat extraction).

7. Biodiversity has been lost through peatland degradation. Evidence suggests that populations of many key species are in decline.

8. Restoration management has the potential to restore peatland function and biodiversity on some sites though reversion to a natural state with the full compliment of peatland species can be an unrealistic aim, in the most degraded situations.

9. Restoration needs realistic aims and a long term approach. It should be accompanied by well planned and resourced monitoring.

10. Peatland management needs to take a flexible adaptive approach to address different drivers. Management advice should be disseminated widely.

1. Introduction: aims, scope and objectives of review

Land covered in accumulated peat is known as peatland. It is active peatland if peat is being formed now. Estimates of the extent of peatland in the UK vary widely but most are between 1.5 and 2.5 million ha (Lindsay 2010). The UK may host between 8.8 and 14.8% of Europe's peatland area (Montanarella *et al*. 2006) and about 13% of the world resource of one peatland type, namely blanket bog (Lindsay *et al*. 1988).

Peatland biodiversity is typically species-poor with a large proportion of highly adapted species. These species include a range of rare, threatened or declining plants and animals. The bird assemblage is highly valued in a European context, leading to protection of large areas under European legislation (Special Protection Areas). Some plant assemblages are better represented in the UK than anywhere else in the world (the best are designated Special Areas for Conservation). However, peatland biodiversity is sensitive to changes in land management and a range of other external drivers.

The aims of this review are to highlight the importance of peatlands for biodiversity, and specifically to:

- identify biodiversity features and characteristics that are specific to peatlands;
- review progress in species and habitat conservation;
- identify peatland management for a range of services which will be beneficial to typical and valued peatland species;
- identify threats to biodiversity that arise from both external drivers and peatland management; and
- make recommendations for maximising future benefits for peatland biodiversity.

1.1 Scope and Definitions

For completeness the following definitions are adopted for use throughout (Bragg & Lindsay 2003).

- **Peat** is partly decomposed plant material that has accumulated *in situ* (rather than being deposited as a sediment) as a result of waterlogging.
- A **peatland** is an area where peat has accumulated *in situ*.
- A **mire** is an area that supports at least some vegetation known to form peat, and usually includes a peat deposit.

Two or three types of mire habitat may be distinguished on the basis of water source, nutrient status and vegetation characteristics. Bog (ombrotrophic mire) obtains mineral nutrients exclusively from precipitation which, at least in unpolluted areas, is a poor source of plant nutrients. Raised bogs are discrete domed peatlands, whereas blanket bog covers entire, usually upland, landscapes. Fen (minerotrophic mire) receives mineral nutrients from both precipitation and water that has been in contact with soil or rock, and so has higher nutrient concentrations. Intermediate types, termed transitional mire, may also be recognised (Bragg & Lindsay 2003). These habitats do not always occur in isolation. Whilst most lowland raised bogs in the UK are now isolated, they were often partly or wholly surrounded by (lagg) fen before intervention by man. Many areas of upland peatland comprise complex habitat mosaics, with adjacent areas of blanket bog, wet heath, pools, flushes, springs, rock exposures and acid grassland which may interact hydrologically.

Throughout this review a standard terminology has also been adopted (Lindsay 2010) for defining peatland topography and scale (Figure 1.1). This terminology is useful for defining the structure and function of peatlands. For example, bird assemblages are typically measured at the macrotope scale, many invertebrates respond to differences at the microtope scale and micro-organism populations will vary at the vegetation scale. All these contribute to the distinctiveness and value of peatland biodiversity

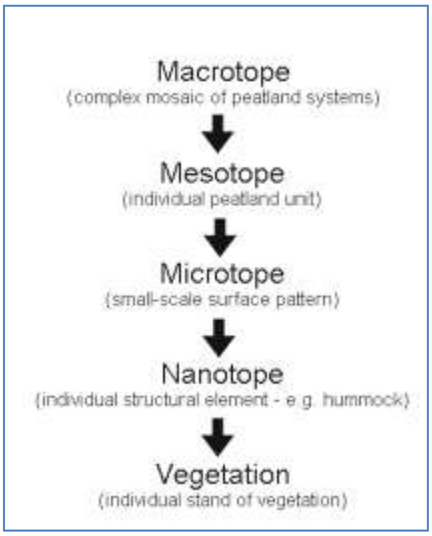

Figure 1.1. *The peatland hierarchy of elements (after Lindsay 2010). These components make up the hierarchy of building blocks and functional units within any peatland system. This is most readily seen in blanket mire landscapes. With respect to peatlands it is important to note that their conservation value within an integrated unit is reflected in the β-diversity at four of the five scales (macrotope, mesotope, microtope, nanotope); at the lowest scale (vegetation) the measurement will be effectively species α-diversity (modified after Whittaker 1960). Reproduced courtesy of Richard Lindsay.*

This review focuses primarily on UK peatlands, especially bogs, though it will draw on evidence from fens and other peatland types elsewhere. Peatland is frequently defined arbitrarily as having deep peat soils with an organic layer deeper than 40 cm in England and Wales or 50 cm in Scotland. However this review recognises that there are functional bogs, on which peatland biodiversity is represented, that fall outside this definition and these too are included where appropriate.

2. Biodiversity Values

In the UK there are significant gradients in altitude and in wetness from north and west to south and east, each of which influences the resultant species and assemblages. There are also features common to peatlands throughout this range. In particular, peatlands tend to have species-poor wildlife assemblages and the usual measures of species diversity are not helpful for measuring the intrinsic value of peatland biodiversity. Furthermore, only relatively few of the species occurring on peatlands are designated as UK Biodiversity Action Plan Priority Species (see Table 2.1) and most of these are not restricted to peatlands. However, peatlands are valued for biodiversity and are included as priority habitats in the UK Biodiversity Action Plans because of the contribution they make to maintaining species diversity at the national and international level and because of the nature of the assemblages that they host. Peatland species are highly specialised and adapted to thriving in waterlogged, acidic and nutrient-poor conditions. The constituent vegetation represents the largest expanse of semi-natural habitat in the country. It is instrumental in fixing carbon within accumulating peat (itself a major carbon store) and therefore provides a valuable ecosystem service (Van der Wal et al, in press). Valuing peatland biodiversity thus requires recognition of its specialisation and naturalness, of the role of biodiversity in shaping the whole system and of our international obligation for conserving it.

2.1 Plants

Active bog is characterised by an abundance of bryophytes, especially the bog moss, *Sphagnum*. Different *Sphagnum* species, with different preferences for degree of ground wetness, form the characteristic hummock and pool systems and thus create habitat variety at the nanotope level (see Figure 2.1). Sedges, such as common cottongrass *Eriophorum angustifolium*, hare's-tail cottongrass *E. vaginatum* and deergrass *Trichophorum cespitosum*, are typical of active peat. Cranberry *Vaccinium oxycoccos* and bog rosemary *Andromeda polifolia* are less common associates whilst cloudberry *Rubus chamaemorus* forms dense patches in places. Nutrient-poor bog conditions are the main environment utilised in the UK by a number of carnivorous plant species, such as sundews *Drosera* spp. Occurring in low density in the most waterlogged areas but more abundantly elsewhere in peatland habitat mosaics are dwarf shrubs, especially heather *Calluna vulgaris* but also cross-leaved heath *Erica tetralix*, bilberry *Vaccinnium myrtillus*, crowberry *Empetrum nigrum* and others.

Sixteen plant communities described in the National Vegetation Classification (NVC) (Rodwell *et al*. 1991) may be associated with peatlands (Table 2.2). High quality blanket mires support distinctive plant communities with well-defined microtopographical variation on the mire surface and a two-layered peat profile. Active blanket bog may be characterised by expanses of vegetation with affinities to the NVC communities M17–19 where cottongrasses predominate along with deergrass and a constant presence of bog asphodel *Narthecium ossifragum* and tormentil *Potentilla erecta* (M17) or hare’s-tail cottongrass and heather (M19) which become more widespread eastwards in Britain. The *Sphagnum*-rich M18 community provides a broad overlap between these two main communities while the bog pool communities M1–M3 occur in localised wetter areas. On shallower peat M15 or M16 communities may be present.

Table 2.1. *UK priority species occurring on peatland. ■: occurs; ■■: main habitat; ?: possible habitat. [1]Trends given are for those from the 2008 BAP reporting round. No trend information yet exists within the BAP system for species that were added to the list of UK Priority Species in 2007. Additional sources used are: [2] breeding population trends for 1995-2008 (Risely et al. 2010); [3]population trend for 1978–2004 and distribution trend for 1970–82 vs. 1995–2004 (Fox et al. 2006a); [4]population trend for 1978–2002 (Fox et al. 2006b); [5]population trend for 1995–2008 (Risely et al. 2010).*

Group	English name	Scientific name	Blanket Bog	Lowland Raised Bog	Lowland Fens	Trend
Amphibians	Common Toad	*Bufo bufo*	■	■	■	
	Great Crested Newt	*Triturus cristatus*			■	Declining (slowing)[1]
Beetles	Zircon Reed Beetle	*Donacia aquatica*			■	Declining (slowing)[1]
	Oxbow Diving Beetle	*Hydroporus rufifrons*			■	Declining (slowing)[1]
Birds	Sky Lark	*Alauda arvensis subsp. arvensis/scotica*	■	■		Declining (slowing)[1]; 11% decline (significant)[2]
	Greenland White-fronted Goose	*Anser albifrons subsp. flavirostris*	■			
	Scaup	*Aythya marila*	■			
	Bewick's Swan	*Cygnus columbianus subsp. bewickii*			■	
	Reed Bunting	*Emberiza schoeniclus*			■	Increasing[1]; 33% increase (significant)[2]
	Black-throated Diver	*Gavia arctica*	■			
	Red Grouse	*Lagopus lagopus subsp. scotica*	■			9% decline (non-significant)[2]
	Grasshopper Warbler	*Locustella naevia*	■	■	■■	24% increase (non-significant)[2]
	Common Scoter	*Melanitta nigra*	■			Declining (continuing/accelerating)[1]
	Curlew	*Numenius arquata*	■			42% decline (significant at $p<0.05$)[2]
	Arctic Skua	*Stercorarius parasiticus*	■			
	Black Grouse	*Tatrao tetrix*	■	■		
	Lapwing	*Vanellus vanellus*	■	■	■	13% decline (significant at $p<0.05$)[2]
Butterflies	Large Heath	*Coenonympha tullia*	■	■		26% population decline, 43% distribution decline[3]
Caddisflies	Window Winged Sedge	*Hagenella clathrata*			■	
Flowering plants	Flat-sedge	*Blysmus compressus*			■■	
	Scottish Small-reed	*Calamagrostis scotica*			?	Status unknown[1]
	Narrow Small-reed	*Calamagrostis stricta*			■	
	Juniper	*Juniperus communis*	■			Declining (continuing/accelerating)[1]
	Tubular Water-dropwort	*Oenanthe fistulosa*			■■	
	Scottish Dock	*Rumex aquaticus*			■	
	Yellow Marsh Saxifrage	*Saxifraga hirculus*			?	Stable[1]
	Irish Lady`s-tresses	*Spiranthes romanzoffiana*			?	No clear trend[1]
	Marsh Stitchwort	*Stellaria palustris*			?	

Group	English name	Scientific name	Blanket Bog	Lowland Raised Bog	Lowland Fens	Trend
Fungi	Agaric	*Armillaria ectypa*	■			No clear trend[1]
	Lousewort Rust	*Puccinia clintonii*		■		
Liverworts	Marsh Earwort	*Jamesoniella undulifolia*		■		Status unknown[1]
	Fen Notchwort	*Leiocolea rutheana*			■	No clear trend[1]
Mammals	Water Vole	*Arvicola terrestris*	■			Declining (slowing)[1]
	Mountain Hare	*Lepus timidus*	■			29% decline (not significant)[5]
	Otter	*Lutra lutra*	■		■	Increasing[1]
	Soprano Pipistrelle	*Pipistrellus pygmaeus*		?	■	Fluctuating - probably stable[1]
Molluscs	Mud Snail	*Omphiscola glabra*			■	
Mosses	Carrion-moss	*Aplodon wormskjoldii*	?			
	Waved Fork-moss	*Dicranum bergeri*	■■			
	Baltic Bog-Moss	*Sphagnum balticum*	■	■		Stable[1]
Moths	The Forester	*Adscita statices*			?	
	Haworth's Minor	*Celaena haworthii*	■		■	80% decline[4]
	Argent and sable	*Rheumaptera hastata*	■	■		Declining (slowing)[1]
Reptiles	Adder	*Vipera berus*	■			
Spiders	A money-spider	*Erigone welchi*		?	?	
	A money-spider	*Notioscopus sarcinatus*	■	■	■	
	A money-spider	*Saaristoa firma*	■	■		
	A money-spider	*Semljicola caliginosus*	■			

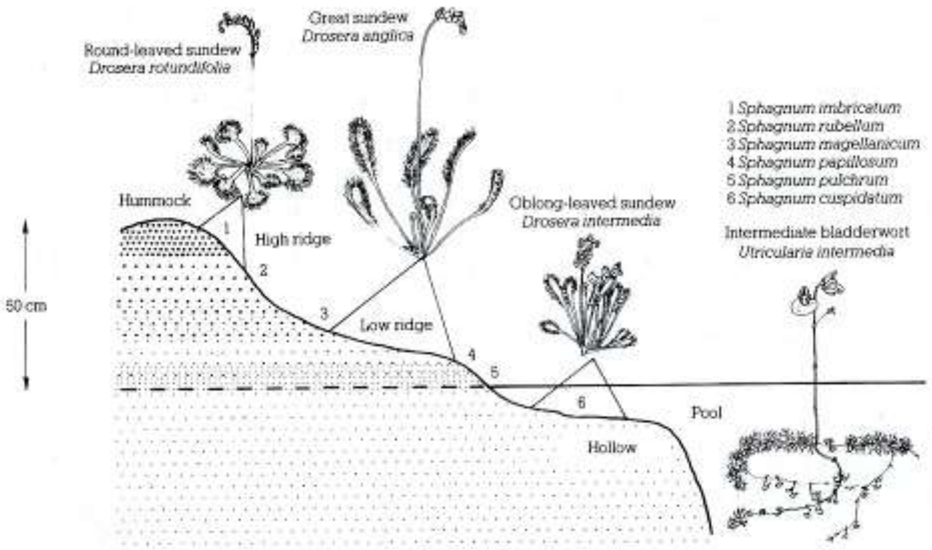

Figure 2.1. *The zonation of vegetation types within the microtopography of a mire. It can be seen here that different Sphagnum species occupy distinct vertical ranges within the typical microtopographic structures found on a bog, as indeed do the various carnivorous plants found in such habitats. Figure reproduced courtesy of Richard Lindsay (2010).*

Table 2.2. *Plant communities of peatlands identified in the British National Vegetation Classification (Rodwell et al. 1991). State indicates if the community is usually associated with semi-natural or modified peatlands or if it is a wet heath community that can also occur on peatlands.*

	NVC class	Description	State
Mires & Wet Heath	M1	*Sphagnum auriculatum* pool	Semi-natural
	M2	*Sphagnum auriculatum/recurvum* bog pool	Semi-natural
	M3	*Eriophorum angustifolium* bog pool	Semi-natural
	M15	*Scirpus cespitosus - Erica tetralix* wet heath	Semi-natural
	M16	*Erica tetralix - Sphagnum compactum* wet heath	Semi-natural
	M17	*Scirpus cespitosus - Eriophorum vaginatum* blanket mire	Semi-natural
	M18	*Erica tetralix - Sphagnum papillosum* raised and blanket mire	Semi-natural
	M19	*Calluna vulgaris -Eriophorum vaginatum* blanket mire	Semi-natural
	M20	*Eriophorum vaginatum* blanket and raised mire	Modified
	M21	*Narthecium ossifragum - Sphagnum papillosum* valley mire	Semi-natural
Heath	H9	*Calluna vulgaris - Deschampsia flexuosa* heath	Modified
	H10	*Calluna vulgaris - Erica cinerea* heath	Wet heath
	H12	*Calluna vulgaris - Vaccinium myrtillus* heath	Modified
	H16	*Calluna vulgaris - Arctostphylos uva-ursi* heath	Wet heath
	H21	*Calluna vulgaris - Vaccinium myrtillus -Sphagnum capillifolium* heath	Wet heath
Upland	U6	*Juncus squarrosus - Festuca ovina* grassland	Modified

2.2 Birds

A distinctive assemblage of birds breeds on blanket mires in the UK. Very few, however, are obligate moorland species apart from red grouse, greenshank *Tringa nebularia* and dunlin *Calidris alpina*. Many utilise habitats other than the deep peats. Some, such as golden plover *Pluvialis apricaria*, depend on invertebrates in inbye fields as well as the moorland environment. The wettest habitats (open pools and un-drained bog) are utilised by wildfowl and dunlin, tall heather provides cover and nesting sites for black grouse *Lyrurus tetrix* and red grouse, golden eagle *Aquila chrysaetos*, curlew *Numenius arquata*, greenshank, dunlin, hen harrier *Circus cyaneus*, merlin *Falco columbarius* and skylark *Alauda arvensis*, whilst golden plover, dunlin and redshank *Tringa totanus* preferentially select shorter vegetation.

Breeding birds on peatlands, especially blanket bogs, include a very high proportion of species that are covered by conservation designations. These are listed in Table 2.3 and include twelve EC Annex 1 species (Stroud *et al*. 1987), twelve species on the Red List of Birds of Conservation Concern for the UK and thirteen on the Amber List (Eaton *et al*. 2009), eleven UK Biodiversity Action Plan Species and thirteen Schedule 1 species of the UK Wildlife and Countryside Act (Table 2.3). There is no overall consensus on what constitutes the peatland bird assemblage and a range of designated species additional to those listed may make some use of peatland habitats for breeding or as non-breeding visitors.

Table 2.3. *Breeding bird species on UK peatlands and their conservation status. Annex 1: European Commission Birds Directive; BoCC: Birds of Conservation Concern Red and Amber lists; W&C: Wildlife and Countryside Act 1981, Schedule 1. This list is not exhaustive and further breeding species may make some use of peatlands. See also Table 2.1.*

		Annex 1	**BoCC Red**	**BoCC Amber**	**UK BAP**	**W&C**
Common Scoter	*Melanitta nigra*		■		■	■
Red Grouse	*Lagopus lagopus*			■	■	
Black Grouse	*Tetroa tetrix*	■	■		■	
Red-throated Diver	*Gavia stellata*	■		■		■
Black-throated Diver	*Gavia arctica*	■		■	■	■
Hen Harrier	*Circus cyaneus*	■	■			■
Golden Eagle	*Aquila chrysaetos*	■		■		■
Merlin	*Falco columbarius*	■		■		■
Peregrine	*Falco peregrinus*	■				■
Golden Plover	*Pluvialis apricaria*	■		■		
Lapwing	*Vanellus vanellus*		■		■	
Temminck's Stint	*Calidris temminckii*		■			■
Dunlin	*Calidris alpina*		■			
Ruff	*Philomachus pugnax*	■	■			■
Whimbrel	*Numenius phaeopus*		■			■
Curlew	*Numenius arquata*			■	■	
Common Sandpiper	*Actitis hypoleucos*			■		
Greenshank	*Tringa nebularia*					■
Redshank	*Tringa totanus*			■		
Wood Sandpiper	*Tringa glareola*	■		■		■
Red-necked Phalarope	*Phalaropus lobatus*	■	■		■	■
Arctic Skua	*Stercorarius parasiticus*		■		■	
Great Skua	*Stercorarius skua*			■		
Short-eared owl	*Asio flammeus*	■		■		
Skylark	*Alauda arvensis*		■		■	
Grasshopper Warbler	*Locustella*		■		■	
Reed Bunting	*Emberiza schoeniclus*			■	■	

Of cultural importance and also of conservation and economic significance are populations of red grouse of the sub-species endemic to UK and Ireland, *Lagopus lagopus scoticus*. Shooting of these birds for sport provides a significant commercial return in northern upland regions and substantial areas of dwarf shrub heath and blanket bog are managed to maximise their densities. The most successful populations are those which utilise wet areas such as bog flushes, especially in summer months when chicks feed especially on soft-bodied invertebrates such as craneflies *Tipulidae* (Park *et al*. 2001).

Management of estates for red grouse can help to maintain at least some aspects of biodiversity. For example predator control may benefit ground nesting birds (Fletcher *et al*. 2010). However hen harriers breeding on heaths and bogs in northern UK can locally suppress grouse numbers (Thirgood *et al*. 2000) prompting their illegal persecution by gamekeepers. Diametrically opposed positions taken by game managers and the conservation community over this issue can be a barrier to progressive cooperation over other aspects of upland management (Thirgood & Redpath 2008) although a recent initiative is attempting to make progress on this issue (www.langholmproject.com).

2.3 Invertebrates
The numbers of invertebrate species on peatlands may be up to 30 times higher than vertebrates and their biomass an order of magnitude larger (Coulson *et al*. 1995). In particular, upland blanket bog supports high numbers of enchytraeid worms, mites, spiders and bugs with a high biomass of flies, bugs, mites and springtails (summarised by Tallis 1998). The peak emergence of craneflies in late May/early June is significant for breeding birds while (Coulson & Butterfield 1978) consider that blanket bog invertebrates play an essential role in the initial fragmentation of plant litter, prior to fungal and bacterial attack, which plays a part in the peat accumulation process.

Invertebrate groups that are species rich on peatlands tend to be those that are more dependent on vegetation structure than species composition. These include spiders (Scott *et al* 2006), especially money spiders (Lyniphidae) (Coulson & Butterfield 1986) and ground beetles (Usher 1992). Bog pools are particularly important for dragonflies and damselflies. Two thirds of Britain's 38 species breed on bogs. Eleven of these species are virtually restricted to peatland habitats in this country of which seven are regarded as rare or local in Britain (Brooks 1997).

Few peatland invertebrates are afforded legal conservation status although four spiders, three moths, one butterfly, a caddisfly and two beetles that use peatlands are designated as UK Biodiversity Action Plan Priority Species (see Table 2.1).

2.4 Below-ground Biodiversity
Below-ground peatland biodiversity is a much neglected topic. However the microbial community plays an important role in the functioning of peatlands. Early evidence suggests that it is closely linked to vegetation assemblages and will change in parallel with the vegetation during succession (Artz *et al*. 2008). However techniques for cataloguing microbial diversity are currently limited and much remains to be learnt about its role in influencing, for example, success of peatland vegetation restoration.

3. Drivers of Change

3.1 Drainage
Drainage or *'*gripping*'* of peatlands has been carried out in the past primarily for purposes of grazing or game management but also to direct water flows into reservoirs. About 20,000 ha/year was drained in the 1960s and 1970s (Stewart & Lance 1983) funded by Ministry of Agriculture grants (70% of cost) although grant aid ceased in 1985. Past drainage has degraded peatland mesotopes by causing localised drying and disrupting overland flows. This causes in particular reductions in plants that are highly dependent on waterlogged conditions such as cottongrasses and *Sphagnum capillifolium* (Stewart & Lance 1991). Even relatively small changes in water table can have a significant effect on the species composition and particularly on the nature of the primary peat forming sphagnum species. Drainage has also led to peatland erosion, especially where drains are on slopes, as well as to an increase in suspended sediment and dissolved organic carbon in water flows (Holden *et al.* 2007). Drain blocking is frequently successful at facilitating re-vegetation and stalling erosion. However severely eroded sites and drains on steep slopes can prove resistant to restorative management (Armstrong *et al*. 2009). Moor draining has now been demonstrated to be of limited actual value for grazing or game management (Stewart & Lance 1991) and must be regarded as inappropriate on peatlands.

3.2 Forestry
Tallis (1998) gives an estimated 3,500 km^2 of blanket mires in Britain and Ireland are afforested, or 16% of the total area but the current figure may be much higher with a

separate estimate of 4,500 km^2 planted in Scotland alone (Scottish Government 2009). Afforestation requires deep-ploughing and draining. This leads to long-term erosion, shrinkage, deep-cracking and oxidation both within and beyond the plantation area. The planted region loses peatland vegetation when the forest closes to thicket after 10-15 years (e.g. Stroud *et al*. 1987). Hence afforestation may modify peatlands at the mesotope or macrotope scale.

3.3 Cutting/Extraction

Peat cutting can take the form of small scale operations for domestic use, principally in far northern and north-western parts of the UK (see Figure 4.2d), or of more industrial-scale peat extraction at the mesotope or macrotope scale, especially for horticultural use. Extraction results in drying and loss of the peat mass, loss of surface vegetation and trampling/compaction of access routes. The long-term impact on peatland biodiversity will differ between sites but in many cases there will be changes away from assemblages typical of active peatlands (e.g. Tallis 1998). The area impacted varies between regions although around 7% of Scotland's blanket mires are modified by domestic peat cutting (Coupar *et al*. 1997).

3.4 Grazing

High grazing levels by domestic livestock have long been recognised as a driver of upland vegetation change, for example from dominance of dwarf-shrubs to grasses, at the macrotope scale. The impact of high grazing levels on blanket bog species can be negative and indeed continued intensive grazing on blanket bog that has deteriorated into dwarf shrub heath may reduce the ability of the system to return to a moss dominated community. Some bog species, such as the 'mosscrop' of cottongrass flower buds, are a significant attractant in early spring as they provide valuable nutrients when ewes are coming into lactation. However peatlands have a lower carrying capacity than most other upland plant assemblages in livestock terms. For example on a Pennine blanket bog, a sheep density of just one sheep per 4 acres (= 0.62 sheep ha^{-1}) suppressed dwarf-shrubs and facilitated increased proportions of graminoid species such as purple moor grass *Molinia caerulea* and heath rush *Juncus squarrosus* (Welch & Rawes 1966). Furthermore high grazing levels, especially if coupled with burning, can exacerbate problems of erosion (Yeloff *et al*. 2006). Increases in sheep numbers, the emergence of new hardy varieties, the use of winter supplementary feeding, changes in sheep management (such as removal of wethers from the moors) and the removal of cattle from many moorlands were all factors in stock management that have resulted in reduced plant diversity.

Recent years have seen a reversal of the trend of over-grazing in at least some regions. Although detailed figures for grazing on peatlands are not available, there has been a steady decline in UK sheep numbers since 2000 with many upland areas, where peatland habitats are best represented, being abandoned altogether. The impact of compensatory processes, such as increased deer browsing, is not yet fully understood but ultimately undergrazing has the potential to become a problem for some peatlands.

3.5 Burning/Muirburn

Prescribed burning is controlled by legislation and it is generally not allowed in the late-spring and summer months (Anon 2007; Anon 2008a; Anon 2008b). It is carried out to remove the surface vegetation and litter, leaving the underlying soil surface undamaged; after the fire the vegetation regenerates. Although it has long been a part of peatland management, burning has increased considerably since the Industrial Revolution (Yeloff *et al*. 2006; Chambers *et al*. 2007). Prescribed burning has the potential to destroy eggs and chicks of ground-nesting birds (Moss *et al*. 2005) and can significantly alter vegetation assemblages and reduce the amplitude of surface patterning features (Hamilton *et al*. 1997). There is conflicting evidence on the form that changes to the vegetation take. For example

Sphagnum austinii was formerly a major part of some peatland systems at the mesotope or macrotope scale (see Section 4 and Chambers *et al*. 2007) but its demise in the peat record coincided with an increase in burning activity. Its revival in recent decades at Cors Fochno, Wales, was linked to the control of burning activity on that reserve (Bailey 2003). However Shaw *et al*. (1997) found no firm evidence that managed burning results in long term damage to *Sphagnum* cover of blanket bogs. It has also been argued that prescribed burning leads to a dominance of heather and a reduction in other species (McVean & Ratcliffe 1962) although a systematic review of the impacts of prescribed burning on blanket bog found that there was a tendency for burning to cause an increase in bryophytes and bare ground and a switch from ericoids to graminoids (Stewart *et al*. 2005).

Burning is currently discouraged on blanket bogs unless they are heather-dominated (Anon 2007) though they may as a result be at greater risk from wildfire. Wildfire is unintentional fire, usually outside the legal burning season, which can be much more extensive than any managed fire. It usually occurs after periods of persistently dry and often hot weather (Anderson 1986). If the root mat is damaged, the peat can be exposed. Overland flow increases on bare peat, rills and then gullies can form and in the worse cases, extensive bare gully systems can develop as in many areas in the Peak District and South Pennines (Phillips *et al*. 1981). Moreover, recovery from such damaged states can take a very long time (Maltby *et al*. 1990; Anderson *et al*. 1997).

3.6 Pollution

Global production and emission of reactive nitrogen has increased substantially over the last 200 years (Galloway & Cowling 2002). Peatland vegetation is generally oligotrophic (adapted to low nutrient conditions). Elevated nitrogen levels will impact differently on different plant species leading to a change in vegetation composition. The growth of *Sphagnum* spp., crucial to peat accumulation, may be inhibited by nitrogen- (N) deposition (Limpens & Berendse 2003). Heather, on the other hand, may respond with increased growth though with reduced tolerance to stressors such as frost (Carroll *et al*. 1999). N-deposition may further impact on peatland vegetation by increasing insect herbivory as a response to elevated foliar nitrogen levels. Such a process can lead to ‘outbreaking’ of populations such as of heather beetle *Lochmaea suturalis* with resultant vegetation defoliation (e.g. Rosenburgh & Marrs 2009).

Emissions of sulphur dioxide (SO_2) linked with heavy use of fossil fuels, disproportionately affect peatlands downwind of areas of heavy industry at the mesotope scale. Again *Sphagnum* especially is vulnerable to SO_2 pollution (Baxter *et al*. 1991) and the Peak District and South Wales, in particular, suffered their disappearance in the mid 19th century linked to emissions of SO_2 from centres of industry in southern Lancashire (Yeloff *et al*, 2006). Pollution may act in a more substantial way than simply altering the vegetation composition. The onset of erosion in Pennine peatlands has been linked to this loss of the *Sphagnum* layer (e.g. Tallis 1998; Yeloff *et al*. 2006) and its absence may inhibit colonisation by other plants of bare ground such as after wildfire. The long term effect of SO_2 pollution on the peats near industrial centres has been a reduction in pH to as low as 2.8 (Anderson *et al*. 1997). It is impossible to restore vegetation onto bare peat with pH this low without adding lime and fertiliser to raise levels to within the more normal range.

3.7 Construction and Development

The most frequent construction works on peatlands are windfarms and communications masts. Associated infrastructure, such as access tracks and foundations, can interfere with peatland hydrology, thus altering vegetation at the microtope and possibly mesotope scale. Construction can lead to significant areas of peat disturbance and bare ground. Furthermore some bird species actively avoid wind turbines and breeding densities of several key species present on peatland, including hen harrier, golden plover and curlew, may be depressed in the proximity of wind farms (Pearce-Higgins *et al*. 2009).

3.8 Restoration Management

Peatland restoration typically involves managing areas to reinstate peatland function and biodiversity. Restoration may be low-intensity, such as grazing livestock control on degraded vegetation, or high-intensity, such as laying down an artificial substrate to stabilise bare peat prior to re-seeding. In the latter case a 'nurse crop' of grasses is sometimes used to establish a stable peat surface rapidly. Peatland vegetation can then become established into this (see, for example, Anderson & Radford 1988). On sites with impoverished plant assemblages, *Sphagnum* may be introduced directly to promote peatland function (e.g. Robroek *et al*. 2009). Restoration management can be expensive but is likely to be good value compared to the cost to society placed on carbon loss from non-restored peats (Anon 2009). Furthermore significant funds are now available for well planned projects with clear outcomes from, for example, EU LIFE funding.

4. Status and Trends

4.1 Vegetation Trends

Our perception of what constitutes a desirable or optimum peatland vegetation can be biased by living-memory recollections or recent monitoring data although old accounts (e.g. mixed *Sphagnum* and dwarf-shrub assemblage. However, palaeoecological evidence has shown that whilst an overwhelming abundance of purple moor-grass may be a recent phenomenon, there were previous periods when this species formed at least a substantial part of the vegetation.

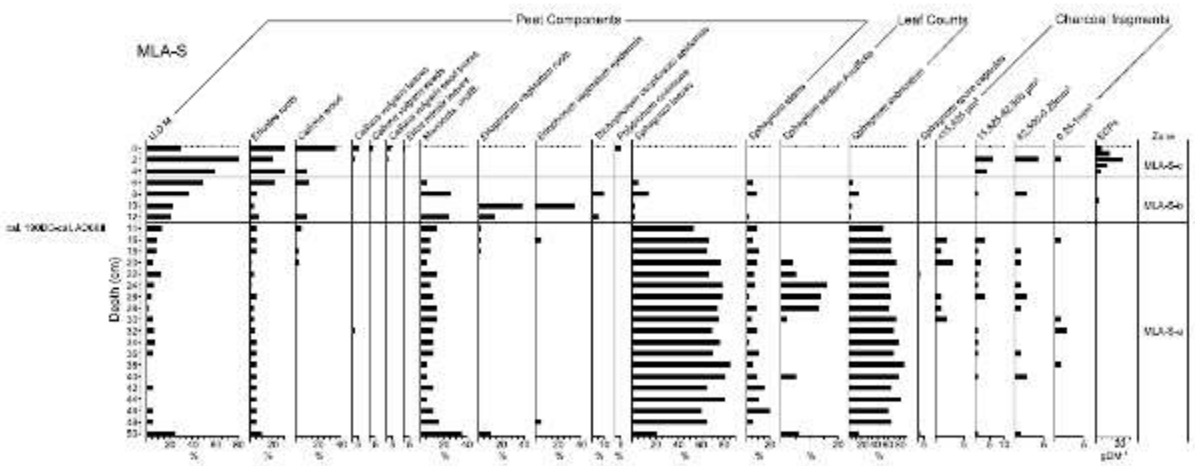

Figure 4.1. *Selected plant macrofossil data for Mynydd Llangatwg. This site is presently a Calluna vulgaris-Eriophorum vaginatum mire, Erica tetralix sub community (M19a: (Rodwell et al. 1991). The profile shows the former presence of Sphagnum imbricatum. Charcoal records at 8 to 10 cm depth mark a change to a more 'xeric' mire community with increase in Ericales roots (Calluna and Erica spp.) and virtual disappearance of Sphagnum spp. Figure reproduced with permission of Elsevier from Chambers et al. (2007).*

Callunetum (heather-dominated vegetation) may also have little historical precedence. Instead sites may have been dominated by other species with, for example, millennial-scale dominance of *Sphagnum imbricatum* recorded from a Welsh blanket bog (see Figure 4.1; Chambers *et al*. 1999; Chambers *et al*. 2007). Similarly, at a series of West Pennine bogs, *Sphagnum* spp., especially *Sphagnum papillosum*, were constantly dominant for around

2000 years up to the start of the twentieth century when they were replaced by hare's-tail cottongrass, bilberry, crowberry, *Hypnum cupressiforme*, *Dicranum scoparium* and wavy hair-grass *Deschampsia flexuosa* (Mackay & Tallis 1996).

4.2 Condition Trends

Only around 400,000 ha (18%) of the blanket mire resource in the British Isles is in a natural or near-natural condition (Tallis 1998). Section 2.1 describes the plant communities associated with such peatlands. Modification of blanket bog is usually reflected in the vegetation which tends to have lower plant diversity and significantly reduced *Sphagnum* and sometimes other bryophytes. There is often a predominance of hare's-tail cottongrass (NVC M20) or purple moor-grass and communities representing drier bog surfaces (some of the heathland H9 or H12 vegetation types) (see Table 2.2). Tallis (1998) presented an approximate figure of 900,000 ha (40%) for the extent of such modified blanket mire in the British Isles and 350,000 ha (16%) for the extent of eroded peat. Figure 4.2 depicts some of these different states of peatland condition.

Site condition or extent of modification can be assessed in several ways but there is a trade-off between broad scale surveys, with general findings, and more detailed studies with narrower remits. Some of the data that are potentially useful are collected as part of monitoring of agri-environment schemes. However deriving trends may be hampered by the use of site-specific metrics such as the "Indicators of Success" used to measure scheme compliance on designated sites in England. Higher Level Stewardship, the primary financial means of delivering management on priority sites in England, does not provide for adequate long-term monitoring to assess outcomes for biodiversity. Whilst rapid and easily applied assessment methods might be desirable for use within agri-environment schemes, peatland management and restoration schemes require long-term detail on hydrological function, habitat change and key species trends for their efficacy to be reliably assessed.

Figures 4.2a-f. *Peatland states and impact on biodiversity*

Figure 4.2a. *Severely degraded blanket bog in the Western Pennines. This site is heavily grazed by cattle and sheep and has been spread with manure. As a result the surface is rather bare. Little of the typical blanket bog vegetation remains though the site has a thin cover of hare's-tail cottongrass. (Photo Penny Anderson)*

Figure 4.2b. *This Western Pennines site has been subject to drains dug into blanket peat along with severe subsequent overgrazing. The vegetation comprises a number of common pasture herbs colonising the vestiges of a cottongrass blanket bog vegetation. (Photo: Penny Anderson)*

Figure 4.2c. *This image, from the South Pennines, shows the effect of wildfire in producing 'peat pans' which fill with water in wet weather, then dry out with caked algal mat in the bottom. They do not fill with Sphagnum and whilst some common cottongrass may colonise, they mostly stay bare under high grazing pressure. It is possible that these were once the hummocks comprising species such as crowberry. These burn hotly and become hollows once eroded out. Gully formation may follow if the peat pans are connected with others. (Photo: Penny Anderson)*

Figure 4.2d. *Peat cutting on Shetland. Small-scale shallow peat cutting may permit recovery of some elements of the peatland vegetation, such as the cottongrasses in the lower part of this view that have re-colonised the previously cut blanket bog. (Photo: Nick Littlewood)*

Figure 4.2e. *Blanket bog in good condition on Shetland. This site has a varied topography with cottongrasses and Sphagnum dominating the lower parts and ericoids in the more elevated sections. (Photo: Nick Littlewood)*

Figure 4.2f. *Close-up of a blanket bog in Bowland in good condition with cranberry growing through Sphagnum. (Photo: Penny Anderson Associates)*

None of the monitoring schemes discussed below measures physical factors directly, for example the integrity of macroptopes and hydrological function. Instead they use biodiversity measures or the presence/absence of particular features such as drains as indicators of peat condition.

The only statistically reliable monitoring system for wide-scale habitat trends is the **Countryside Survey** (Carey *et al*. 2008) which covers all ecosystems within the UK. This provided an estimate for the UK extent of Bog habitats at 2,393,000 ha (9.7% of the land area) in 2007 and this figure is little changed from the previous survey in 1998. Whilst condition trends cannot be directly inferred from Countryside Survey results, some aspects of data collection allow assessment of change in the characteristics of plant assemblages and of soils of blanket bog. In particular, between 1998 and 2007 plant species richness declined. Grasses and other competitive plants increased, whereas ruderal plants, associated with disturbance, decreased. Other vegetation changes reflected a decreasing nutrient status and increasing acidity. Whilst these trends may be indicative of deterioration in bog condition, the Countryside Survey report cautions that further investigation is required. Insufficient lowland raised bog samples were included in the Countryside Survey to draw conclusions for this habitat.

On designated sites monitoring of SSSI features has been carried out as part of the **Common Standards Monitoring** programme (Williams 2006). These permit some comparison of trends in peatland condition by country within the UK. Whilst 58% of condition assessments of blanket bog at designated sites came out as favourable, there was a distinct northerly bias in the results. At most Scottish sites the overwhelming majority of features were assessed as favourable whereas English sites were shown to be in much poorer condition (see Figure 4.3a). Over-grazing and burning were the most frequent adverse activities recorded that contributed to unfavourable status. The situation for lowland raised bogs was considerably worse with just 22% of the 79 assessments returning a 'favourable' outcome. Again there was a tendency for more assessed features to be favourable on more northerly sites. A considerable proportion of bogs in Northern Ireland were assessed as being 'unfavourable-recovering' reflecting the outcome of positive conservation management (see Figure 4.3b). The most frequent adverse activities on lowland raised bogs were poor water management, lack of remedial management and invasive species.

The condition of non-designated peatland is not assessed or collated nationally. However local monitoring can provide at least some insight into trends on non-designated areas. For example in the Yorkshire Dales National Park over half of SSSI-designated blanket bog was in a 'favourable' or 'unfavourable-recovering' state whilst less than a quarter of undesignated bog was in an equivalent condition (see Table 4.1). It is unclear whether this is because only bogs in better condition have been designated or because enhanced incentives or effort exists for appropriate management and restoration on SSSI-designated sites.

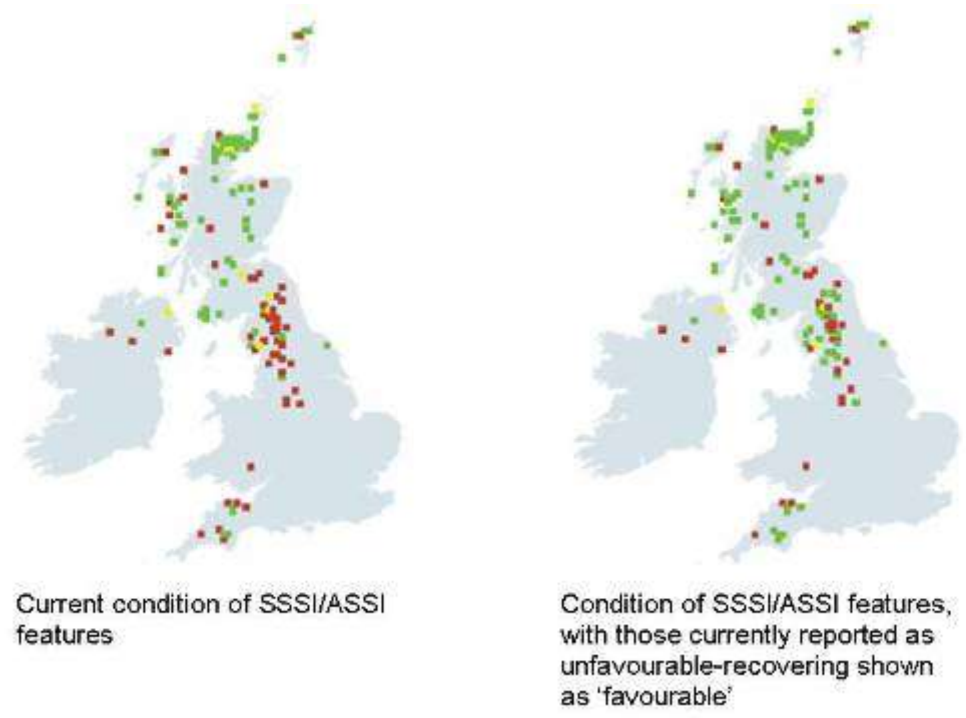

Figure 4.3a. *The condition of features on designated blanket bogs assessed by Common Standards Monitoring. Reproduced from Williams (2006) with permission of JNCC.*

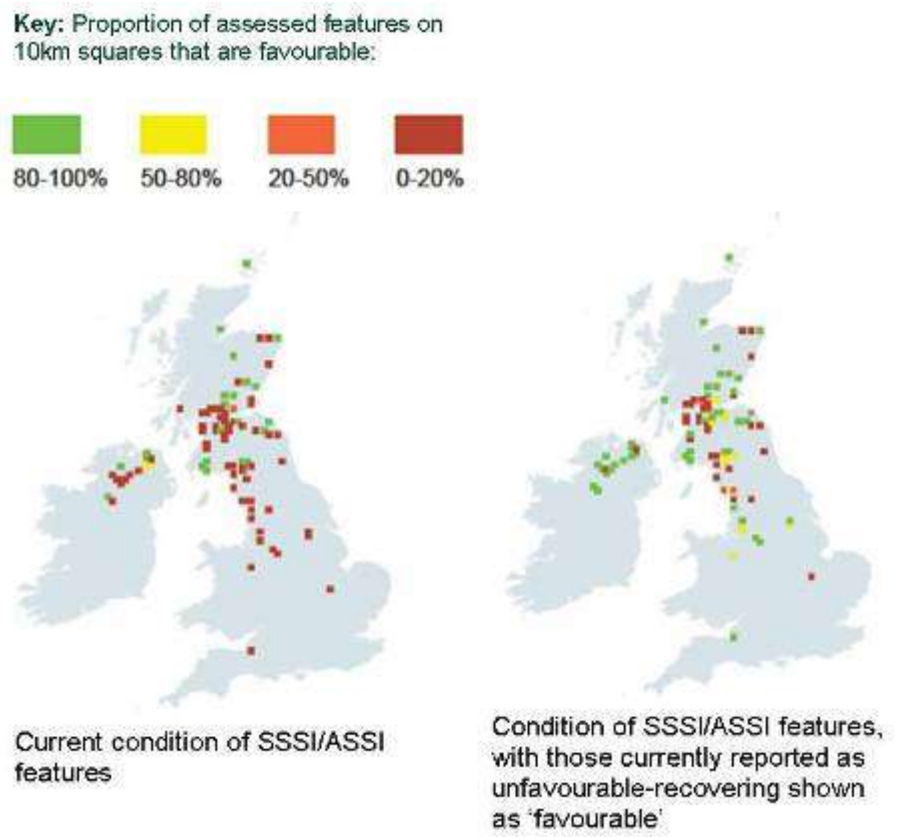

Figure 4.3b. *The condition of features on designated lowland bogs assessed by Common Standards Monitoring. Reproduced from Williams (2006) with permission of JNCC. Key as for Figure 4.2a.*

Table 4.1. *Condition of designated and non-designated blanket bog in the Yorkshire Dales National Park surveyed between 2002 and 2008. For non-designated sites, condition assessment is based on Natural England Higher Level Stewardship monitoring and is broadly equivalent to the aggregates of the categories shown for SSSI monitoring. Data courtesy of Tim Thom, Yorkshire Dales National Park Authority.*

	SSSI		**Non-SSSI**	
	Measured Area (ha)	Condition (%)	Measured Area (ha)	Condition (%)
Favourable	2292	18	1472	21
Unfavourable-recovering	4254	36		
Unfavourable-no change	5377	46	5594	79
Unfavourable-declining	8	0		
Unfavourable -no trend	731			
Unknown condition	2219		10252	
TOTAL (ha)	**15301**		**18302**	

4.3 Trends in Key Species

Priority species, designated under the UK Biodiversity Action Plan process, are subject to published targets but monitoring and reporting of progress towards these targets is patchy. For species that occur across other habitats as well as peatlands, progress is not collated in a way that allows a break-down by habitat type. However, for peatland species where UK trend information from a variety of sources is available, fourteen were found to be declining and only three increasing (see Table 2.1).

Trends in breeding bird populations on peatlands are difficult to define as few data are published that separate peatlands from other habitats. Local trends must be interpreted with care as factors affecting birds may vary geographically. As mentioned in Section 2, the Flow Country of Caithness and Sutherland is an important peatland area for breeding birds and has been subject to repeat surveys. Stroud *et al*. (1987) showed how numbers of some key species declined in the 1970s and 1980s as a result of habitat loss to forestry. In addition to the direct loss of habitat, subsequent surveys in 1993 and 1994 showed continued losses of these species (Whitfield 1997) (see Table 4.2). As some plantations were adjacent to some of the best bogs for these birds, this may have been due to 'edge-effects' of altered hydrology or cover for predators (Avery 1989; Hancock *et al*. 2009).

Priority species designation does not always guarantee conservation action and the policy frameworks of key organisations may be influenced by other factors. For example the UK government conservation agencies concentrate work on designated sites (SSSIs etc.). This may be to the benefit of species on lowland raised mires in England (most of which by area is designated as SSSI) but less advantageous to those inhabiting blanket bog in Scotland (of which only about 11% is designated).

Table 4.2. *Trends in the number of breeding pairs of three wading bird species on the Flow Country of Caithness and Sutherland. The primary period of forest expansion was late 1970s and early to mid 1980s.*

	Pre-afforestation (early 1970s) (Stroud *et al*. 1987)	**1987 (Stroud *et al*. 1987)**	**1993/94 (Whitfield 1997)**
Golden Plover	4900	3980	3767
Dunlin	4620	3830	3095
Greenshank	760	630	464

5. Good Management Practice

The success of imposed management depends on the starting point and the objective to be achieved. Good management requires an assessment of the initial floristic composition and of physical factors, including hydrology, at all scales from macrotope to vegetation. At severely degraded sites, such as those that have been damaged by cutting, creation of a poor fen rather than raised bog might be regarded as success, at least in the short term, especially if the long-term trajectory is towards eventual bog formation. Monitoring of management schemes is crucial to assessing their efficacy (and the importance of monitoring, including collection of baseline data, should be fully recognised in funding schemes). However aims need to be appropriate for the timescales involved with intermediate benchmarks set where progress towards active peat formation is a very long-term goal.

5.1 Grazing

Tallis (1998) concluded that natural blanket bog vegetation may be the result of long-continued low-intensity grazing. He cites studies on peat covered islands where, without any grazing, *Sphagnum* cover reduced and woody plants became dominant. Different peatland habitats respond differently to grazing depending on the species, their palatability and digestibility, their coverage and the mixture on offer across a site (which usually extends well beyond the peatland area). Whilst grazing exclusion might produce benefits when trying to restore peatland vegetation from a highly degraded state (e.g. Rawes 1983), in many situations light grazing by sheep is likely to be beneficial, especially summer grazing in situations where grasses might otherwise rise to dominance. Some breeding birds may also benefit from grazing, especially, for example, golden plover and curlew where grazing helps to break up tall uniform heather (Grant 2002). Furthermore the structural diversity of vegetation associated with light grazing on heaths promotes increased invertebrate diversity (e.g. Gardner *et al*. 1997) and the same may apply on bogs with related vegetation types.

5.2 Hydrology
Hydrological integrity is crucial for good management for peatland biodiversity, both in upland blanket bog and lowland raised bog systems. Where there is good hydrological integrity this must be maintained; where hydrological processes are sub-optimal they should be improved. Such management is difficult on small scales and should ideally be carried out on the mesotope scale. The extent of modification to hydrology may not be immediately apparent, for example the extent of peat pipes resulting from wildfire or other damage. Restoration of the hydrology may be impossible where the site is in the later stages of complete erosion and loss of much of the peat mass. Sites where part of the mesotope has been previously modified by agricultural reclamation will present particular challenges to prevent bog desiccation. Whilst peat-bunding can produce some success at buffering active peatlands from surrounding drained land (e.g. Bailey 2003) taking control of hydrology on adjacent land is a better option where this is possible.

5.3 Scrub Management
On sites where the water table has been lowered there is a risk from scrub encroachment, especially on lowland raised bogs. Some scrub may be viewed as a natural part of bog vegetation and may help form very specific habitat requirements for rare species, such as the 10-spotted pot beetle *Cryptocephalus decemmaculatus* which has only been found on small willows *Salix* and birches *Betula* within bog habitats (Anon 2010). At sites subject to succession where the water table has been lowered and there is no prospect of reversing this, allowing succession to fen carr rather than trying to recreate raised bog may be appropriate (Bowler 2002). However an expansion of scrub will usually be viewed as a threat to typical peatland biodiversity and scrub control forms a major part of management at some key sites.

5.4 Burning
Burning is a regular part of the management of some vegetation assemblages that are closely related to those typically associated with peatlands. However, except for heather-dominated sites in England, burning on blanket bogs is now discouraged (Anon 2007; Anon 2008a; Anon 2008b) and there is little evidence to recommend otherwise.

5.5 Restoration
Restoration may be carried out for a variety of reasons including carbon sequestration, water quality, recreation and biodiversity. In many cases good practice management for one of these factors will benefit the others but this may not always be the case especially where one of the other factors is being managed to its maximum. For example over intensive recreation can lead to species disturbance and erosion from unmanaged access tracks.

When restoration is carried out from an extremely degraded state, key elements of peatland biodiversity may no longer be represented on a site or close enough by for natural re-colonisation. In such cases re-introduction could be considered following successful habitat restoration.

Restoration projects must have clear aims and be planned over timescales that are realistic for these aims. Some projects, such as those purely involving withdrawal or control of grazing livestock, may take many years before recovery of the desired vegetation becomes apparent (e.g. Yalden 2004). Funding schemes need to recognise these long-term challenges.

5.6 Barriers to Good Practice

Information for land managers is often scattered or even conflicting. Much is hidden in the scientific literature or in unpublished reports. There are collations of information in a Management Handbook for bogs (Brooks & Stoneman 1997) and, recently, one for fens (McBride *et al*. 2010) and a new handbook on best practice upland restoration is in preparation. These should be promoted among peatland management practitioners. Further initiatives to make information on management for biodiversity more readily available include the publication of 'user-friendly' habitat management information on BAP priority Habitats (Anon 2010) and advice sheets from DEFRA relating to sustainable grazing on heather-dominated sites. Peatland practitioners should be encouraged where possible to report back on the results of management initiatives. There is a journal dedicated to mires and peat (www.mires-and-peat.net) and the dissemination of results from management interventions is facilitated through initiatives such as the online journal, Conservation Evidence (www.conservationevidence.com).

Species identification skills are required for accurate monitoring of ecosystems but there is increased consensus that these are generally lacking in university training. This issue is especially acute for peatlands as much monitoring relies on knowledge of more 'difficult' groups such as bryophytes. Initiatives to address this shortfall need to be developed much more seriously.

Moorland management and, especially, restoration is expensive. Work carried out under Higher Level Stewardship in England requires payment up front by the landowner, making uptake impossible for some. Even when funding is more readily available, moorland managers may have priorities that differ from those of promoting biodiversity. Furthermore management hierarchies in upland areas are often complicated by separation of ownership, shooting rights and grazing rights, especially on commons, which may serve to make coherent management difficult or impossible.

Finally, as mentioned in Section 2, historical conflicts between land managers and those representing the environmental sector have created atmospheres of suspicion, entrenched positions and non-cooperation. It is imperative for the future of peatland management that common ground is recognised, main principles agreed, that land owners and scientists input to policy planning and that good management is encouraged by good example and sufficient support rather than by coercion. To this end demonstration sites can work well in fostering good practice, and specifically helping to foster good relations between stakeholder groups and by showing that there can be mutual benefit in common-good management.

8. Possible Future Climate Change Impacts

Current predictions indicate that peatlands will be subject to pressures of drying (with possible increased peat cracking), increased storminess (with associated potential for erosion) and increased temperatures with a concomitant effect on plant decomposition and on drying. The extent to which peatlands remain resilient to such changes will have crucial importance for the protection of peatland biodiversity. Resilience here refers to the ability of an ecosystem to respond to perturbation by changing back towards its original state (see Mitchell *et al*. 2000 for discussion). In terms of peatlands, by original state we mean being an active peatland as much as we mean the specific vegetation components. Changes to peatland vegetation assemblages are likely to occur and indeed have done so periodically in the past (see Section 4). However the fact that each former vegetation type laid down deposits in accumulating peat layers indicates a degree of resilience to climate change, insofar as peat formation has continued through previous climate changes. Part of the mechanism giving rise to this resilience involves changes in microtope characteristics, such as a reduction in pools and increase in hummocks and ridges which in turn will alter the quantity and quality of habitat for other life forms. Degradation may reduce the ability of a peatland to further adapt to climate change. Hence identifying boundaries to such resilience would be of considerable use for long term peatland conservation planning.

Further potential climate change impacts relate to seasonality of activity on peatlands. Some bird species, for example, only use peatlands during the spring and early summer breeding season. Climate change-related mismatches between Golden Plover breeding and the emergence of a primary food source, adult craneflies, have already been identified in the Peak District (Pearce-Higgins *et al*. 2005). It is likely that the impact of such asynchronous shifts in activity will be greater on species that are at or close to the edge of their range, as is the case for many of the important breeding birds on UK peatlands and, thus, the resilience of such populations may be tested under future modelled climate scenarios (Pearce-Higgins *et al*. 2010).

9. Conclusions and Key Messages

- Traditional diversity indicators are generally inappropriate for assessing the value of peatland biodiversity. Instead the naturalness of the system should be recognised and assessment should encompass habitat condition, microtope patterns and key species trends.
- There has been significant modification of peatlands over time, but particularly in the last 300 years from aerial deposition, high grazing levels, regular burning (managed and wildfire) and drainage together with other losses of systems to forestry, peat extraction and other developments.
- Where it has not been modified, maintaining hydrological function of the macrotope is of paramount importance for maintaining peatland biodiversity.
- Restoration of modified sites may not produce pristine peatland vegetation, at least in the short term, but has the potential to set sites on a trajectory of change in the direction of becoming functioning semi-natural systems. Restoration prioritisation should be given to sites where the hydrology of the macrotope can be controlled in order to achieve better functioning bogs, and where there is a good remnant population of bog species to facilitate rapid. However restoration of bare and eroding peat should not be neglected where biodiversity and other benefits can be identified.
- The process of setting targets for peatland management and restoration projects should, where possible, take account of available palaeoecological evidence. Whilst long-term change in peatland vegetation may be a normal process, recent and/or adjacent vegetation may have been promoted by moderately recent human activity and might not necessarily be considered an optimum target.
- Peatland management needs to take a flexible approach to address different drivers influencing each site. Management advice should be disseminated widely.

Acknowledgements

We thank Clifton Bain, Aletta Bonn, Frank Chambers, Alistair Crowle, Andrew Coupar, Chris Field, Richard Lindsay, Helen Perkins, Mick Rebane, David Smith, Rob Stoneman and Tim Thom for their input into the review process.

References

Anderson,P. (1986) *Accidental Moorland Fires in the Peak District*. Peak Park Joint Planning Borad, Bakewell.

Anderson,P. & Radford, E. (1988) *Moorland Management Project: a national review of moorland restoration techniques*. Peak District Moorland Management Project, Bakewell.

Anderson,P., Tallis, J. & Yalden, D. (1997) *Restoring Moorland. Peak District Moorland Management Project, Phase III Report*. Peak Park Joint Planning Board, Bakewell.

Anon (2007) *The Heather and Grass Burning Code*. DEFRA, London.

Anon (2008a) *The Heather and Grass Burning Code for Wales*. The Welsh Assembly Government, Cardiff.

Anon (2008b) *The Muirburn Code*. The Scottish Government, Edinburgh.

Anon (2009) *The Peatlands of Scotland: the urgent need for restoration and conservation*. RSPB, Scotland.

Anon (2010) *Managing Priority Habitats for Invertebrates*, 2nd. edn. Buglife, Peterborough.

Armstrong, A., Holden, J., Kay, P., Foulgar, M., Gledhill, S., McDonald, A. T. & Walker, A. (2009) Drain-blocking techniques in blanket peat: a framework for best practice. *Journal of Environmental Management*, **90**, 3512-3519.

Artz, R.R.E., Chapman, S. J., Siegenthaler, A., Mitchell, E. A. D., Buttler, A., Bortoluzzi, E., Gilbert, D., Yli-Petays, M., Vasander, H. & Francez, A. J. (2008) Functional microbial diversity in regenerating cutover peatlands responds to vegetation succession. *Journal of Applied Ecology*, **45**, 1799-1809.

Avery, M.I. (1989) Effects of upland afforestation on some birds of the adjacent moorland. *Journal of Applied Ecology*, **26**, 966.

Bailey, M.P. (2003) Reserve focus - Cors Fochno (Borth Bog), West Wales. *British Wildlife*, **14**, 195-198.

Baxter, R., Emes, M. J. & Lee, J. A. (1991) Transition metals and the ability of *Sphagnum* to withstand the phytotoxic effects of the bisulphite ion. *New Phytologist*, **118**, 433-439.

Bowler, P. (2002) Reserve focus: Askham Bog, North Yorkshire. *British Wildlife*, **13**, 323-326.

Bragg, O. & Lindsay, R. (Eds) (2003) *Strategy and Action Plan for Mire and Peatland Conservation in Central Europe*. Wetlands International, Wageningen, The Netherlands.

Brooks, S. & Stoneman, R. (1997) *Conserving Bogs: the Management Handbook*. The Stationery Office, Edinburgh.

Brooks, S.J. (1997) Peatland dragonflies (Odonata) in Britain: A review of their distribution, status and ecology. *Conserving Peatlands* (eds L. Parkyn, R.E. Stoneman & H.A.P. Ingram), pp. 112-117. CAB International, Wallingford.

Carey, P.D., Wallis, S., Chamberlain, P. M., Cooper, A., Emmett, B. A., Maskell, L. C., McCann, T., Murphy, J., Norton, L. R., Reynolds, B., Scott, W. A., Simpson, I. C., Smart, S. M. & Ullyett, J. M. (2008) *Countryside Survey: UK Results from 2007.* NERC/Centre for Ecology & Hydrology.

Carroll, J.A., Caporn, S. J. M., Cawley, L., Read, D. J. & Lee, J. A. (1999) The effect of increased deposition of atmospheric nitrogen on *Calluna vulgaris* in upland Britain. *New Phytologist*, **141**, 423-431.

Chambers, F.M., Mauquoy, D., Gent, A., Pearson, F., Daniell, J. R. G. & Jones, P. S. (2007) Palaeoecology of degraded blanket mire in South Wales: Data to inform conservation management. *Biological Conservation*, **137**, 197-209.

Chambers, F.M., Mauquoy, D. & Todd, P. A. (1999) Recent rise to dominance of *Molinia caerulea* in environmentally sensitive areas: new perspectives from palaeoecological data. *Journal of Applied Ecology*, **36**, 719-733.

Coulson, J., Bauer, L., Butterfield, J., Downie, I., Cranna, L. & Smith, C. (1995) The invertebrates of the northern Scottish Flows, and a comparison with other peatland habitats. *Heaths and moorland: cultural landscapes* (eds D.B.A. Thompson, A.J. Hester & M.B. Usher), pp. 74-91. Stationary Office, Edinburgh.

Coulson, J.C. & Butterfield, J. (1986) The spider communities on peat and upland grasslands in northern England. *Holarctic Ecology*, **9**, 229-239.
Coulson, J.C. & Butterfield, J. E. L. (1978) An investigation of the biotic factors determining the rates of plant decomposition on blanket bog. *Journal of Ecology*, **66**, 631-650.
Coupar, A., Immirzi, P. & Reid, E. (1997) The nature and extent of degradation in Scottish blanket mires. *Blanket Mire Degradation; Causes Consequences and Challenges* (eds J.H. Tallis, R. Meade & P.D. Hulme), pp. 90-100. Macaulay Land Use Research Institute, Aberdeen.
Eaton, M.A., Brown, A. F., Noble, D. G., Musgrove, A. J., Hearn, R., Aebischer, N. J., Gibbons, D. W., Evans, A. & Gregory, R. D. (2009) Birds of Conservation Concern 3: the population status of birds in the United Kingdom, Channel Islands and the Isle of Man. *British Birds*, **102**, 296-341.
Fletcher, K., Aebischer, N. J., Baines, D., Foster, R. & Hoodless, A. N. (2010) Changes in breeding success and abundance of ground-nesting moorland birds in relation to the experimental deployment of legal predator control. *Journal of Applied Ecology*, ***47,*** 263-272.
Fox, R., Asher, J., Brereton, T., Roy, D. & Warren, M. (2006a) *The State of Butterflies in Britain and Ireland*. Pices Publications, Newbury.
Fox, R., Conrad, K. F., Parsons, M. S., Warren, M. S. & Woiwod, I. P. (2006b) *The State of Britain's Larger Moths.* Butterfly Conservation and Rothamsted Research, Wareham, Dorset, UK.
Galloway, J.N. & Cowling, E. B. (2002) Reactive nitrogen and the world: 200 years of change. *Ambio*, **31**, 64-71.
Gardner, S.M., Hartley, S. E., Davies, A. & Palmer, S. C. F. (1997) Carabid communities on heather moorlands in northeast Scotland: The consequences of grazing pressure for community diversity. *Biological Conservation*, **81**, 275-286.
Grant, M. (2002) Habitat requirements of waders on blanket bogs. *Management of Heath and Blanket Bog for Priority Species, Report of a workshop held at Moorhouse-Upper Teesdale National Nature Reserve, 22-23 July 2002.* (ed H.Adamson), pp. 17-19. ADAS, Rochester.
Hamilton, A., Legg, C. & Zhaohua, L. (1997) Blanket mire research in north-west Scotland: a view from the front. *Blanket Mire Degradation: Causes, Consequences and Challenges* (eds J.H. Tallis, R. Meade & P.D. Hulme), pp. 47-53. The Macaulay Land Use Research Institute, Aberdeen.
Hancock, M.H., Grant, M. C. & Wilson, J. D. (2009) Associations between distance to forest and spatial and temporal variation in abundance of key peatland breeding bird species. *Bird Study*, **56**, 53-64.
Holden, J., Gascoign, M. & Bosanko, N. R. (2007) Erosion and natural re-vegetation associated with surface land drains in upland peatlands. *Earth Surface Processes and Landforms*, **32**, 1547-1557.
Limpens, J. & Berendse, F. (2003) Growth reduction of *Sphagnum magellanicum* subjected to high nitrogen deposition: the role of amino acid nitrogen concentration. *Oecologia*, **135**, 339-345.
Lindsay,R. (2010) *Peatbogs and carbon: a critical synthesis to inform policy development in oceanic peat bog conservation and restoration in the context of climate change*. University of East London.
Lindsay, R.A., Charman, D. J., Everingham, F., O'Reilly, R. M., Palmer, M. A., Rowell, T. A. & Stroud, D. A. (1988) *The Flow Country. The Peatlands of Caithness and Sutherland*. Nature Conservancy Council, Peterborough.
Mackay, A. & Tallis, J. H. (1996) Summit-type blanket mire erosion in the forest of Bowland, Lancashire, UK: predisposing factors and implications for conservation. *Biological Conservation*, **76**, 31-44.
Maltby, E., Legg, C. J. & Proctor, M. C. F. (1990) The ecology of severe moorland fire on the North York Moors - effects of the 1976 fires, and subsequent surface and vegetation development. *Journal of Ecology*, **78**, 490-518.

McBride, A., Diack,I., Droy,N., Hamill,B., Jones,P., Schutten,J., Skinner,A., Street,M. (Eds) (2010) *The Fen Management Handbook*. Scottish Natural Heritage, Perth.
McVean, D.N. & Ratcliffe, D. A. (1962) *Plant communities of the Scottish Highlands*. HMSO, London.
Mitchell, R.J., Auld, M. H. D., Le Duc, M. G. & Marrs, R. H. (2000) Ecosystem stability and resilience: a review of their relevance for the conservation management of lowland heaths. *Perspectives in Plant Ecology, Evolution and Systematics*, **3**, 142-160.
Montanarella, L., Jones, R. J. A. & Hiederer, R. (2006) The distribution of peatland in Europe. *Mires and Peat*, **1**, Article 1, 1-10.
Moss, C.E. (1913) *The Vegetation of the Peak District*. Cambridge University Press, Cambridge.
Moss, D., Joys, A. C., Clark, J. A., Kirby, A., Smith, A., Baines, D. & Crick, H. Q. P. (2005). *Timing of Breeding of Moorland Birds*. BTO Research Report No. 362. British Trust for Ornithology, Thetford.
Park, K.J., Robertson, P. A., Campbell, S. T., Foster, R., Russell, Z. M., Newborn, D. & Hudson, P. J. (2001) The role of invertebrates in the diet, growth and survival of red grouse (*Lagopus lagopus scoticus*) chicks. *Journal of Zoology*, **254**, 137-145.
Pearce-Higgins, J.W., Dennis, P., Whittingham, M. J. & Yalden, D. W. (2010) Impacts of climate on prey abundance account for fluctuations in a population of a northern wader at the southern edge of its range. *Global Change Biology*, **16**, 12-23.
Pearce-Higgins, J.W., Stephen, L., Langston, R. H. W., Bainbridge, I. P. & Bullman, R. (2009) The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology*, **46**, 1323-1331.
Pearce-Higgins, J.W., Yalden, D. W. & Whittingham, M. J. (2005) Warmer springs advance the breeding phenology of golden plovers *Pluvialis apricaria* and their prey (Tipulidae). *Oecologia*, **143**, 470-476.
Phillips, J., Yalden, D. & Tallis, J. (Eds), (1981) *Peak District Moorland Erosion Study: Phase I Report.* Peak Park Joint Planning Board, Bakewell.
Rawes, M. (1983) Changes in two high altitude blanket bogs after the cessation of sheep grazing. *Journal of Ecology*, **71**, 219-235.
Risely, K., Baille, S. R., Eaton, M. A., Joys, A. C., Musgrove, A. J., Noble, D. G., Renwick, A. R. & Wright, L. J. (2010) *The Breeding Bird Survey 2009*. British Trust for Ornithology, Thetford.
Robroek, B.J.M., van Ruijven, J., Schouten, M. G. C., Breeuwer, A., Crushell, P. H., Berendse, F. & Limpens, J. (2009) Sphagnum re-introduction in degraded peatlands: The effects of aggregation, species identity and water table. *Basic and Applied Ecology*, **10**, 697-706.
Rodwell, J.S., Piggott, C. D., Ratcliffe, D. A., Malloch, A. J. C., Birks, H. J. B., Proctor, M. C. F., Shimwell, D. W., Huntley, J. P., Radfors, E., Wigginton, M. J. & Wilkins, P. (1991) *British Plant Communities: Mires and Heaths*. Cambridge University Press, Cambridge.
Rosenburgh, A. & Marrs, R. H. (2009) *The Heather Beetle: A Review*. The Heather Trust, Dumfries.
Scott, A.G., Oxford, G. S. & Selden, P. A. (2006) Epigeic spiders as ecological indicators of conservation value for peat. *Biological Conservation*, **127**, 420-428.
Scottish Government (2009) Parliamentary Questions:
http://www.scottish.parliament.uk/business/pqa/wa-10/wa0514.htm
Shaw, S., Wheeler, B. & Backshall, J. (1997) Review of effects of burning and grazing of blanket bogs; conservation issues and conflicts. *Blanket Mire Degradation: Causes Consequences and Challenges* (eds J.H. Tallis, R. Meade & P.D. Hulme), The Macaulay Land Use Research Institute, Aberdeen.
Stewart, A.J.A. & Lance, A. N. (1983) Moor-Draining - A Review of Impacts on Land-Use. *Journal of Environmental Management*, **17**, 81-99.
Stewart, A.J.A. & Lance, A. N. (1991) Effects of moor-draining on the hydrology and vegetation of northern Pennine blanket bog. *Journal of Applied Ecology*, **28**, 1105-1117.

Stewart, G.B., Coles, C. F. & Pullin, A. S. (2005) Applying evidence-based practice in conservation management: Lessons from the first systematic review and dissemination projects. *Biological Conservation*, **126**, 278.
Stroud, D.A., Reed, T. M., Pienkowski, M. W. & Lindsay, R. A. (1987) *Birds, Bogs and Forestry. The Peatlands of Caithness and Sutherland*. Nature Conservancy Council.
Tallis, J.H. (1998) Growth and degradation of British and Irish blanket mires. *Environmental Reviews*, **6**, 81-122.
Thirgood, S. & Redpath, S. (2008) Hen harriers and red grouse: science, politics and human–wildlife conflict. *Journal of Applied Ecology*, **45**, 1550-1554.
Thirgood, S.J., Redpath, S. M., Rothery, P. & Aebischer, N. J. (2000) Raptor predation and population limitation in red grouse. *Journal of Animal Ecology*, **69**, 504-516.
Usher, M.B. (1992) Management and Diversity of Arthropods in *Calluna* Heathland. *Biodiversity and Conservation*, **1**, 63-79.
Van der Wal, R., Bonn, A., Monteith, D, Reed, M., Blackstock, K., Hanley, N., Thompson, D., Evans, M., Alonso, I. & Beharry-Borg, N. (in press). *UK National Ecosystem Assessment. Chapter 4: Mountains, Moorlands and Heath*.
Welch, D. & Rawes, M. (1966) The intensity of sheep grazing on high-level blanket bog in Upper Teesdale. *Irish Journal of Agricultural Research* **5,** 185-196.
Whitfield, D.P. (1997) Waders (Charadrii) on Scotland's blanket bogs: Recent changes in numbers of breeding birds. *Conserving Peatlands* (eds L.Parkyn, R.E.Stoneman & H.A.P.Ingram), CAB International, Wallingford.
Whittaker, R.H. (1960) Vegetation of the Siskiyou mountains, Oregon and California. *Ecological Monographs*, **30**, 279-338.
Williams,J.M. (2006) *Common Standards Monitoring for Designated Sites: First Six Year Report.* JNCC, Peterborough.
Yalden, D.W. (2004) The slow recovery of eroded blanket-bog vegetation in the Peak District. *Naturalist*, **129**, 113-117.
Yeloff, D.E., Labadz, J. C. & Hunt, C. O. (2006) Causes of degradation and erosion of a blanket mire in the southern Pennines, UK. *Mires and Peat*, **1**, Article 4, 1-18.