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Impacts of livestock grazing on lowland heathland

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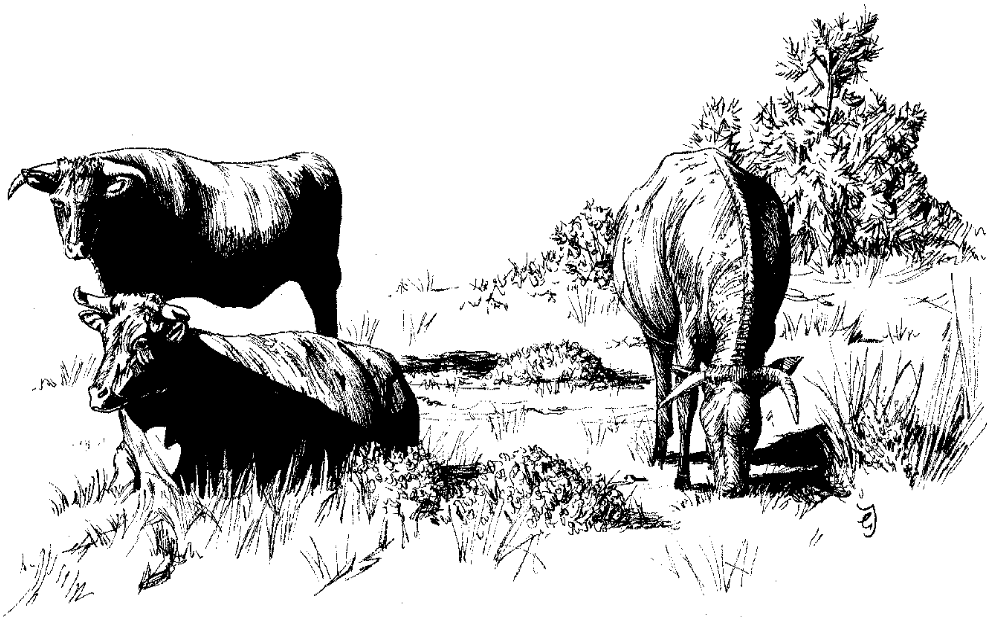

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Impacts of livestock grazing on lowland heathland in the UK

Sophie Lake, James M Bullock and Sue Hartley

NERC Centre for Ecology and Hydrology and Sussex University

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Executive summary

General conclusions

a. Grazing by livestock is an appropriate management for lowland heathland, to deliver conservation objectives.

b. Management regimes using appropriate grazing can produce a greater diversity of habitats and thus a greater biological diversity than other management types such as burning or cutting.

c. Grazing impacts must always be considered in terms of the intensity of grazing and the livestock types used; negative effects, or poor achievement of targets can arise from inappropriate grazing. The negative impacts of grazing on biodiversity over much of upland heathland in Britain illustrates the consequences of overgrazing.

Summary

1. In recent years, grazing has been reintroduced to many UK (and European) lowland heaths, in an attempt to provide appropriate, sustainable conservation management.

2. To provide information to guide the use of livestock grazing on lowland heathlands, this report has the following objectives.

    a. To review and synthesise information on lowland heathland grazing history, methods and impacts.

    b. To obtain this information from published and unpublished literature, observation and anecdote from site managers, and ongoing research.

    c. To highlight gaps in our understanding of lowland heathland grazing and prioritise data requirements in terms of conservation needs.

    d. To identify appropriate research methodologies for studying lowland heathland grazing and recommend research protocols to fulfil data requirements.

3. Grazing was a fundamental part of traditional lowland heathland use until its decline during the 20th century. Little is known about how traditional practices in Britain, but it is likely that these were similar to those in other parts of Europe. In these, heathlands were an integral part of the cultural landscape and managed in conjunction with arable land and improved pasture.

4. The following aspects of livestock behaviour are important for lowland heath grazing.

    a. Livestock use habitats on heathland sites selectively; the major factors are forage availability and quality.

b. Stock species and breed can be chosen to focus impacts onto certain communities and species.

c. Site geography, including location of water and shelter and the distribution pattern of habitats within the site can influence livestock behaviour.

5. The following points are important in considering the suitability of livestock for lowland heathland grazing.

   a. Cattle, ponies, sheep and goats have all been used for grazing of lowland heath.

   b. While there is a considerable amount of information on the general attributes of different livestock species, few comparative studies have been carried out on lowland heathland, and information is mostly site specific and often anecdotal.

   c. Comparative studies of livestock breeds are few and none have been done on lowland heathland. Differences due to age, gender and origin are even less studied.

   d. Little is known about the interaction between these components of livestock type, how they may be influenced by husbandry, or their relative importance in determining suitability for conservation grazing.

6. Stocking rate is important in determining the impact of livestock on heathland vegetation.

   a. However the impact of a given stocking density may vary between both sites and years.

   b. Recorded stocking rates used for conservation grazing on lowland heathland sites vary between 0.03 and 0.50 LU $ha^{-1} yr^{-1}$

   c. Stocking rate may be useful for broad comparisons of livestock impact, but its usefulness for predicting vegetation change is limited. Utilisation rate, as used in studies in the uplands, may be more useful.

7. Direct impacts of livestock on species and the heathland habitat may arise through feeding, trampling, poaching, dung and urine deposition, dispersal, erosion and human activities associated with managing livestock. Many impacts on species are indirect, leading on from habitat changes caused by grazing.

8. Lists are provided of species of conservation concern for lowland heathland, along with the best information available for their responses to grazing.

9. Impacts of livestock on lowland heathland vegetation will vary according to stocking density, livestock type, grazing season, vegetation start point, site characteristics and climate.

   a. Grazing is likely to produce maximum species and structural diversity on all heathland vegetation types at intermediate stocking densities. High and low extremes will both lead to an increase in grass cover, and reduction in dwarf shrub cover. Low density will generally allow an increase in scrub cover.

b. Little is known about the degree of structural diversity and the scale of vegetation mosaics created by livestock presence.

c. Livestock can control and reduce invasive species such as *Deschampsia flexuosa* and *Molinia caerulea*. The effects of livestock on bracken and in particular scrub require further research.

d. Populations of many characteristic heathland plants should benefit from an increase in bare ground and reduction of competitive grasses. However, variables such as livestock breed, grazing intensity and grazing season will have individualistic effects on species depending on their ecology and phenology.

10. Not enough is known about the ecology and life histories of many key species of lowland heathland invertebrates, to predict how livestock grazing may affect populations.

    a. Invertebrates have very specific habitat requirements, so to maximise invertebrate diversity, a heathland should have a range of vegetation types and a varied habitat structure from bare ground to small trees.

    b. Habitat mosaics are vital; many species need range of habitats available within a small area.

    c. Appropriate grazing management may achieve the required habitat diversity. Equally, over or undergrazing may lead to loss of the habitats required by particular invertebrate species.

11. The responses of vertebrates to grazing of lowland heath are poorly studied, and there is much controversy in the absence of key information.

    a. Several bird species of conservation concern may be benefited by appropriate levels of livestock grazing on heathlands, particularly through increased structural diversity and potential increase in invertebrate prey.

    b. There is controversy over the impacts of livestock on reptile species. Research is needed to clarify the interaction between livestock-induced habitat change and population changes in key species.

    c. High grazing pressure has been shown to reduce small mammal diversity in the New Forest. It is not known whether this is likely to occur under lighter grazing.

12. Much of the data now available on the impacts of grazing on lowland heath are not easily interpretable, having been collected from sites with no baseline monitoring, from studies which were insufficiently replicated and/or with insufficient monitoring.

13. The lack of good information means there must be work done to compare the effects of different grazing regimes on the heathland habitat and biota to allow management to be planned to achieve particular biodiversity objectives.

14. In studying grazing regimes, the variables that need to be considered in terms of the impact on biota are: grazing intensity; timing and duration of grazing season; type of livestock, including species, breed, gender, age, origin, and husbandry. The following approaches could yield important information.

    a. Establishing full replicated experiments in which different heaths in a region are used as replicate blocks.

    b. Establish detailed monitoring on ongoing and new grazing projects*:*

    c. Carry out a meta-analysis of existing data from monitoring of heathland grazing projects.

    d. Study diet selection, intake rates, habitat selection and ranging behaviour of livestock types in established and new grazing projects, to suggest the different impacts on vegetation structure and composition.

    e. Carry out autecological studies of key species to precisely understand their habitat requirements.

15. Monitoring should involve mapping changes in each heathland vegetation type, and measuring vegetation structure and monitoring key plant, invertebrate and vertebrate species. A list of examples of key species is given.

16. Aside from conservation aims, there are a number of practical issues that need to be addressed when considering the reintroduction of grazing to heathland. There is now a considerable body of experience which could be used to produce a guidance note.

17. Heathland grazing is inhibited by its lack of financial viability unless funding by the conservation sector can be sustained. Socio-economic research into re-establishing the links between agricultural exploitation and other uses of a “cultural” landscape may offer a way forward.

Contents

1. Background

Grazing by domestic livestock is a traditional use of European lowland heathland and there are extensive records of grazing of lowland heathland by sheep, cattle or ponies, both for the UK and other parts of Europe. However, during the 20th century there was a massive decline in the agricultural grazing of lowland heaths throughout Europe and many authors cite this as one of the major causes of the degradation and loss of biodiversity of European lowland heaths. In recent years, grazing has been reintroduced to many UK (and European) lowland heaths, in an attempt to provide appropriate, sustainable conservation management. A problem with this approach is that there is little scientific literature to guide such management in terms of appropriate animals, stocking rates, grazing season, and husbandry or how these factors affect the heathland ecosystem, particularly in terms of specific management objectives. There is much anecdotal and observational information from site managers and unpublished reports, but there is a need to collate these data, along with the scientific studies, to provide a clear statement of the extent and quality of our knowledge about the grazing of lowland heaths. This will allow recommendations as to appropriate grazing practices, identification of gaps in our knowledge and the setting of research priorities. This report aims to provide such a review, and has the following objectives.

OBJECTIVE 1: To review and synthesise information on lowland heathland grazing history, methods and impacts. Information will be obtained from published and unpublished literature, observation and anecdote from site managers, and ongoing research.

OBJECTIVE 2: To highlight gaps in our understanding of lowland heathland grazing and prioritise data requirements in terms of conservation needs.

OBJECTIVE 3: To identify appropriate research methodologies for studying lowland heathland grazing and recommend research protocols to fulfil data requirements.

2. Data sources

Data on the history, practice and impacts of livestock grazing of lowland heaths were obtained for this review from a variety of sources. Particular data sources were more appropriate for specific aspects of heathland grazing.

Data on the history, practice and impacts of livestock grazing of lowland heaths were obtained for this review from a variety of sources. Particular data sources were more appropriate for specific aspects of heathland grazing.

Scientific journals and books were used to provide high quality data in terms of objectivity and statistical rigour. However, there are few scientific studies of lowland heath grazing, so these data are limited. Further, the constraints of experimental design (e.g. replication meaning small plots) may limit the practical relevance of some studies. Studies of upland grazing are much more abundant and have been reviewed where relevant.

Ongoing research on lowland heathland grazing taking place in Britain and Europe. Contact was made with relevant researchers to ensure the information used was up-to-date.

Published and unpublished reports: Reports by the statutory agencies, Joint Nature Conservation Committee (JNCC), English Nature (EN), Scottish Natural Heritage (SNH) and Countryside Commission for Wales (CCW), and by other conservation bodies such as Royal Society for the Protection of Birds (RSPB) and the National Trust (NT) were obtained through interrogation of the bibliographic databases and by personal contacts. The Centre for Ecology and Hydrology (CEH) also holds a number of relevant published and unpublished studies. Other sources include the Proceedings of the European Heathland Workshops and the Heathlands Conferences. These reports contain a mixture of scientific research and observational data and are a rich source of information.

Historical documents and studies were accessed to a small degree to obtain information on past lowland heathland management. Use of this resource was limited because it is extremely time consuming and provides low returns. However, there is the potential for a very informative study of these records.

Observational and anecdotal information on aspects of lowland heathland grazing were obtained from site managers, older farmers, and researchers. These sources of data were exploited by selective interviews. Five sites from each heathland area (where possible) were selected on the basis of advise from local grazing project officers and English Nature staff. Results may not be entirely representative of all grazed heathland sites, since those recommended were generally either those with more well-established projects offering most information or those where grazing management was considered particularly successful. However, they represent a diversity of different heathland types and management practices. Where willing to participate, site contacts were asked a number of standardised questions about the site, management objectives, success in meeting these through grazing and other management techniques and details of the grazing regimes used. Responses have been incorporated into the relevant sections of this report. The sites reviewed are listed in Appendix 10.

3. Lowland heathlands of the UK

Lowland heathland is widespread throughout much of lowland UK. For example, 27 of England's 120 Natural Areas contain areas of heathland of national significance, with a further 14 containing areas of local significance. The 10 major grazed UK lowland heathland areas are listed in Table 1. The review (especially those parts dealing with herbivores, stocking rates and livestock behaviour) concentrated on information from these 10 major areas. However, these data were supplemented with information from other areas, where available. The reviews of grazing history, impacts and methodologies used data from all lowland heathland areas, because these data are few.

The term 'lowland heathland' is used here to include all habitat types associated with lowland heathland sites, and so includes dry and wet heather heath, grass heath, lichen heath, chalk heath, valley mire, gorse *Ulex* spp. and bracken-dominated heath, and associated areas of grassland, scrub and woodland (see Rose *et al*., 2000). 'Heath communities' refers specifically to heather dominated vegetation communities as described in the National Vegetation Classification (Rodwell, 1991).

Table 1 Natural Areas sensu English Nature and other areas with outstanding significance for lowland heathland, and therefore those targeted mostly in this review

Key issues largely extracted from Michael (1996)

Natural Area	Heaths	Area of lowland heath (ha)	Significance	Key lowland heathland NVC types	Key issues relating to grazing
46. Breckland	Breckland	581.7	Of outstanding importance for dry lowland heathland, which occurs in intimate mosaic with acidic and calcareous grassland.	H1	Maintaining or reinstating traditional heathland management especially sheep and rabbit grazing Re-creating heathland on farmland or forestry
49. Suffolk Coast & Heaths	Suffolk Sandlings	473.2	A key area for dry grassy lowland heathland.	H1, H8	Reintroducing traditional management to all sites
66. London Basin	Thames Basin heaths	3271.7	Includes important areas of dry and wet heath.	H1, H2, H3, M16	Reintroducing traditional management of lowland heathland, especially light grazing Achieving the erection of fencing on common land to enable the light grazing of heathland
70. Wealden Greensand	Surrey, Sussex & Hampshire greensand heaths	1878.2	Includes an important lowland heathland component	H2, M16	Reintroducing traditional heathland management Achieving the erection of fencing on common land to enable the light grazing of heathland
72. High Weald	Ashdown Forest	665.9	Includes largest expanse of heathland in SE England, dry and wet heathland communities	H2, M16	Reintroducing traditional heathland management.
77. New Forest	New Forest	7871.9	Of outstanding importance for lowland heathland, including dry, humid and wet heath, valley mire, acid and humid grassland and seasonal pools	H2, H3, M16	Maintaining the traditional heathland management system practiced by the commoners in the New Forest Restoring valley mire systems
81. Dorset Heaths	Purbeck and East Dorset heaths	4571.9	Of outstanding importance for lowland heathland and mires	H2, H3, H4, H8, H11, M16	Reintroducing traditional heathland management, particularly light grazing
90. Devon Redlands	East Devon pebblebed heaths	970	Very important for lowland heathland	H4, M16	Reintroducing traditional heathland management
95. Cornish Killas & Granites 96. West Penwith 97. The Lizard	Cornish heaths	1445.7	Contains significant areas of lowland heathland, particularly humid & coastal heath	H4, H6, H5, H8, M16	Reintroducing traditional management practises, particularly light grazing and burning
N/A	Pembrokeshire heaths	2500	Significant areas of dry wet heath and valley mire	H4, H7, H8, M16, M25	Reintroducing traditional management practises, particularly light grazing and burning.

4. Context and history

Grazing is increasingly being considered as a suitable management tool for maintaining and enhancing the favourable conservation status of lowland heathland in Britain (e.g. UK Steering Group, 1995; Michael, 1997). The rationale behind this has frequently been that grazing was a traditional management practice on lowland heathland. Comparison between the biodiversity of the New Forest, an area remarkable in having a continuous grazing history, and other un-grazed heathlands supported the view that grazing could provide an ecologically sustainable management tool for heathlands (e.g. Byfield & Pearman, 1995). However, little is known about traditional lowland heathland grazing practices in the UK. Available information is reviewed here, and supplemented with information from other European heathland systems.

Lowland heathlands are considered to have arisen about 4000 years ago as a result of forest clearance followed by use of the land for grazing stock, cutting fuel, burning, and harvesting vegetation for fodder (Webb, 1998). This use prevented the regeneration of heathland to forest (Gimingham, 1972). Before human activity, a thin forest cover on poor soils allowed a heathland ground flora to develop (Webb and Haskins, 1980; Tubbs, 1997), which may have been maintained under canopy gaps by large wild herbivores (Van Wieren, 1989). Heathland once extended over several million hectares in Western Europe and was maintained by traditional cultural practices until this century (Webb, 1998). These traditional forms of land use have been lost together with all but 350,000 ha of Atlantic heathland (Webb, 1998).

4.1 The role of grazing in traditional heathland management

Although little is known about traditional heathland management in the UK, more is known in continental Europe, and it is possible that heathland management may have been similar to that in Britain. Webb (1998) describes a range of traditional management practices that where responsible for the maintenance of open heathland until at least the 20th century. Management practices included grazing, burning, cutting vegetation, and cutting turf and peat. Many of these activities occurred in combination, and the relative importance varied from region to region. Livestock grazing played a fundamental role in transferring nutrients from the heath onto cultivated land. In typical heathland management from the north-western European heathlands of Flanders, the Netherlands and Germany sheep were herded on the heath for about six hours a day and confined to barns for the remainder of the time. Small irregular areas of heathland were burnt from time to time to provide a continuous supply of nutritious forage. In the winter, fodder for animals in the byre was supplemented with heather, which was cut on a 3-5 year cycle. Dried, crumbled peat and cut turves were used in byres to absorb excrement and were then spread on arable plots. In Denmark, a similar system was used, with sheep remaining out all year and cattle periodically tethered on the heaths and taken to their stalls for the collection of dung.

This system of land-use shows clearly the key role that heathlands played in the cultural landscape of Atlantic Europe (Diemont & Jansen, 1998). The landscape comprised areas of heathland linked by traditional farming practices to adjacent or nearby arable land and meadows. For example, settlements on the west coast of Norway comprised an infield area around the settlement used for pasture, haymeadows and arable plots, surrounded by extensive outfield areas of heathland (Webb, 1998). Heathland was used in conjunction with these other habitat types, and the farming system would not have been sustainable using only one element of the landscape.

In Britain, less is known as the traditional system has not been practised within living memory. Heathlands were frequently common land (Rackham, 1986), and played a similar role in the cultural landscape to that described above. It is known that heaths were grazed and burnt and turves and gorse *Ulex* spp. cut (e.g. Cunningham, 1974; Tubbs, 1986; Traynor, 1995; Allchin, 1997) and there is evidence in Dorset to suggest arable plots were fertilised with dung of animals grazed on the heaths (Webb, 1998). The type of livestock used tended to depend on locality. In East Anglia, where sheep were predominantly used, animals were grazed on the heaths during the day and folded onto arable land at night. Free-ranging cattle and ponies were traditionally used in areas such as the New Forest and Ashdown Forest, where pigs were also grazed. The New Forest in particular still retains its ancient practices and grazing rights (Tubbs, 1986). In such free-ranging grazing systems the social behaviour of the livestock is a key factor in determining the pattern and structure of the vegetation since the animals are not herded.

4.2 Decline of heathland grazing in Europe

Grazing management of heathlands declined throughout the 18th and 19th centuries as agricultural improvement changed traditional farming practices and heathland became increasingly redundant. For example, in the New Forest the number of cattle and ponies grazing in the late 19th century reduced from around 2200 and 3000 respectively to around 1000 and 750 in 1940, although it has subsequently risen (Tubbs, 1968). In the 1860s over 750,000 sheep were grazed on the Lüneburg heaths of Germany reducing to 250,000 by 1900 and 25,000 by 1950 (Henke, 1979). Similarly, on the heathlands of the Monts d'Arrée in Brittany, the extensive sheep grazing known to have occurred around 1900 had ceased entirely by the 1970's (Lefeuvre, 1980). Grazing on some of the Breckland heaths of East Anglia had ceased by 1956 (Sheail, 1971; Crompton & Sheail, 1975). In Pembrokeshire, the heathland commons had fallen into disuse by the 1960s (Evans, 1989). Agricultural intensification reduced the use of heaths for livestock grazing throughout the 1940s and 1950s and grazing of farm workhorses declined with the advent of the tractor in the 1940s. Use for grazing gypsy horse also declined through the 1940s and 1950s. Similar unquantified declines have been recorded from other heathlands across Europe (e.g. Ejlerson, 1992; de Beaulieu & Fichaut, 1992; Påhlsson & Danielsson, 1995; Rösberg, 1995).

However grazing is now increasingly being reintroduced to sites as a conservation management tool (WallisDeVries *et al*, 1998). A third of heathland National Nature Reserves were being conservation grazed by 1997 (Michael, 1997), and the numbers continue to rise. For example, in Dorset, where only two sites were still intermittently grazed before 1990, grazing now has been reinstated on at least 20 sites (Ian Alexander, pers. comm.). In general, grazing management is less intensive than previously - livestock remain on the heath throughout the night and are generally free-ranging, although in some cases confined (by temporary fencing rather than shepherding) to particular areas of heathland sites for more limited time periods. Grazing is generally used in conjunction with other management practices such as cutting and burning, and less frequently peat, turf or soil stripping. However, in many places heathlands no longer form an integral part of a functioning cultural landscape, and their management is generally detached from that of the surrounding land.

4.3 Historical stocking rates

Historical references to livestock numbers are few, and generally contain insufficient information to estimate stocking rate. Sheep densities on 930ha of heathland at Lakenheath Warren were nearly 2.3 ha^{-1} (Crompton & Sheail, 1975). On 660ha of unenclosed heath in the Suffolk Sandlings sheep densities were 1.3 ha^{-1} in 1770 (Chadwick, 1982). Stocking rates in the New Forest (including woodland) in the late 19th century averaged 0.11 cattle and 0.18 ponies ha^{-1}, although numbers have fluctuated widely (Tubbs, 1997). It is worth remembering that these stocking densities were aimed at maximising agricultural returns from the heaths, rather than meeting conservation objectives, and were influenced by market prices and the state of the pastoral economy (Tubbs, 1997). Agricultural returns were likely to have been different from those expected today - for example, wool was more important that meat in medieval sheep farming (Small, 1994), while an important role of sheep on the light East Anglian soils was manuring (e.g. Crompton & Sheail, 1975). These would have required less forage per capita than purely meat production would. Welfare concerns were probably also different.

The manorial system under which much of rural lowland Britain functioned from the medieval period until the 19th century meant that most heathlands were grazed in common by tenants of the manorial estates. The earliest historical sources are the Anglo-Saxon charters (7th - 11th centuries) - the legal means of land conveyance, which in some cases contain information on management practices (Rackham, 1986). The Domesday Book from the 11th century frequently records livestock numbers and types but categorises heathland under pasture, which is only recorded from the south west of England. Manor court books (generally held by County Records Offices) contain some references to grazing rights on common land heaths between the 10th and 18th centuries, and have the advantage that later books are written in English as opposed to Latin.

A preliminary investigation of the manorial court records for estates in Dorset revealed limited useful information. For example it is known that 'the usual cattle and horses' could be pastured on commons and heaths of a farm near Bere Regis (Cunningham, 1974), but the numbers of animals this entailed is not specified. There is some evidence to suppose that common grazing rights were not in fact static (Gasden, 1988), but may have changed between years. Where rights were quantified, the upper limit to commonable livestock numbers was generally that which each commoner could support throughout the winter off the common (those *couchant* and *levant* on the tenanted land). The numbers established by this method did not therefore provide an absolute right, and may have changed according to the amount of forage available and the commoners' circumstances. An example of grazing rights is given by Brocklehurst (1968) for Affpuddle in Dorset in 1573. Commoners were entitled to graze five sheep on the heath per acre of tenanted (i.e. non-heathland) land, and one cow or horse per two acres of tenanted land. A thorough search of manorial court books is likely to reveal more of such figures. These could be used to estimate historical stocking densities for heathland in individual manors where figures can be found for (a) the number and acreage of tenanted holdings with common rights and (b) the size of the commonable heathland at the time.

It is not known to what extent common rights of pasturage were taken up. Records of fines imposed for exceeding stocking rates in both Affpuddle and other parishes in Dorset indicate that rights were over rather that under-exploited in this area. Young (1771) comments that the 'Dorset wastelands were held in common and so suffered from overstocking and overgrazing'. Given the relative stability of the agricultural system from the 10th century until the agricultural revolution at the end of the 17th century, it may be assumed that heathland stocking rates must have been sustainable or this particular aspect of the agricultural system could not have persisted - there was no means of supplementary feeding from outside of the immediate agricultural unit and (at least in theory) the animals grazed on the heath were the same individuals as those supported by the tenanted land in winter. However, it seems possible that stocking rates on heaths increased throughout the late 18th and 19th centuries as the areas of commonable heathland diminished relative to the areas of tenanted land through enclosure. Gasden (1988) suggests that this may have led to overstocking on commons in general.

More recent sources of information on heathland grazing include various agricultural and land surveys and reports, e.g. Claridge (1793), Abraham & Driver (1794), and Tavener (1937). Few of these contain actual heathland stocking densities, although Tavener (1937) gives densities of 7-21 sheep and 2-6 cattle per 100 acres of *total* land area in parishes on the Bagshot sands of SE Dorset. These are predominantly heathy areas, but although Tavener estimates that 20% of the land area is permanent grassland he does not give a figure for the percentage comprising heathland. The Commons Registration Act (1965) produced a more recent source of information on stocking rates, as it required all common rights holders to register and quantify their grazing rights. However, Evans (1989) considers that, at least in Pembrokeshire, the figures in fact bear little relation to the actual rights practiced, which may also be the case elsewhere.

References to grazing season are more easily found than those for stocking density. For example, in Dorset sheep could be pastured on the Weld Estate heaths throughout the winter from St. Thomas' Day (December 21) until the middle of March[1]. Ponies remained on the New Forest heaths all year (Tubbs, 1991) as did farm workhorses (when not in use) on the Pembrokeshire heaths (Evans, 1989) while in Cornwall ponies grazing on Bodmin Moor during the summer may have been brought to the coastal heaths for the winter (Simon Ford, pers. comm.). However, there is insufficient information to establish whether the timing and duration of grazing seasons were relatively constant for similar heathland types or within particular areas.

4.4 Animal types

There is very limited information available about the types of animal used. It is known that sheep were generally grazed on the drier grassier heaths of East Anglia (e.g. Crompton & Sheail, 1975; Chadwick, 1982). Cattle, ponies and pigs were pastured on the New Forest (Tubbs, 1991), and cattle, sheep, goats, geese and horses were grazed on the Pembrokeshire

[1] DRO D10/181 Accounts of Court Barons in the estates of Thomas Weld 1783-1800

heaths (Evans, 1989). Gyspy horses apparently had a considerable impact on the Pembrokeshire commons until the early 20th century, together with goats and geese. In some areas changes in the type of livestock used may have occurred over long time scales - for example it is suggested that ponies were formerly important on coastal heaths in Cornwall (John Harvey, pers. comm.), although cattle were subsequently more common.

Prior to 1750 few farm livestock breeds were recognised, although there were regional types reflecting local needs and environmental influences (Small, 1994). Most breeds were created in the late 18th –19th centuries and subsequent use of these reflected changes in market demands. It seems likely that the hardy breeds most similar to the regionally adapted types were used on lowland heathlands. It is known that New Forest ponies were grazed in the New Forest, and in his literature Hardy refers to the 'heathcroppers' of Dorset. Chadwick (1982) refers to the Southdown and Norfolk sheep being used in the Suffolk Sandlings, and notes that they were simply called 'heath sheep'.

4.5 Shepherding

Traditional practises in Europe point to fairly intensive livestock management, with animals shepherded on the heaths, and often returned to the farms at night. It is probable that this also occurred in Britain. Evans (1989) notes that references to children shepherding stock across the unfenced Pembrokeshire commons were made in the late 16th and early 17th centuries. More recently, interviews with local farmers revealed that cattle and sheep were shepherded during the day and brought back to the farms at night. Chadwick (1982) reports that sheep were shepherded on the Suffolk Sandlings, being walked out each morning from the farms and returned at night to be folded onto arable or improved grassland. Recent research (N.Webb, unpub. data) suggests that similar patterns of use may have occurred in Dorset. Manor court books in heathland areas in Dorset frequently refer to the employment of a shepherd within the parish. A census carried out in the parish of Corfe, SE Dorset in 1795 lists four shepherds, who presumably worked on the adjacent heathland and downland (Legg, 1986). Legg also mentions records of labourers who kept single cows on the common (in this case acid grassland rather than heather heath) and brought them back to the village daily for milking.

4.6 Conclusions

a. Grazing was a fundamental part of traditional heathland use until its decline during the 20th century.

b. While little is known about how traditional management was practiced in Britain, it is likely that this was similar to systems in Europe. In these systems heathlands were an integral part of a larger cultural landscape and were managed in conjunction with arable land and improved pasture.

c. There is limited information about historic stocking rates and animal types used. While such information should not be used prescriptively in conservation management, further knowledge would increase understanding of how heathland communities were maintained in the past, some of which may be relevant to contemporary heathland management.

5. Livestock behaviour

Knowledge of the habitat and dietary preferences of livestock is vital for an understanding of the likely vegetation changes that will result from livestock presence on lowland heathland. Most studies of the ranging behaviour of both domestic and wild ungulates show a differential use of habitats types (Jarman & Sinclair, 1979; Duncan, 1983; Gordon, 1989). This is clearly illustrated in the New Forest, where free-ranging stock have been observed to spend 50% of their time on grassland habitats which comprise less than 5% of the total area (Pratt *et al.*, 1986). Herbivores are also selective in their choice of plant species. Together with habitat selectivity, this can lead to large spatial variation in the impacts of livestock on vegetation. This variation is a key consideration in the use of grazing to meet conservation management objectives on lowland heathland, since heathland sites generally contain a mosaic of different habitat types in addition to dwarf shrub communities. For example, the predominantly grassy heaths characteristic of the Brecks include both acid and chalk grassland, the New Forest includes areas of valley mire, woodland, streamside lawns, acid grassland and improved grassland, while the coastal heaths of Cornwall include maritime grassland (Farrell, 1993). Livestock selectivity will therefore influence which, and to what extent, particular vegetation communities present on a heathland site are affected.

With the notable exception of the New Forest (e.g. Pratt *et al.*, 1986; Tyler, 1972; Pollock, 1980; Putman *et al.*, 1987; Ekins, 1989), there is no published literature concerning habitat selection and use of lowland heathland habitats by livestock in Britain. Work from the New Forest is reviewed here, although it should be noted that the New Forest may be considered fairly atypical of lowland heathland sites due to its large size and continuous grazing history. There is, however, a substantial body of work from upland heathland on domestic livestock, which may give some indication of the likely behavioural patterns on lowland heathland (e.g. Gates, 1979; Gordon et al. 1985; Gordon, 1989b&c; Grant *et al.*, 1987; Duncan *et al.* 1994; Clarke *et al.*, 1995b; Grant *et al.*, 1996; Hester *et al.*, 1996; Hester & Baillie 1998; Hester, 1999). In addition, there are a number of studies of grazing on heathland and other semi-natural habitats from other countries (e.g. Duncan, 1983; Bakker *et al.*, 1983; van Wieren, 1991; WallisDeVries, 1991; Prins, 1992; Bokdam & WallisDeVries, 1992; Fedele *et al.*, 1993; Bartolome *et al.*, 1998), which provide a useful framework for considering heathland grazing in the UK. Literature concerning grazing by wild herbivores is not included within this review. Appendix 1 summarises the findings of relevant studies of both habitat and diet selection by livestock on heathland and related habitats.

The key to differential habitat selection lies in differences in herbivores' foraging strategies, which in turn reflect herbivore physiology and social behaviour. Environmental factors such as topography and climate (e.g. Rawes & Welch, 1964) and disturbance (e.g. Tyler, 1972; Duncan, 1983; Pratt *et al.*, 1986;) also play a role. Since foraging strategy is determined by the herbivores' need to meet nutritional requirements (Partridge, 1978), factors such as relative abundance and quality of plant material (e.g. Grant *et al.*, 1985) are clearly important in defining differential habitat use. Here we consider factors relating to the herbivore first (e.g. gut morphology, body size, behaviour), then move on to consider plant-based factors (e.g. variation in plant nutrients within and between species, the distribution of plants within the sward). The implications of livestock factors in the choice of appropriate livestock for conservation grazing on lowland heathland will be discussed in section 6.

5.1 Herbivore-based factors

5.1.1 Digestive morphology

Domestic herbivores include both hind-gut fermenters (equids) and ruminants (bovids). In general, hind-gut fermenters have a higher rate of nutrient extraction from forage (including low-quality forage such as that found on lowland heathland) than ruminants (Duncan et al, 1990). Non-ruminant hind-gut fermenters, such as ponies, are less efficient digesters than ruminants and have a faster throughput of food. However, as their intake is not limited by rumen capacity, they are able to realise a much larger quantity of forage, which more than compensates for their digestive inefficiency. Their fast throughput means they tend to spend more time grazing than ruminants. Comparative work in the New Forest suggests that ponies spend up 75% of their time grazing, while cattle graze for only 57% of the time (Pratt *et al.*, 1986). The digestive system of hind-gut digesters also suggests they are likely to be less selective, as they can make up for reduced quality by increasing quantity, provided this is not limited. Putman *et al.* (1987) show this to be the case in the New Forest, where ponies show weaker preferences for more habitat types than cattle. In addition, since hind-gut fermenters are more likely to be able to keep up their intake out of the growing season by consuming poor quality (including dead) material, they are less likely to experience winter nutrient stress. For example, van Wieren (1991) observed that Highland cattle lost a significantly greater proportion of their body weight over-wintering on a conservation area in the Netherlands than Shetland ponies. Such differential effects of a decline in winter forage quality are also illustrated in the New Forest, where the majority of cattle are taken off the Forest for the winter, whereas ponies are generally out-wintered (Ekins, 1989).

Hofmann (1989) categorised ruminants along a continuum from grazing animals limited to consuming graminoids and forbs at one extreme, to browsing animals which concentrate on lignified, woody vegetation at the other. Differentiation between browsers and grazers is based upon gut morphology and consequent digestive ability, which lead to differential diet selection. Grazers, such as cattle and sheep, retain forage within the rumen for a longer period than browsers, enabling breakdown and exploitation of plant cell wall contents so can cope with poor quality forage. Browsers such as roe deer have a short retention time and exploit rapidly digestible cell contents. This strategy requires forage with better quality cell contents, so browsers are likely to be more selective than grazers. Goats are intermediate, grazing some graminoids species but switching to browsing when these become too fibrous. The difference between browsers and grazers is seen reflected in habitat choice in a number of studies carried out on heathlands (e.g. Bullock, 1985; Bartolome *et al.*, 1998; Gordon, 1989) (see Appendix 1).

Recent studies have shown, however, that whilst fibre digestibility is superior in grazers compared to browsers, as predicted by Hofmann (1989), there are few other digestive differences between grazers and browsers. In fact, several key elements of foraging strategy are better explained by body mass (see below) than by Hofmann’s classification (Iason & van Wieren 1999).

5.1.2 Body size

Body size influences feeding strategy through its relationship with metabolic rate. Smaller animals have a greater metabolic rate per unit of body weight than larger ones, and so need relatively better quality forage to satisfy their metabolic requirements. Larger animals must intake a greater quantity of forage, but their relatively lower metabolic requirement plus the longer retention time of forage within the rumen means they can use forage of a lower quality (e.g. Jarman & Sinclair, 1979; Demment & Van Soest, 1985; Illius & Gordon, 1992). This was observed by Grant *et al.*, (1985) in the uplands, where cattle show a greater readiness to graze more fibrous elements of the sward than sheep. In addition, larger animals have a smaller incisor breadth (determining bite size and so food intake) in relation to their metabolic requirements (Illius & Gordon, 1987). These two factors mean that larger animals cannot tolerate the short swards that can support smaller species, and so may be excluded by grazing pressure from mutually preferred swards (Clutton-Brock & Harvey, 1983). This has been described from grazing areas including heathland on the Isle of Rhum (Gordon, 1989), where cattle are excluded by red deer from highly digestible species-rich grassland when the amount of available forage decreases in winter. The cattle are then forced to move onto less digestible oligotrophic grassland, where they can intake a greater amount of lesser quality forage. In turn, Osborne (1984) suggests that the presence of sheep on upland heathland in the west Highlands reduces the degree to which red deer use their more strongly preferred swards.

The effects of body size are also seen in the process of facilitation or “grazing succession” i.e. the sequential replacement of large grazers by smaller ones, (Clutton-Brock & Harvey, 1983). In this process, larger animals graze longer swards (e.g. Grant *et al.*, 1985), exposing smaller food items and stimulating dense short growth of plants, so creating sward conditions which cannot support them but to which smaller animals are better adapted (Illius & Gordon, 1987). No studies concerning facilitation in multi-species livestock grazing systems are known from heathland habitats. However, sheep are sometimes used on grass heaths in the Brecks and Sandlings to reduce sward height and so encourage the rabbit grazing considered necessary to produce the very tightly grazed sward desired.

The relationship between body size and metabolic requirements may also lead to sexual segregation and differential habitat choice in dimorphic species. This has been observed in goats Rhum (Gordon, 1989) and red deer in Scotland (Osborne, 1984), where larger males forage on more oligotrophic communities than smaller females when resources become scarcer in winter. This differences can be exploited for conservation grazing purposes, for example, differentiated flocks of wethers, first winter ewe lambs, or non-breeding ewes have been used in the Suffolk Sandlings according to the sward type (Steve Clarke, pers. comm.).

5.1.3 Incisor morphology

The effects of relative incisor breadth on habitat selection have been discussed above. However, other morphological aspects of the mouth also affect ungulate foraging. Non-ruminants such as ponies have powerful opposed incisors that can easily cut through fibrous stems (van Wieren, 1991). Ruminants lack upper incisors (the lower incisors closing obliquely against a hard palate) and tear vegetation rather than cut it. They also use the tongue to wrap around vegetation and pull. This difference allows non-ruminants to graze closer to the ground than ruminants. In addition, species with smaller muzzles are more likely to be able both to graze shorter swards and to select plants from within a mixed sward. For example, sheep and deer have been shown to graze closer to the substrate surface than cattle, which are less able to be selective while feeding from fine-scale mixtures (Grant *et al*. 1985; Grant *et al*., 1987). Sheep also appear to be able to increase their search effort for preferred species when forage is scarce by taking fewer bites per step (Laca & Soriguer, 1993).

Although recorded in the uplands, sexual segregation, facilitation and competitive exclusion have not as yet been recorded from lowland heathland sites. However, these processes may occur on sites of sufficient size, where a sufficient choice is available to herbivores. They are less likely to be observed on smaller sites where the choice and extent of habitat types is limited.

5.1.4 Seasonal variation in foraging behaviour

Seasonal variation in foraging behaviour and therefore habitat selection is likely to occur on lowland heathlands as resource availability changes. It may differ between livestock species due to the constraints imposed by body weight, digestive ability and muzzle morphology outlined above. When forage availability declines in preferred habitats larger ruminants and hind-gut fermenters, such as ponies, are more likely to move onto areas with a greater abundance of poorer quality forage, while smaller ruminants stay on what remains of the better quality forage (as seen on Rhum). In the New Forest, ponies show a significant shift from grasslands to gorse brake and woodland in the winter (Pratt *et al.*, 1986). However, this may be related to an increased requirement for shelter during winter. Cattle do not show a similar seasonal shift since supplementary feeding of those animals remaining in the Forest over winter strongly influences habitat choice, as they spend most time in the area where the feed is supplied (Ekins, 1989). Behavioural observations of cattle grazing the Dorset heaths between May and November suggests that seasonal variation may occur when supplementary feeding is not carried out (S. Lake, unpub. data). Duncan (1983) found that habitat selectivity by Camargue horses was greatest in the growing season. Gordon (1989) also noted seasonal trends on Rhum, where cattle, ponies, goats and red deer all show a greater degree of habitat selectivity in the summer and winter, broadening their habitat use in spring and autumn.

Seasonal changes also occur in the length of time spent grazing. New Forest ponies spend slightly more time feeding in winter to maintain their metabolic requirements (Pratt *et al.*, 1986). They may also reduce intake in the summer as they spend several hours in the middle of the day ‘shading’ rather than grazing (see below) (Tyler, 1972). In contrast, cattle are likely to reduce their metabolic requirements during winter, and consequently reduce forage intake (van Wieren, 1991).

5.1.5 Herding behaviour

Cattle show strong herding behaviour (Arnold & Dudzinski, 1978). In the New Forest, cattle form groups of at least 10 individuals and are therefore less widely dispersed over the forest than ponies, which form smaller groups. Vegetation types occurring in small patches (e.g. <10ha) such as roadside verges and streamside lawns tend to be avoided - possibly because they are too small to accommodate the whole herd (Putman *et al.*, 1987; Ekins, 1989). The size of both the herd and the grazing unit may affect dispersal patterns – small numbers of cattle on small (<10ha) heathland sites in the London Basin are considered to roam as widely as ponies (Rob McGibbon, pers. comm.). There are no data available on the relationship between herd and site size and dispersal patterns (but see Size of Grazing Unit below).

In general, ponies and sheep tend to be more widely dispersed than cattle. Although wild horse populations with natural sex ratios generally have a harem structure (Wells & von Goldschmidt-Rothchild, 1979; Gates, 1981), on many sites grazed for conservation stallions tend to be removed, and therefore this structure is infrequently found. For example, New Forest ponies tend to form small family groups or associations of two to three individuals (Tyler, 1972). This results in a much wider dispersion of ponies than would exist if large herds existed. Territorial behaviour is also generally absent, although groups tend to maintain home ranges and grazing pressure is greatest where these overlap. The sex ratio of sheep flocks is generally similarly altered. Sheep on upland heathlands form matrilineal groups that use particular parts of the home range in a regular daily fashion (known as hefting), and do not herd as a whole unit (Hunter & Milner, 1963). This means that sheep tend to be widely dispersed over the grazing area. Social behaviour in sheep has not been reported from heathland habitats in the lowlands. Hefting is generally associated with upland breeds, and is less likely to occur on smaller sites. Feral goats also form matrilineal groups, with male groups that often range separately (Bullock, in prep.). However, home ranges have clearly defined boundaries with little overlap.

In the New Forest, cattle were observed on purposeful 'route marches' between grazing and resting areas, sometimes moving several miles. Ponies in the New Forest were not observed to do this but rather drifted between habitats, often continuing to graze. This suggests that ponies will use a greater diversity of habitat types for grazing than cattle, which is in fact the case in the New Forest (Putman *et al.*, 1987). It also suggests cattle will create fewer, more intensely trampled paths, although this has not been studied. The behavioural difference is not apparent on the Dorset heaths, where both Exmoor and New Forest ponies also undertake such 'route marches' (S. Lake unpub. data). Again, it may be related to herd and site size.

5.1.6 Learning behaviour

There is evidence to suggest that diet selection is learnt from an animal's mother and the other animals with which a young animal associates, and that this is more important than breed effects (Key & McIver, 1980; Provenza & Balph, 1987, 1988; Dwyer & Lawrence, 1997). For example, Provenza & Balph (1988) have shown that the diet selected by fostered lambs relates to their foster dam rather than to their breed. Feeding preferences may also reflect regionally determined feeding experience handed down by mothering (Biquand & Biquand-Guyot, 1992; Provenza, 1994). This is seen in goats from different regions of Italy, which when grazing together select different species from the sward (Fedele *et al.*, 1993). To what extent the observed differences in diet selection that occur between livestock breeds (Mercer *et al.*, 1997; Bartolome *et al.*, 1998; Wright *et al.*, 2000) are in fact due to learning behaviour is unclear. Learning behaviour has not been studied on heathlands, although a number of grazing managers interviewed for this review considered that it might be important in determining site usage.

5.1.7 Inter-specific interactions

On lowland heathland sites with more than one species grazing, interspecific interactions may also have an effect on habitat selection. Once resources become depleted, only smaller animals are able to exploit them, and larger animals are forced to move to areas where forage is still easily available, although of lesser quality (as discussed under *Body Size*). Such indirect competition has been observed on Rhum between cattle and red deer (see above and Appendix 1). This process has also been observed in reverse (Clutton-Brock & Albon, 1992), where removal of sheep from upland heathland in Scotland has been followed by an increase in deer numbers. However, in manipulative experiments, the overall patterns of foraging behaviour by sheep and deer on upland heathland were found to be little affected by the presence or absence of the other species (Hester *et al.*1999).

Direct competition has rarely been reported between domestic livestock species grazing semi-natural communities. Ponies are considered dominant over cattle in the New Forest (Ekins, 1989), although the extent to which this may affect habitat choice by cattle is not clear. Exmoor ponies were observed to be dominant over both New Forest ponies and cattle on a heathland site in Dorset (S. Lake, unpub. data). This appears to be of limited importance in enclosed areas only, and again suggests that site size and structure will influence livestock behaviour.

5.1.8 Physiological status

The nutritional status of a herbivore is another factor which might be expected to influence its foraging decisions. Duncan *et al.* (1994) found that high protein dietary supplements did not affect the ability or readiness of sheep to selectively forage on fertilised heather swards but anecdotal evidence suggests that this may not always be the case. Some grazing managers interviewed for this review consider the use of supplementary protein blocks such as ‘Rumevite’ to successfully encourage a greater intake of fibrous forage (e.g. Harris & Jones, 1998, R. Ekins, pers. comm.) although no data are available for this. Previous diet has been shown to influence preference in sheep on improved swards (Parsons *et al.*, 1994), with an initial preference for the opposite species to the one they had been grazing followed by a return to the previous “familiar” species. How such a tendency might manifest in more complex vegetation is unclear. In the same study, lactating and non-lactating ewes showed the same preference behaviour despite major differences in energy requirement, although lactating ewes did have a higher intake rate. There is some evidence that other indicators of physiological state, particularly feeding motivation, immune status and parasite load, do influence foraging behaviour in sheep, cattle and ponies. For example, sheep have also been shown to avoid areas of the sward with faeces present, presumably due to the risk of parasitism. They will feed in these areas if their feeding motivation is high, but to a higher sward depth (Lozano, 1991; Hutchings *et al.*, 1998; Kyriazakis *et al.*, 1998; Hutchings *et al.*, 1999). In general, lack of data hinders any real understanding of how physiological status may affect grazing livestock behaviour on lowland heathland sites.

5.1.9 Dunging

Non-random dunging behaviour leads to nutrient transfer within and between vegetation communities. Work in the New Forest (Edwards & Hollis, 1982; Ekins, 1989) suggests that ponies segregate feeding and dunging areas on grassland communities. The ponies' reluctance to graze latrine areas leads to distinct areas of short and longer swards. This behaviour is well known from horses in captivity (Odberg & Francis-Smith, 1976), but has not been observed on extensive semi-natural habitat. Non-selective dunging has been observed from ponies in heath and mire communities in Dorset (S. Lake, unpub. data). Cattle are considered to dung at random (Marsh & Campling, 1970) although there is a tendency for aggregations of dung to occur in areas used for lying up and around gates. This occurs with both cattle and ponies on Dorset heathland sites where the same areas are used repeatedly for lying up following grazing bouts, and leads to nutrient transfer from grasslands to heath and woodland.

5.2 Plant-based factors

5.2.1 Plant quality: within and between species differences

Like other herbivores, domestic livestock are constrained in their dietary selection by the variables associated with their body size and behaviour discussed above. However a further factor driving diet selection is the variation in forage quality, both within a species (e.g. younger foliage is often more nutritious than older foliage) and between species (plant species differ markedly in their nutrient and secondary compound content). Some heathland plant species are well known to be relatively unpalatable; for example bracken has a variety of toxic constituents, whilst *Nardus stricta* is fibrous and has high levels of silica. In contrast other species, such as many grasses (e.g. *Agrostis* and *Deschampsia* species) are very attractive to large herbivores. Generally plants or plant parts that are low in nitrogen or other nutrients and high in lignin, fibre and secondary compounds will be relatively unattractive to herbivores because of their poor digestibility. Palatable species or plant parts have the opposite characteristics.

The majority of work on dietary selection by livestock concerns sheep in upland systems. Sheep have been shown to avoid *Nardus, Molinia* and *Juncus* spp. in favour of other grasses and *Calluna* (Welch, 1986; Hartley, 1997; Alonso *et al*., 2001). In addition to showing marked between-species preferences, sheep are also very adept at detecting small variations in plant quality within a species. For example, they will graze the new shoots on *Nardus* tussocks; these are higher in nitrogen and less tough than the older shoots. They have also been shown (Duncan *et al.*, 1994) to detect changes in the quality of *Calluna* produced by fertiliser, even though this experimental manipulation produced no visual cues (e.g. fertilised shoots were no longer, nor did they have more flowers). Cattle are believed to be rather less selective than sheep; for example, they will graze on *Nardus* and can decrease its cover (Welch, 1986).

5.2.2 Plant quantity: the relative abundance of plant material

Despite the selection behaviour described above, studies on a range of herbivores have shown that plant quantity may be more important that plant quality in diet selection.

Herbivores often prefer areas of highest biomass when they can maximise their intake rate. For example, Arnold (1987) found that sheep concentrated their grazing in patches of the highest yield; only once this was taken into account were effects of species palatability detected. Similarly, deer were found to select the trees they browsed purely on the basis of tree size (Hartley *et al.*, 1997). The chemical composition of the trees in terms of nitrogen and secondary compound content had no measurable effect on preference and the sole effect of fertiliser on preference was via the effects of nutrient addition on tree size.

5.2.3 Interaction between plant quality and quantity and livestock behaviour

Domestic herbivores need to acquire sufficient nutrients to survive whilst avoiding plant toxins and digestibility-reducing components but not taking so long over the feeding process that they fall victim to predation. Selective foraging to avoid the adverse effects of secondary compounds increases forage digestibility, but decreases intake rate because of the greater searching time required. Thus, herbivores can be considered as having a choice between poorer quality food that can be eaten quickly and better quality food that can only be eaten more slowly. Mathematical models (Belovsky, 1978) described the foraging behaviour of mammalian herbivores in the light of four of these sorts of feeding constraints:

1. digestive capacity and its fill by different food plants
2. daily foraging time and its utilization by the cropping of different food plants
3. daily energy requirements and the energy provided by different food plants
4. daily nutrient requirements and the nutrient content of different food plants

These models are known as "Optimal Foraging" models because they focus on maximising energy or nutrient intake per unit foraging time, so a key parameter of optimal foraging models is intake rate. The relationship between intake rate and forage availability is known as the functional response and was first derived as a model of predator-prey interactions (Holling, 1959). Many herbivores show type II functional responses, i.e. the rate at which consumption increases as food availability increases gradually declines until a plateau is reached. In uniform food-rich patches this response is due to the competition between cropping and chewing. In patchy environments, the costs of movement between patches are an important factor in foraging decisions and the time spent foraging in a patch increases with patch size. On smaller patches, animals take bigger bites to maintain intake (Spalinger & Hobbs, 1992). Initially, diet selection and foraging theory focussed on the physiological constraints on intake rates and largely ignored the effects of secondary compounds, but the chemical and physical defences of plants do modify foraging parameters. For example, fibrous forage is harder to chew, so fibre content affects intake rate. Foraging may reflect trade-offs between food quality/quantity and factors such as the risk of parasitic infection from faeces (see above). Predation (Fryxell, 1991) should not be ignored either when considering mammalian herbivore foraging behaviour. Foraging may reflect trade-offs between food quality/quantity and factors such as predator abundance, or the risk of parasitic infection from faeces (see above).

Little direct work has been carried out on the implications of optimal foraging by domestic livestock on semi-natural communities. However, given that the need to meet food requirements is a primary determinant of differential habitat use by herbivores, clear relationships between the amount and suitability of forage available in habitat and habitat use may be expected on a broad scale. Duncan (1983) shows such a relationship between habitat use and forage availability for horses in the Camargue, where habitats with abundant green (as opposed to dead) forage are preferred. In contrast, Putman & Pratt (1987) found no clear correlation between forage availability and habitat use in the New Forest. Any such link may have been obscured by other factors (discussed below). In the uplands, diet selection has been shown to remain constant despite decreasing forage availability: both sheep and deer have been found to maintain their preference for grass over heather despite a decreasing availability of grass (Hester *et al.* 1999). Behavioural adaptations to minimise predation risks have been explored in domestic livestock (e.g. Dumont & Boissy, 2000; Hansen *et al.*, 2001) but generally from the perspective of vigilance behaviour, which is of less relevance to heathland grazing than the effects such behaviour on habitat selection.

5.2.4 Plant distribution: spatial variation in vegetation

Many heathland sites support relatively fine-grained mosaics of different vegetation community types. This spatial distribution of vegetation has an influence on selection. For example, in the New Forest, cattle herds seem reluctant to graze areas less than 10 hectares and so may avoid suitable habitat when it occurs in areas smaller than this (Putman *et al.*, 1987). Again, most work in this area has been done in the uplands and has examined how sheep forage in grass heather mosaics (Clarke *et al.*, 1995 a and b; Hester *et al.*, 1998, Hester & Baillie 1998, Hester *et al.*, 1999). Since sheep prefer palatable grasses (e.g. *Agrostis* and *Festuca* spp.) over woody species such as heather, they are attracted by grass patches within the heathland canopy. Over-grazing can then lead to fragmentation of heather cover and an increase in grass patches of a variety of sizes, shapes and distributions. Sheep have been shown to prefer smaller grass patches (less than 6 m^2) and also to prefer grazing facing uphill, leading to differential utilisation of heather on uphill vs. downhill edges of the grass patch (Hester *et al.* 1999). In this study, utilisation of heather was far greater at the edge of grass patches than further away in the canopy, regardless of the size of the grass patches (Hester & Baillie, 1998). These results demonstrate the importance of understanding the role of vegetation pattern in herbivore behaviour if robust predictions of their impacts, and hence their management, are to be made.

The distribution of plant species within a particular vegetation community also interacts with foraging strategy. For example, Grant & Suckling (1985) observed that cattle grazed taller elements of blanket bog and heather moor swards than sheep, although this was of secondary importance in determining intake to selection in the horizontal plane. Selection in the horizontal plane was greater in sheep (as discussed above) due to their greater ability to select with fine-grain mixture. This suggests that selectivity by smaller animals will be greater than larger ones where the species in question is scattered throughout the sward rather than clumped. Bartolome *et al.* (1998) showed that goats selected higher components of the sward than sheep (Illius & Gordon, 1990), although this may be because goats preferentially selected woody species that were generally taller than the graminoids favoured by sheep.

5.3 Site-based factors

5.3.1 Shelter

The importance of shelter varies with species and with site characteristics including climate. Pratt *et al*. (1986) found that foraging defines habitat use by New Forest ponies during the day, while the need for shelter is more important at night. Grassland communities are used during daylight hours, and woodland and gorse brakes are used more frequently after dusk, although they still graze for up to 67% of the night. Cattle also move off grasslands at night, but tend to move onto dry heathland in clear conditions, only using woodland when visibility is reduced. They graze little at night. Few other studies included diurnal observations. New Forest ponies and cattle also show a clear selection for shelter in winter, increasing their use of gorse brake and woodland at the expense of grassland.

There are a number of examples of weather conditions influencing habitat selection. In the New Forest ponies, and to a lesser extent cattle, seek out shaded areas conferring protection from sun and flies during the middle of the day in summer, and have been observed travelling up to 4 miles to reach it (Tyler, 1972; Ekins, 1989). Shaded grasslands are used to a greater extent than more exposed ones during this time (Ekins, 1989). Sheep studied in the Basque region of Spain searched for shelter from the sun and rested for between 3 and 6.5 hours in the middle of the day during summer in N Spain (Marijuan-Angulo, 1996; Isabel Alonso pers. comm.). Goats require shelter in winter (Oates & Bullock, 1997), and make greater use of beaches for winter-feeding on Rhum due to the proximity of caves providing shelter (Gordon, 1989). Rawes & Welch (1964) showed that strong winds decreased the use of exposed Pennine slopes by sheep, and Oates *et al*., (1998) note that Welsh Mountain ponies and sheep caused localised vegetation damage by sheltering certain location in exposed weather on a Pembrokeshire coastal heathland. However, in contrast, shelter was not an important factor in habitat choice by Camargue horses (Duncan, 1983), although protection from flies and windy conditions was observed to have a minor affect on non-feeding activities.

5.3.2 Water

Availability of water is assumed to have an affect on habitat choice (e.g. Tyler, 1972). However this will only occur on lowland heathland where water availability is limited in the preferred grazing habitat. Water is generally readily available near most of the highly grazed areas of the New Forest, and habitat selection is attributed to forage rather than water availability (Ekins, 1989). On Dorset heaths, where water is often not available on the preferred grassland habitats, livestock move off at least once a day to a water source- generally valley mires or pools on wet heath (S. Lake, unpub. data).

5.3.3 Site characteristics

Other aspects of the geography of a site may affect livestock behaviour, notably the distribution of habitat patches. The juxtapositioning of preferred habitats with those less preferred may result in a greater use than expected of the latter. This occurs particularly where livestock have to cross the less preferred habitat to reach the preferred habitat. For example, Exmoor ponies on a Dorset heath have only ever been observed on a large valley mire system while travelling between two areas of grassland situated on either side of the mire (Geoff Hann, pers. comm.). This also suggests that if habitats are found in a number of small patches rather than fewer, bigger patchs, stock will move around the site more and encounter more habitat types. There is no published research on the influence of habitat distribution on livestock behaviour on lowland heathland.

5.4 Conclusions

a. Habitat use by domestic stock on heathland sites will be selective. Forage availability and quality are generally the most important factors in determining selective habitat use.

b. Forage availability on lowland heathlands varies seasonally - grazing season can therefore be manipulated to ensure stock have maximum impact on target communities and species.

c. Ruminants are more likely to select better quality forage than non-ruminants, who consume more per body weight and are more likely to eat dead material.

d. Browsing ruminants are more likely to consume woody material than grazers, whose digestive systems are not adapted to cope with it.

e. Smaller animals have a greater ability to preferentially select species from fine-grained mixture and can graze shorter swards. They may alter habitat selection by larger stock if resources become limited. Together with c and d above, this means that stock species and breed can be chosen for maximum impact on target communities and species.

f. Differential dunging behaviour between species may lead to differential nutrient and seed transfer between vegetation communities.

g. Wild herbivore presence may affect habitat use by domestic stock through indirect competition for resources.

h. Differences in foraging strategy occur both between and within breeds due in part to learning behaviour. This may be a complicating factor in selecting appropriate breeds.

i. Site geography, including location of water and shelter and the distribution pattern of habitats within the site can influence livestock behaviour.

6. Livestock suitability for conservation grazing on lowland heathland

The need to ensure that livestock of an appropriate type are used in nature conservation grazing is widely accepted (Oates & Tolhurst, 2000). Although there is a considerable amount of experience in using grazing management as a tool for nature conservation management (e.g. Small *et al.*, 1999), there has been little direct comparison of livestock types. The physiological and behavioural reasons for differences in grazing impacts between and within species have been described in the Livestock Behaviour section, and examples of research comparing species and showing species characteristics are summarised in Appendix 1. This section reviews how these differences affect the suitability of particular livestock types in achieving management objectives on lowland heathland sites. Little experimental research has been carried out in this area and observational information from grazing managers forms the bulk of what is known.

'Livestock type' is a term used to describe livestock species, breed, gender, age, background (including previous experience and learning) and husbandry, all of which are considered to affect suitability for use in grazing management (e.g Oates & Tolhurst, 2000). Selection of livestock type is evidently focussed on finding a type most likely to achieve the specific management aims of a site. However, welfare concerns demand that it should also result in a type that can maintain condition on the habitat in question. This is of particular importance where agricultural aims are integrated into conservation grazing projects. The components of livestock type are discussed in turn.

6.1 Species differences

There is a substantial amount of work on physiological and behavioural differences between livestock species (discussed in section 5 Livestock Behaviour). This section outlines how these differences determine the suitability of particular livestock species in achieving specific management objectives on lowland heathland sites.

6.1.1 Cattle

Cattle preferentially select grassy habitats within heathland sites, (e.g. Pratt *et. al* 1986) and in the summer are likely to concentrate on grassland and on wet heath supporting abundant purple moor-grass *Molinia caerulea*. Precise diet preferences are hard to determine from available information (e.g. Small *et al*, 1999), since the range of species available evidently influences diet selection. However, some generalisations are possible. Cattle are likely to be useful in reducing the amount of rank vegetation such as tussocky *Molinia* on a site. As large ruminants they are relatively unselective feeders, and are likely to take longer, coarser forage than smaller species. Dead material may make up a larger proportion of the diet that in other ruminants (e.g. Grant *et al*. 1987; Hearn, 1995). Although Putman *et al.* (1997) found that *Molinia* was not greatly used in the New Forest, other sources (e.g. Grant *et al.*, 1987 and observations from site managers interviewed for this review) suggest that *Molinia* is general readily eaten, particularly in early summer. Putnam *et al.* (1987) found that valley mire communities were used less than by ponies, and attributed this to the larger size and weight of cattle. The greater hoof pressure of cattle may create more poaching in wet areas than other stock.

Cattle only move onto dry heath when forage becomes limited on preferred grazing areas (e.g. Putnam *et al.* 1986, Gordon, 1989b), when moving between feeding sites, or when resting, particularly on areas adjacent to woodland or scrub shelter (S. Lake unpub. data). *Calluna* can form a significant part of the diet in winter (e.g. Putnam et al, 1987). *Erica* spp. are largely avoided (e.g. Grant *et al.*, 1976; Grant *et al.*, 1987). Cattle are less discriminate than sheep when grazing *Calluna*, and are more likely to cause damage through shoot death, uprooting and trampling. However, cattle grazing has less impact on regenerating heather than sheep, which tend to select the growing tips (van Wieren, 1989). Cattle grazing is not considered particularly suitable for *Calluna* dominated stands in the uplands (Welch, 1984), but can be effective in reducing invasive grasses, such as *Nardus stricta*, and encouraging *Calluna* regeneration. Cattle are not likely to play a major role in scrub management. They may break up scrub stands by trampling and pushing through them, and, although not predominantly browsers, they are nonetheless known to eat species including gorse (particularly dwarf gorse *Ulex minor*), birch *Betula* spp, willow *Salix* spp., pine *Pinus* sp. and aspen *Populus tremula* (Tubbs, 1991; Rob McGibbon, pers. comm.). Cattle have successfully killed birch on heathland by grazing regenerating shoots (R. McGibbon, pers. Comm.)

Cattle may under-utilise habitats which are too small for the whole herd (Putnam *et al*. 1987). However a herd may also break into smaller units as forage becomes limited, enabling utilisation of smaller areas (S. Lake, unpub. data). In general, when moving between feeding areas cattle will move together, often in single file, along paths (Ekins, 1989), but may disperse at the end of the summer when feeding on dry heath (S. Lake, unpub. data, Lesley Kerry pers. comm.). The location of water may have a key role in determining movements across a site, particularly if water is not available on preferred grassland communities.

Cattle are more likely to create a tussocky sward than other species (e.g. Treweek *et al*., 1997), although they can create an even short sward if grazing pressure is high e.g. (Harris & Jones, 1998). They are also likely to create more bare ground and larger degree of micro-topographical variation due to their greater weight, particularly in wet heathland habitats.

Cattle also have a more significant impact through dunging than other species. Dung is concentrated at habitual resting sites (Harris & Jones, 1998; Brian Wilson, pers. comm., S. Lake unpub. data) and due to differential habitat use for grazing and resting this may lead to nutrient transfer between mesotrophic grazing sites and more oligotrophic resting sites. Seed introduced through dunging may lead to vegetational compositional changes on dry heath Welch, (Welch, 1984; Dai, 2000) and these may be significant where dunging intensity is high (S. Lake unpub. data).

Oates (1994) considers that cattle may be superior to ponies in grazing lowland heathland. Cattle are currently the most frequently used livestock on lowland heathland - 47% of the 55 sites considered for this review were cattle grazed.

Most breeds of cattle have been developed to be reasonably tractable and do not become stressed when handled. They are more adapted to confined situations such as barns and being transported than ponies (Tolhurst, 1997). As a consequence they may be more suitable where regular handling and transportation are required. They are generally unaffected by dogs. Bulls, frisky young bullocks and cows with very young calves may be a problem on sites with visitor access.

6.1.2 Ponies

Although like cattle ponies will preferentially select grassland communities on heathland sites (Pratt *et al*., 1985; Gordon, 1989), they have been shown to have significantly different patterns of habitat use (e.g. Putnam *et al*., 1997). Ponies are more likely to venture further into valley mires than cattle (Pratt *et al* 1985; Ekins, 1989), and may have a greater impact than cattle on valley mire communities. As non-ruminants they have a greater throughput of forage than cattle, and are more likely to eat poor quality (e.g. dead) forage. Tubbs (1991) suggests that one pony may be the equivalent of at least two cattle in terms of forage intake. Unlike sheep, they are considered not to preferentially graze flower heads (Oates, 1994), and may be better in maintaining flower-rich swards. Observational information suggests that ponies can nevertheless be selective, particularly in the summer (R. McGibbon, pers comm.) In enclosed areas of grassland they are likely to produce a mosaic of long and short patches through avoidance of latrine areas.

When forage becomes limited in winter ponies will make extensive use of woodland and gorse brake if available (Gates, 1982; Pratt *et al*, 1985). However they may have less impact on dry heath communities, which they were found to use less than cattle in the New Forest (Pratt *et al*. 1985). Heather forms a limited component of their diet (< 4% in the New Forest, Putnam et al., 1987). Ponies are likely to play a limited role in managing scrub on heathlands, although Tubbs (1991) notes that ponies can kill gorse by grazing regeneration following burning, and they have been observed to kill coppiced *Betula* sp. by browsing the re-growth (Rob McGibbon, pers. comm.). Gorse *Ulex* spp. and holly *Ilex aquifolium* may be selected in winter (Putman *et al*., 1987), and Oates (1994) considers they may be particularly useful in hindering gorse from becoming over-dominant on maritime heath. Birch *Betula* sp., oak *Quercus* sp. and willow *Salix* sp. may also be eaten but pine *Pinus* spp. and *Rhododendron* are thought to be avoided (Oates, 1994). Ponies may however help open scrub by pushing through it (Bill Makin, pers. comm.). Ponies will graze bracken in late summer (Putman *et al*, 1987; Oates, 1994) when its toxicity declines (Evans, 1976) and may trample heavily through bracken swards helping reduce their density.

In the New Forest, ponies form widely dispersed small groups of two and threes (Tyler, 1972; Pollock, 1980). This suggests they will have a more evenly distributed impact over a site than cattle. However, data from Dorset suggests that this may not always be the case and that, depending on breed, season and husbandry, ponies may move around the heath in much larger groups. Although ponies do not require as much water as cattle, Oates (1994) suggests that the location of water can influence grazing behaviour on a site. This was not observed in the New Forest (Ekins, 1989), but may occur on the Dorset heaths (S. Lake, unpub. data).

Oates (1994) considers that there are many aspects of lowland heathland vegetation that ponies either do not adequately manage or tend to overgraze. However, ponies are likely to have a greater impact on valley mire communities and will have less impact on dry heath through grazing and trampling than cattle. They are frequently used on lowland heathland sites - 42% of sites considered in this review were pony grazed.

Ponies are more likely to revert to wild behaviour than cattle, and unless initially ‘broken’ and subsequently handled regularly, can become problematic to handle. However they are also most likely to be offered (often inappropriate) food by visitors and may learn to congregate in areas where there is greatest public presence such as car parks, picnic areas and roadsides. This is can lead to an increased risk of road casualties where roads are not fenced. In addition, ponies may bite or kick if the expected food is not forthcoming. Ponies are generally robust in the face of harassment by dogs, and may fend them off. The presence of stallions may be problematic in areas with regular horse-riders.

6.1.3 Sheep

Sheep have been shown preferentially select heathland habitat over grasslands in the winter (e.g. Bakker, 1983), although they prefer grasslands in the summer. Sheep are more selective grazers that cattle (e.g. Buttenschøn & Buttenschøn, 1982; Grant *et al.*, 1987) and have a more variable diet (Grant & Suckling, 1985). On grass communities within heathlands they tend to produce a short sward due to their ability to crop closely. Their light weight makes them less likely to damage lichen-rich swards than cattle and ponies. On dry heath they can damage *Calluna* by selectively grazing growing tips in autumn, but are less likely to damage mature and degenerate *Calluna* through trampling. The amount of *Calluna* eaten will vary according to what alternative sources of forage are available (Milne & Grant, 1987; Bartolome, 2000), but is likely to increase in the winter (Grant *et al.*, 1976; Bullock, 1985).

Sheep are predominantly grazers, and most breeds will not preferentially select scrub. However, Hebridean sheep are known to be an exception (Braithwaite, 1994; Wilkinson, 2000), and their browsing abilities have been effectively used on at least one lowland heathland site (Caroline Fitzgerald, pers. comm.)

Sheep herding behaviour in the uplands suggests they are more likely to be dispersed across a site than cattle, although they do maintain home ranges (Lawrence & Wood-Rush, 1988). However it is not known at what size of site and stocking density hefting may occur on lowland heathland. In addition, hefting is a learned behaviour that may take generations to fully develop – again it is not known how long it might take to establish a heft from scratch.

The relatively small size of sheep makes them easier to handle than cows and ponies. Most sheep breeds are relatively easy to manage with a sheepdog. Their size also makes them suitable for small sites that require short periods of grazing. Their water requirement is also much less than larger animals, which is an advantage where water supply is problematical (Tolhurst, 1997). However, they are often considered to be somewhat more disease prone than other livestock (e.g. Oates & Bullock, 1997). They are highly susceptible to harassment by dogs, and may be inappropriate in areas frequented by dog-walkers.

6.1.4 Goats

Goats are not commonly grazed on heathlands, and there is limited experience of their use. However, there is increasing interest in the use of goats for nature conservation grazing due to their ability to reduce scrub cover (e.g. Oates & Bullock, 1997), and this is reflected in heathland conservation - 13% of sites considered are currently goat grazed (although this may be a significant over-estimate of the total proportion of goat grazed sites in Britain). Goats are predominantly browsers, and will browse for up to 50% of their time, provided there is sufficient scrub, spending significantly more of their time in wooded areas than sheep (e.g. Bullock, 1985; Bartolome *et al.*, 1998). They will both ring bark and defoliate preferred species such as elder *Sambucus nigra* and ash *Fraxinus excelsior*, and avoid hawthorn *Crataegus monogyna* (Oliver *et al.* in prep). They will also eat bog myrtle *Myrica gale*, which is of potential benefit on sites where this species is avoided by other livestock (e.g. Bacon, 1998). However, diet preferences have not been researched on lowland heathlands in Britain, although they are considered to have reduced both blackthorn *Prunus spinosa* and birch

Betula pendula invasion on lowland heaths (Rob McGibbon, Simon Ford, pers. comm.). They also appear to show a distinct preference for Scot's pine *Pinus sylvestris* over ericaceous species on lowland heathland, and males will ring bark stems up to 15cm in diameter (Rob McGibbon, pers. comm.).

Goats have been shown to preferentially select heathland over grass rich areas (Smith & Bullock, 1993), although they will also graze grassy swards. They are unlikely to produce as short a sward as sheep (Milne, 1998). Goats have been shown to eat more *Molinia caerulea* than sheep in the uplands, and may be expected to have a greater effect on *Molinia* dominated communities on lowland heath. Although notorious in disliking wet conditions, they have been observed tussock-hopping in *Molinia* dominated swards, apparently keeping dry while grazing (Rob McGibbon, pers. comm.). The effects of goat grazing on dry lowland heath communities are not known. In the uplands they may eat more *Calluna* than sheep in winter (Bullock, 1985), and also eat gorse *Ulex* spp. On a heathland site in Spain they ate less *Calluna* than sheep, but this was balanced by an increased intake of *Erica arborea*, which does not occur on British heaths (Bartolome *et al.*, 2000).

In addition to controlling scrub, goats may have a unique role on maritime heath in deterring less sure-footed stock from attempting to graze on difficult terrain such as cliff ledges. By reducing the amount of available forage in these areas, goats make them less attractive to other stock. The consequent reduction in forage then makes these areas less attractive to other stock. Goats were traditionally used in this way in the uplands (David Bullock, pers. comm.) and are currently being successfully used in Cornwall for this purpose (Simon Ford, pers. comm.).

Goats are notoriously difficult to contain, although fencing can work if it is appropriate and there is sufficient suitable forage within the fenced area. The susceptibility to harassment by dogs is probably similar to that of sheep. Goats may be herded, but are less tractable than sheep.

6.1.5 Current use of different livestock species for lowland heathland grazing

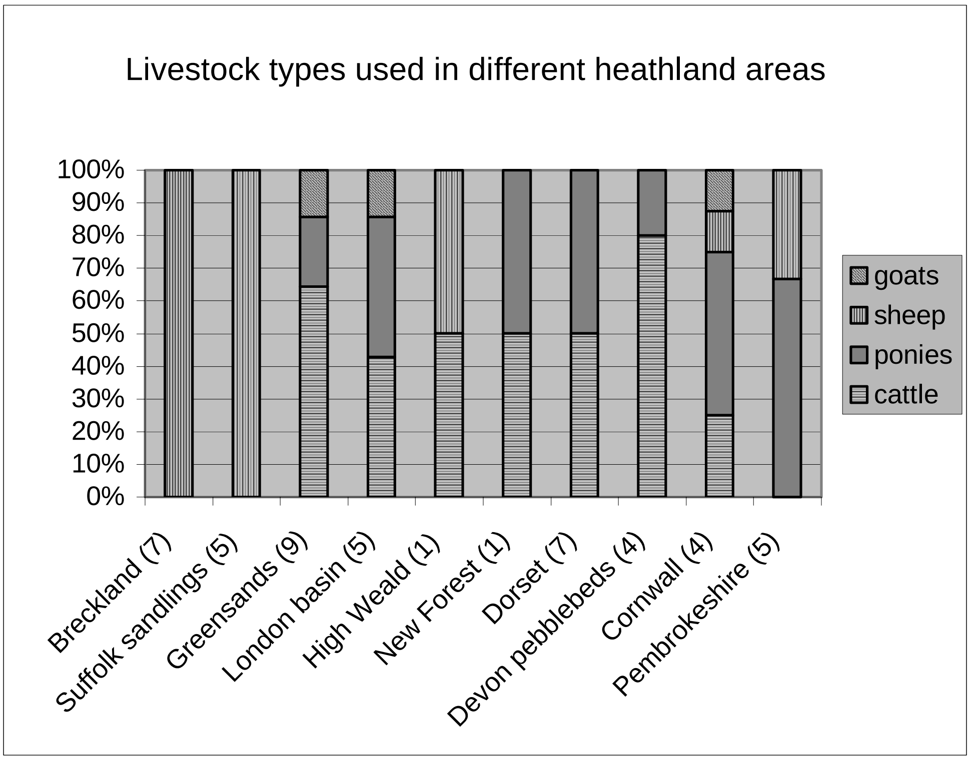

Figure 1 The proportion of sites within each area that are grazed by each livestock species

Numbers in brackets shows the number of sites sampled. Note that the New Forest and Ashdown Forest are considered as one site.

Figure 1 shows the proportion of sites within each heathland area that are grazed by each livestock species according to information given by site managers for the year 2000. Although these figures should not be taken as entirely representative since sites were not objectively chosen (see section 2 Data Sources), they give some indication of geographical variation in the use of different species. Note that both the New Forest and Ashdown Forest, although presented as heathland areas, are actually both considered as single sites. Where unreferenced, the information below is sourced from site managers. A list of the sites managers interviewed is included in Appendix 10.

The most striking feature of this distribution is the use of sheep in the Brecks and the Suffolk Sandlings. Sheep are traditional in both areas (e.g. Crompton & Sheail, 1975; Chadwick, 1982), and are considered most suitable for maintaining the dry short grass heath swards characteristic of these areas. Sheep are not generally used at all in the New Forest, London Basin, Dorset, and Devon and rarely in Cornwall. In the London Basin and Cornwall this due to problems with dogs harassment – both areas have high visitor pressures. The Devon and New Forest heaths are all common land and these grazing patterns may be a reflection of historical use. In both Devon and Dorset species have been selected for their ability to graze predominantly the wet heath communities, and so cattle and ponies are preferred.

Table 2 summarises the suitability for each of the above livestock species in achieving specific heathland management objectives. The objectives are those that were most commonly given by heathland sites managers when interviewed.

Table 2 Summary table of suitability of each livestock species for common lowland heathland management aims

	Improving structure in dwarf shrub dominated heath	Reducing grass dominance on dry heath	Reducing grass dominance on wet heath	Restoring and maintaining grass heath	Scrub management	Increasing bare ground and microtopographical variation
Cattle	Suitable in autumn when will graze dwarf shrubs. May cause trampling damage to old *Calluna* stands.	Only suitable during late summer/autumn when forage on other habitats is unavailable	Highly suitable for reducing *Molinia* dominance and breaking down tussock on damp-wet heath and mire edges	Preferential grazers, can produce short sward at high densities, although preferentially graze longer areas.	May browse some species including *Pinus* and *Betula* and open up scrub stands by trampling and pushing through them.	Highly suitable on both sandy and wet ground.
Ponies	Less likely to cause trampling damage but only graze dwarf shrubs to a limited degree.	Only likely to graze opportunistically in passing, but show greatest preference of grasses	Highly suitable for reducing *Molinia* dominance on damp-wet heath. Will graze well into mires.	Preferential grazers, can produce short sward. Likely to produce long/short mosaic due to avoidance of latrines	May browse some species including *Ulex* and *Betula* and open up scrub stands by trampling and pushing through them	May create bare ground around water sources etc, especially on wet ground, but not as effective as cattle
Sheep	Graze dwarf shrubs in autumn and winter but preferentially select growing tip therefore maybe unsuitable for managing regenerating heath.	Will preferentially graze grass on dry heath in summer, but may damage regenerating *Calluna* in autumn/winter	A selective species, preferring fine grasses, not particularly suitable for grazing wet heath/mire, although some hardy breeds may do well. Unlikely to graze far into mires.	High suitable for attaining short grassy sward. Light weight therefore less likely to damage lichen rich sward.	Limited suitability for grazing young *Betula* some hardy breeds highly suitable.	More limited contribution to bare ground creation (although some thermophilic species do require the small hoof-prints which sheep and goats produce).
Goats	Potential unknown, but preferentially select heathland communities over grassland. May reach inaccessible areas avoided by other stock	Potential unknown, but will probably preferentially select *Calluna* in winter. May reach inaccessible areas avoided by other stock	Predominantly browsers, but will graze *Molinia*. Unlikely to graze far into mires	Less suitable, although likely to have some impact.	Highly suitable, will ring bark and defoliate a number of species.	As for sheep, plus goats expose bare ground as a result of scrub browsing and demolition.

6.2 Breed differences

The relative suitability of different livestock breeds for achieving various conservation aims has frequently been discussed e.g. (WallisDeVries, 1993; Oates, 1994; Read, 1994; Alderson & Small, 1997; Mercer et al., 1997; Oates & Bullock, 1997; Read, 1997; Bullock & Oates, 1998; Bullock & Armstrong, 2000; Oates & Tolhurst, 2000). Modern livestock breeds, used on agriculturally improved swards, are often perceived to be unsuitable for nature conservation grazing in nutrient poor habitats such as heathlands (Bullock & Armstrong, 2000). For example, a recent comparison between commercial Hereford cross bullocks grazed on improved grassland and heathland in Dorset suggests that live-weight gains on heathland maybe up to 40% lower than on the improved sward (Karl Barton, pers. comm.). In contrast, hardy breeds generally evolved in specific locations and are considered to be well adapted to their environment (Alderson & Small, 1997). Grazing project managers have often sought out hardy breeds, some of which are also threatened or rare (Small et al., 1999), anticipating that these will both fare better on unimproved vegetation and have a greater impact on target species.

Research aimed at establishing whether behavioural differences between breeds are reflected in their impacts on semi-natural vegetation is scarce. Information regarding which breeds are best suited for particular vegetation types or management objectives are generally site specific and subjective. However, two available pieces of research suggest that breed may make a significant difference to the effects of livestock on vegetation, and that the differences in impact need not just be between hardy and improved breeds. Wright *et al.* (2000) found that the traditional Welsh Black breed of cattle was able to achieve a higher live-weight gain than a commercial continental breed on unimproved pasture. Newbourne *et al.* (1993) compared two hardy breeds and found that Hebridean sheep grazing upland moorland grazed significantly more purple moor-grass *Molinia caerulea* than Swaledale sheep. Although such information may be valuable, it is complicated by the interaction between breed, age, gender and background. This is discussed below. It is not clear whether differences in any of these factors may be stronger than differences in breed.

The Grazing Animals Project is publishing a handbook which will provide a guide to the selection of livestock breeds for grazing management of wildlife sites (including lowland heaths). This will provide profiles of cattle, equine and sheep breeds, detailing hardiness, physical attributes, husbandry, social behaviour, grazing preferences, suitability for use on sites with public access, and marketability. The information in the guide will be largely derived from the experience of grazing managers.

6.3 Other aspects of livestock type

6.3.1 Gender

Gender in dimorphic species affects the suitability of animals in achieving particular grazing objectives. As discussed previously, allometric rates of net energy gain mean that males may be more likely to graze nutrient poor swards than females. This may occur if forage becomes scarce on more nutritive swards (Gordon, 1989) or in bad weather if high quality forage habitats are more exposed (Conradt *et al.*, 2000). The difference is exploited in the uplands where wethers are used to graze relatively unpalatable matt grass *Nardus stricta* and heath rush *Juncus squarrosus*, promoting the growth of more a more palatable bent fescue *Agrostis-Festuca* sward (Bullock & Armstrong, 2000). This difference is not known to have been deliberately exploited for conservation purposes on lowland heathland.

Differences may also occur as a direct consequence of height variation between genders. For example, Pollock (1980) observed female New Forest ponies sifting litter in woods while taller males browsed holly *Ilex aquifolium*. Small *et al*. (1999) report differences in number of dietary preference between genders for sheep and cattle on several semi-natural habitats.

Other differences unrelated to body size will be found in all species and concern reproductive state. For example, the nutritive requirements of lactating females (discussed above under Livestock Behaviour), behavioural changes in mothers with young offspring, and changes in male behaviour around receptive females will all affect the relative grazing behaviour of livestock.

6.3.2 Age

Livestock characteristics related to age can also affect the relative suitability of animals in achieving lowland heathland management aims. Young animals have higher nutritional requirements than their mature counterparts, and may do less well on oligotrophic heathland habitats. Physiological changes throughout an animal's life will also affect its grazing impact, such as the development of a full set of teeth, or loss teeth in old age. Generally, older animals are more experienced at finding forage, but may be less willing to try novel species. Younger animals tend to be more adventurous, but are less likely to avoid toxic species (Provenza & Balph, 1987; 1988). A diverse age structure within herds is likely to improve habitat utilisation it increases the opportunity for younger stock to learn appropriate foraging behaviour from older stock (see below), while younger stock may be more flexible.

6.3.3 Origin

Differences occur between individuals of the same species, breed and gender that may attributable to past experience, learning and lineage, generally referred to collectively as origin. Tolhurst (1997) states that stock get better at utilising a habitat if given time to learn. This has been noted on a number of lowland heathland sites (e.g. de Beaulieu, 1998; Neil Gartshore, pers. comm.), where animals with previous experience of foraging on heathland habitats have appeared to do considerably better than those without. In addition, animals' experience of a particular site over several years may be important (A. Nicholson, pers. comm.). Although the importance of learning and genetic origin (discussed above under Livestock Behaviour) is acknowledged (e.g. Oates & Tolhurst, 2000), little work has been done in directly comparing the grazing impact between experienced and inexperienced stock of the same type. Lineage may also be important. For example, Gill (1987) suggests that certain 'bloodlines' of New Forest ponies survive best due to an ability to utilise a greater range of forage source, notably gorse. This may of course be due to learning - Biquand & Biquand-Guyot (1992), showed that effects on foraging strategy from prior experience can last for several years and may be passed on to offspring. However, while it is generally accepted that willingness to browse gorse varies between individual New Forest ponies (Rue Ekins, pers. comm.; S. Lake unpub. data), anecdotal evidence suggests this may not necessarily be passed on from mother to offspring, whether genetically or through learning

(Brian Wilson, pers comm.). Evidently more work is needed in determining the importance of origin in the suitability of livestock for nature conservation grazing.

6.3.4 Husbandry

Harris & Jones (1998) comment that only on light extensive grazing ranges will animals' preferences exert a strong impact on the vegetation - elsewhere it is the husbandry practices adopted by the grazier that are most influential in the development of the pattern and species composition of the vegetation. The importance of good husbandry is often overlooked in discussing the merits of various livestock types for conservation grazing. Good knowledge of vegetational changes in response to livestock grazing needs to be mirrored by equally good knowledge of livestock response to vegetation if conservation objectives are to be met. The importance of husbandry has not been studied. Ethics obviously prohibit experimental bad husbandry, but further knowledge of the ways in which good husbandry can influence the impacts of conservation grazing is needed.

6.4 Conclusions

a. There is a considerable amount of information available on the attributes of different livestock species. However, few comparative studies have been carried out on lowland heathland, and evidence for differences is generally site specific and often anecdotal.

b. Information of differences between livestock breeds is generally anecdotal and site specific. Very few comparative studies have been carried out and none on lowland heathland. Information of differences due to age and gender are less well understood.

c. The importance of differences between animals due to origin is generally acknowledged, but their implications are not well understood. Again, little work has been carried out in the context of lowland heathlands.

d. Although varying amounts are known about the different components of livestock type, little is known about the interaction between components, or how they may be influenced by husbandry. There is currently no consensus on the relative importance of different components in determining suitability for conservation grazing.

7. Stocking rates

A key aspect of the conservation grazing of lowland heathland is the density of animals used and the time period they are used for, i.e. the stocking rate. Work on grassland communities suggests that the choice of livestock species used has a minor effect compared to the stocking rate (Gibson, 1996), so it is clearly important to understand how to determine an appropriate rate to use in a given situation. The impact of stocking rate will, however, depend on the types of animal used, the timing of the grazing period, the habitat preferences of the livestock, and site characteristics including the state of the vegetation before grazing commences. Use of stocking rate to describe or prescribe livestock grazing should therefore be used with caution.

Although much work has been done in establishing appropriate stocking rates for heaths, most of this is aimed at agricultural grazing on upland heath. In addition the duration of grazing is defined in very general terms (e.g. winter/summer), and stocking density rather than rate is concentrated on. Grazing pressures of 2.7 sheep ha^{-1} or 0.23 cattle ha^{-1} (Grant & Hamilton, 1981; Welch, 1984) are considered to be the limit above which *Calluna* heath will change to grassland communities. Current agri-environment schemes (e.g. Environmentally Sensitive Area) aimed at maintaining a healthy heathland sward recommend densities between 0.7 and 1.3 ewes ha^{-1} in summer and <0.5 – 0.7 ewes ha^{-1} in winter. Countryside Stewardship schemes (MAFF, 1998) aimed at regenerating suppressed heather moor with < 25% dwarf shrub cover use densities of <0.1 LU ha^{-1} (<0.66 ewes ha^{-1}) in summer and none in winter for the first five years, and 0.15 LU ha^{-1} (= 1 ewe ha^{-1}) in the summer plus 0.07 LU ha^{-1} (= 0.47 ewes ha^{-1}) in the winter for the next five years.

These stocking rates are largely aimed at ameliorating the effects of over stocking. Very little research has been carried out to establish appropriate stocking density and duration when grazing lowland heaths for conservation. For example 'light' summer grazing is recommended for lowland heathland under Countryside Stewardship, but this is not further defined. In general, stocking densities used in conservation management are much lower than the agricultural equivalents (Bullock & Marriott, 2000). However, the range of stocking densities currently used in lowland heathland sites is greater than that recommended in the uplands. The stocking rates used on lowland heathland sites considered for this review range between 0.03 and 0.50 LU ha^{-1} yr^{-1}, with a mean of 0.19 LU ha^{-1} yr^{-1} (st.dev = 0.18) (the equivalent of 1.25 ewes $ha^{-1}yr^{-1}$). Bacon (1998) described grazing practices from 14 lowland heaths in England. Densities ranged from 0.12 - 2.19 LU ha^{-1}, stocking rates from 0.07 - 0.40 LU ha^{-1} yr^{-1}. Stocking rate varies less than density, suggesting overall livestock pressure is more even between sites than at first appears to be the case.

Interactions between stocking rate, stock type, heath vegetation, season, site characteristics and husbandry are discussed below.

7.1 Stock type

Livestock units are often given rather than species densities in an attempt to take account of the species of livestock used. Although useful if applying general stocking rates, these are of limited value in other respects. Firstly, equivalences are not always considered to be the same. For example, ponies may be equated with one livestock unit or up to 2.5 (e.g. Tubbs, 1997). Secondly, grazing impact will vary according to livestock breed and type as well as species. Use of livestock units can mask these differences. Livestock units per hectare per year are often used to express stocking rate, where LU ha^{-1} yr^{-1} = (no. of livestock x livestock unit equivalence x proportion of year grazed) / grazing unit area.

Table 3 Livestock unit equivalences based on MAFF (1998) and Tubbs (1991)

Animal	Livestock unit (LU)
Dairy cow	1.0
Beef cow (excluding calf)	1.0
Cattle over 2 years old	1.0
Cattle 6 months - 2 years	0.6
Lowland ewe and lamb	0.15
Hill ewe	0.10
Ram and tegs over 6 months	0.15
Pony/horse	1-2
Goat	0.1

7.2 Stocking rate and season

As discussed above, the impact of livestock grazing is partially determined by the interaction between stocking density and the length of time for which grazing is carried out (i.e. stocking rate) and the season within which it occurs. No literature directly examining the consequences of this interaction on lowland heathland has been found, although its relevance is illustrated in the diversity of grazing practices carried out. For example, some grazing projects use episodic grazing schemes to achieve precise conservation goals, usually the removal of vegetation growth to control a species when it is most vulnerable (Steve Clarke, pers. comm.), or when desired species have flowered and set seed (e.g. Harris & Jones, 1998). Others use year-round grazing to achieve a wider diversity of goals.

The effects of a given stocking rate will vary in different seasons depending on the amount and palatability of vegetation. For example, sheep use of *Calluna* is greatest in autumn (Clarke & Welch, 1995), so grazing at the same stocking density at this time of year will have a greater impact on dry heath communities than in the summer. On the southern English heaths cattle and pony grazing is greatest on wet heath and mire communities in late summer (Pratt, 1985; S. Lake unpub. data) and will have a greatest impact for a given density at this time. Goats and Hebridean sheep selectively graze birch foliage in April, so higher stocking rates later in the season may have less effect on this species. Maritime heath is grazed in the winter, to remove growth from the previous season after key species have flowered and set seed (e.g. Harris & Jones, 1989b). These patterns were illustrated in the survey of grazing regimes - the majority of sites were summer grazed only, but a number of the largest sites were grazed all year, and three, all maritime heathland, were winter grazed.

7.3 Stocking rates for different heathland types

Lake & Day (1998) noted a significant positive correlation between increasing grazing density and the proportion of grass and mire habitats present on lowland heathland sites. A negative correlation was found between increasing density and cover of dry heather heath. Clearly grazing pressure varies according to the amount of each vegetation type present on site. This is to be expected, since different vegetation types will offer different amounts of forage, more oligotrophic communities providing the least, therefore needing least grazing pressure to maintain them. However, it should be noted that management aims also vary between regions. For example, the aim of 'maintaining short sward' might encompass heavy grazing pressure to maintain the very short sward suitable for breeding stone curlew in the Brecks or lighter pressure to maintain species diversity in maritime heath on the Lizard.

It was possible to gain accurate stocking rates from 24 of the 40 lowland heathland sites considered in this review. A particularly wide variation in the data due to the pronounced differences in site characteristics makes detailed analysis of stocking rate and heathland vegetation communities inappropriate.

7.4 Management aims

Different conservation management aims require different stocking densities. For example, higher densities will be needed to restore a *Molinia* dominated wet heath than to maintain it, as there is more biomass to remove during the restoration phase. Livestock may be encouraged to consume unpalatable species or more fibrous grasses or dead material by stocking at a higher density. Serious welfare issues must be addressed when forcing stock to use less nutritious forage by limiting resources if animals suffer a serious loss of condition as a consequence.

Table 4 Examples of livestock densities used for specific conservation aims and the results achieved

Stocking density (ha^{-1})	Season	Stocking rate (LU days ha^{-1} yr^{-1})	Aim	Result	Source
Dry Heath					
3 sheep	June-Sept	0.15	Experimental assessment of impact on *Calluna*	*Calluna* growth suppressed	Hewson (1977) in McGrath *et al*, 1994
2 sheep	June-Sept	0.10		*Calluna* growth stimulated	
3 sheep	All year	0.45	Rejuvenating heathland vegetation	Calluna sward became grassier, increase in young seedlings & tillers, Structural & species diversity increased	Bakker *et al*., (1983)
Wet heath/bog					
<0.63 sheep	Summer	0.05	Experimental assessment of impact on *Calluna* in upland bog	*Calluna* retained on bog	Welsh & Rawes (1966)
0.11 cattle	Summer	0.05	Improve vegetation structure, control *Molinia*	Species diversity and bare ground increased, height decreased	Cox (1998)
0.05 ponies	All year	0.05			
Total		0.1			
Scrub					
2 sheep	Summer	0.13	Reduce scrub	Birch (*Betula*) scrub eradicated.	(Braithwaite, 1997)
5 goats	Winter	0.38	Reduce scrub encroachment (on chalk grassland)	Major but variable impact (not heathland)	(Oliver, in prep.)

Table 4 gives some examples of stocking rates used to achieve particular aims and the recorded results. These are not presented as the most appropriate stocking rates for particular objectives, merely as examples of what has been achieved. Bacon (1998) lists management objectives and a subjective satisfaction rating for an additional 14 sites. Variation in stocking rate reflects that found from site manager interviews. No clear relationships between stocking rate and particular conservation objectives were found in grazing schemes considered for this review. However, this may be due to the small size of the sample size given the diversity encountered. In addition, many grazing projects are not currently achieving their preferred grazing regimes due to problems such as difficulty in obtaining appropriate stock.

7.5 Site characteristics

The size of a heathland site and the habitat patches within it can also influence the stocking rate appropriate for particular management objectives (see Livestock Behaviour section). On predominantly nutrient-poor vegetation types such as heathland, larger sites may support a higher density of animals than smaller sites if they include a greater diversity of habitat types. Bokdam & WallisDeVries (1992) showed that access to a range of vegetation types of different fertilities would provide forage of sufficient quality throughout the year and thus should improve performance of cattle. On nutrient poor lowland heathland sites, the presence of more fertile habitats will increase the stocking capacity. This is evident from the structure of cultural landscapes where more fertile habitats such as meadow or pasture were used in conjunction with heathland. However, these considerations were not supported by data from the sites considered in this review or by Bacon (1998), whereby there was no significant relationship between stocking rates and grazing unit area or other habitats present (but see constraints above).

The spatial distribution and relative size of habitat patches may also affect the grazing intensity exerted on particular habitat types. Even if stocking rates are the same in two sites, one small and the other large, the variation in grazing intensity may be greater across the larger site. This is because herding behaviour may mean the greater number of animals in the larger site is not necessarily reflected in a greater dispersion of animals across the site (provided forage does not become limiting). Thus, at the larger site, grazing pressure will be higher on those areas of habitat frequented by the herd (which has more animals than that at he smaller site). Likewise, the greater area available to the herd at the larger site will mean that it is more likely that some vegetation patches will be grazed rarely or not at all. This scenario is obviously dependent on a number of factors including optimum herd size, the distribution and size of habitat patches across a site and whether forage becomes limited at particular habitat patches.

7.6 Husbandry

Stock control (i.e. shepherding) is one form of husbandry that can have a major effect on the impact of a given livestock density. This has been studied in the uplands (e.g. Anderson & Radford, 1994) and has two main effects. Firstly, it keeps free ranging livestock within their ‘heft’, so preventing a reduction in grazing pressure by animals straying. Secondly, in moving stock around a site, grazing pressure on particular areas can be manipulated. This practice is now uncommon, and no longer occurs on a daily basis in the UK. However sheep are still moved between hefts in the uplands where active shepherding (6-22 gathers a year) was shown to reduce grazing intensity from 2.5 ewes ha $^{-1}$ to 0.18-0.43 ewes ha $^{-1}$ on preferred areas, promoting vegetation growth on previously bare and eroded ground. Shepherding in the uplands is likely to be directed towards equalising grazing pressure over a site. However the process can be used on lowland heathland to promote differential grazing if required and is currently used on some continental heaths (Kottmann et al., 1985). It can also be used to prevent stock congregating around supplementary feeding areas for several hours before and after feeding which results in localised damage.

7.7 Interactions with other species

Appropriate stocking level on a site will also depend on the presence of wild herbivores. For example, rabbit grazing is widespread on the Breck heaths, and livestock levels are manipulated to accommodate fluctuations in rabbit grazing pressure (Sibbet & Lacey, 2000). Other wild herbivores likely to affect the livestock densities used on heathland are deer - interactions between sheep and deer in the uplands have been well studied (e.g. Clarke *et al* 1995 a, b). Although work in the New Forest (Putnam, 1986) suggests deer have a limited impact on heathland communities due to preferential selection of woodland habitat, sika deer on heathland in Dorset have a substantial effect both on wet heath communities (S. Lake unpub. data) and in suppressing birch *Betula* sp. regeneration on dry heath (P. Manning, unpub. data). The relationship between domestic and wild herbivores and their relative impacts on lowland heathland vegetation require further investigation.

7.8 The use of prescriptive stocking rates

The concept of stocking rate is helpful in allowing a broad comparison of the impact of different types of livestock. However, the use of stocking rates as guidance in lowland heathland grazing is of limited value, since the impact of a given stocking rate varies widely according to the aims of the grazing project, the stock type and the vegetation. On grasslands the amount of herbage will vary twofold between sites according to soil type and depth, nutrient status, humidity, altitude, aspect and exposure. Variations in weather, particularly rainfall, may add another twofold variation (Hopkins *et al.* cit. Peel & Jefferson, 2000). Such variation is likely to occur within heathland communities, although the extent has not been quantified. It is reflected in stocking densities, which may vary up to 30% between years (Roy Harris, pers. comm.). Three of the 33 site managers interviewed for this review preferred not to give stocking rates on the grounds that it was misleading, and several more felt it was not useful information.

7.9 Conclusions

a. Stocking rate is important in determining the impact of livestock on heathland vegetation. However the impact of a given density may vary between both sites and years.

b. Current stocking rates used for conservation grazing on lowland heathland sites vary between 0.03 and 0.50 LU ha^{-1} yr^{-1}

c. Stocking rate may be useful for broad comparisons of livestock impact. However its use in predicting vegetation change is limited. Utilisation rate, as used in studies in the uplands, may be more useful.

8. Impacts of grazing on lowland heathlands

Grazing has a diversity of effects on the biota of heathlands and other systems. Livestock may affect a species directly, e.g. by eating it or trampling on it, but many impacts are indirect, leading on from habitat changes caused by grazing. These indirect impacts are multifarious and the responses of species to grazing may be best understood by considering the direct impacts on either species or their habitats. This provides a structure to which the effects of grazing on both communities and individual species can be related. Therefore, below we classify these direct effects, known through ecological theory and empirical studies, review our knowledge of how and why grazing affects biotic communities and then consider the evidence for impacts on heathland communities and on particular plants, invertebrates and vertebrates. In these latter sections we consider Biodiversity Action Plan (BAP) and other key (e.g. Red Data Book, RDB) plant and invertebrate species and the rarer vertebrates of lowland heathland.

8.1 Direct impacts of livestock

Good general reviews of direct and concomitant indirect effects of grazing can be found in Crawley (1983), Hodgson & Illius (1996), Crawley (1997), Olff & Ritchie (1998) and Bullock *et al.* (2001). Much of the following is drawn from these, and additional references are given where appropriate.

8.1.1 Feeding

Livestock remove and eat leaves, stems, flowers and other plant parts. This can lead to injury or death of the plant, but also more subtle effects such as a changed plant structure, reduced height, loss of photosynthetic area, changed plant chemistry, changed growth patterns (including that of roots or of allocation to vegetative *vs* reproductive growth), changed phenology, or increased susceptibility to disease or invertebrate herbivory (by weakening of plant defences). By removing biomass (and redistributing it partly elsewhere in dung and urine) feeding may also lead to a net loss of particular nutrients from the system.

8.1.2 Trampling

As with feeding, trampling by livestock causes damage to and loss of plant parts, with the same potential direct and indirect effects as listed above. However the effects on and responses by individual plant species will differ, for example, *Calluna* may be more damaged by trampling than *Molinia caerulea*. Trampling (and poaching) may occur in different heath areas to those where feeding is concentrated (see the discussion of ranging behaviour). Whereas feeding results in removal of most organic matter, trampling also returns litter and dead material to the soil surface increasing litter depth, soil organic matter and nutrient status and the rate of nutrient cycling. Animals may also be trampled directly, especially sedentary or slow-moving species or during sedentary life-stages (e.g. eggs). An associated impact may be the disturbance of, e.g. nesting birds (e.g. Popotnik & Guiliano, 2000).

8.1.3 Poaching

Movement of livestock may disturb the soil surface, break up and destabilise soil structure, integrate litter into the soil, change soil microtopography (e.g. creating small depressions), and compress the underlying soil. Changes in decomposition rates, incorporation of organic matter and therefore, nutrient cycling will result.

8.1.4 Dung and urine deposition

Livestock return some of the plant material they ingest in the form of dung and urine. This results in the redistribution of nutrients and organic matter gathered over wide areas into small discrete patches. Urine deposition is analogous to addition of inorganic nitrogen fertiliser and can stimulate plant growth (Jaramillo & Detling, 1992). This can increase plant nitrogen concentrations, leading to increased utilisation by livestock (e.g. Day & Detling, 1990). The acidity of urine can also damage plants (Steinauer & Collins, 1995), but dung is more damaging initially as it smothers plants, leading to death in some cases. Dung also contains toxins which can damage and kill plants (Malo & Suarez, 1995). However, dung has high phosphorus and nitrogen concentrations which can stimulate plant growth as it breaks down. Thus both dung and urine can open gaps in the vegetation with increased soil fertility. Furthermore, dung is an important food source for many invertebrates.

8.1.5 Dispersal

Livestock can move plant seeds and other propagules (e.g. rhizome fragments) on their coats and hooves (Fischer *et al.*, 1996). Dung can also contain seeds which have been eaten and passed through the gut (Welch *et al.*, 1990); thus seeds are deposited in a nutrient-rich, competitor-free substrate. In both cases, livestock can transport seeds distances and into areas not attainable by other dispersal modes. Other organisms may also be dispersed by livestock. Obviously diseases and parasites may be transported, but little is known of the potential for livestock to disperse small invertebrates.

8.1.6 Erosion

Loss of vegetation and poaching by heavy grazing may lead to erosion. Thus, the absence of vegetation and root systems to protect and stabilise the soil and the disruption of the soil surface allow wind and water to wash soil away. This can lead to further erosion as the less stable mineral soil layers are exposed. This is a consequence of over-grazing in British upland systems and of serious concern (Bardgett *et al*., 1995; Thompson *et al*., 1995). The potential for similar problems in lowland heathlands is illustrated by erosion caused by human trampling at tourist sites (Harrison, 1981; Toullec *et al*., 1999).

8.1.7 Associated activities

In implementing heathland grazing, many associated activities occur which may have unintentional or even undesirable effects on the heathland biota.

Increased human activity may cause trampling of vegetation, disturbance of animals and even transport of seed and other organisms.

Fencing may restrict movement of larger vertebrates.

Supplementary feeding with mineral licks and roughage licks may concentrate feeding, trampling, poaching, dunging and urination in small areas around the licks. Furthermore, the licks themselves may provide inputs of nutrients and other chemicals into the surrounding soil.

Water troughs may similarly concentrate livestock activity and, through leaks, increase wetness of the surrounding area.

8.2 Impacts on plants

8.2.1 General effects of grazing

By affecting individual plants directly and changing vegetation structure and aspects of the abiotic environment (e.g. soil nutrients), grazing livestock change plant populations and communities. Ecological studies have isolated four mechanisms by which grazing causes changes in species composition (Briske, 1996; Augustine & McNaughton, 1998; Olff & Ritchie, 1998; Landsberg *et al.*, 1999; Bullock & Marriott, 2000; Sternberg *et al.*, 2000; Bullock *et al.*, 2001). These are:

Feeding preferences due to biochemical (e.g. secondary metabolites or high fibre content) and/or morphological (e.g. a rosette growth form or spines), deterrents, which lead to certain species being subjected to greater feeding damage than others.

Tolerance such that species which are able to survive and regrow (and regrow faster than other species) after feeding or trampling damage dominate the grazed community.

Gap colonisation whereby the gaps caused by feeding, trampling, dung or urine present opportunities for regeneration by seed or clonal growth. Differential gap colonisation abilities lead to changes in the community composition.

Changed species dispersal and colonisation patterns caused by differential dispersal by livestock. This may include dispersal of species from outside the community.

One virtually ubiquitous aspect of grazing is that it leads to an increased plant diversity (species richness and evenness) compared to no grazing (Hill *et al.*, 1992; Bullock & Pakeman, 1997; Humphrey & Patterson, 2000). A range of factors may lead to this pattern (see Bullock, 1996; Olff & Ritchie, 1998).

Reduced competition as the tall, dominant species are grazed down, thus releasing resources, especially light, which can be used by competitively inferior species.

Increased large-scale structural heterogeneity caused by spatially patchy grazing allows different vegetation types and thus plant communities to co-exist. For example, a monotonous tall heather community is replaced by a patchwork of vegetation types ranging from short grass to shrub.

Gap dynamics, by which rapidly growing, short-lived early gap colonisers are replaced gradually by slower-growing dominants. The constant creation of gaps and the presence of gaps of different ages allow a range of plant types to co-exist.

A diversity of gap types is created by the different activities of livestock. These include, removal of plant parts, killing and removal of whole plants, trampling, poaching, dunging and urination. All these result in gaps of different sizes and environments (light infiltration, nutrient concentrations, amount of litter, and soil disturbance, compaction and moisture) and may favour different species of coloniser.

However, comparison of different grazing intensities shows a variety of effects on diversity; increased (Smith *et al*, 2000; Bullock *et al.*, 2001), decreased (Bullock *et al.*, 2001), or no effect (Gibson & Brown, 1991; Bullock *et al.*, 2001), of increasing intensity, depending on the habitat and the precise grazing regimes. This may be because while increasing grazing intensity could carry on increasing diversity through the mechanisms listed above, it could also decrease diversity by allowing only a few tolerant species to persist (at high grazing pressures) or by preferential grazing on rarer species (Olff & Ritchie, 1998).

8.2.2 Grazing of lowland heathland – general plant community impacts

Grazing management of lowland heathlands for nature conservation is generally aimed at maintaining open dwarf shrub vegetation with a high diversity of heath species while helping to control scrub and other unwanted species (Bullock & Pakeman, 1997). Although grazing has been reintroduced to large number of UK lowland heathland sites in the last few years (e.g. Davies, 1995; Bacon, 1998; Small *et al.*, 1999) there is surprisingly little research evaluating the success of grazing in achieving these aims (but see Byfield & Pearman, 1996; Bullock, 1997). There is a significant body of work on the impacts of livestock activity on upland heathlands (e.g. Rawes & Welch, 1964; Grant, 1971; Welch, 1984; Grant, *et al* 1985; Armstrong & Milne, 1995; Grant *et al*, 1996; Milne, 1998; Todd, *et al* 2000) but much of this work assesses the impacts of grazing in an agricultural context. The existing literature is reviewed here and supplemented with information from unpublished reports and monitoring schemes from heathland reserves. Work from the uplands and from lowland heaths in other countries is considered where useful. Examples of observed impacts of grazing on lowland heathland communities are discussed and effects of grazing on problematic invasive species are considered. Individual species of conservation concern that may be affected by grazing are given in Appendix 2.

Table 5 Summary of effects of introduction/exclusion of herbivores on heathland systems

Years shows the time after grazing commenced/ceased. (Adapted from Bakker, 1998).

	Introduction of herbivores	Years	Habitat	Source
1.	Increase in mire species, decrease in *Molinia*	3	Lowland wet heath/mire	Cox, 1998
	Destabilisation of *Molinia*, (re)appearance of pioneer plants on wet heath	c8	Lowland wet heath	de Beaulieu, 1998
3.	*Calluna* and grasses decreased.	10	Lowland dry heath	Van der Bilt, 1993
4.	Grasses decreased, *Calluna* increased.	5	Lowland grassland/heath	Bokdam & Gleichman 1989
	Calluna increased Invasive grasses and scrub did not decrease, Initial increase in species diversity	10	Grass heath *Calluna* heath	Bokdam & Gleichman 2000
6.	Grasses decreased	?	Lowland grassland/heath	Bülow-Olsen, 1980
	Locally increased species diversity, greater variation in vegetation type and structure, tree seedling prevented from developing	4	Lowland dry heath/grassland	Bakker *et al*, 1983
	Exclusion of herbivores			
1.	Decline in species associated with wet heath and related habitats	c60	Lowland wet heath & related habitats	Byfield & Pearman, 1996
2.	Increase in *Molinia*, *Juncus acutiflorus*		Lowland wet heath/mire	Clarke, 1988
3.	Tree invasion	10	Lowland heath	Bokdam & Gleichman, 1989
4.	Increase in ericoids and tall grasses	25	Upland heath	Rawes, 1981
5.	Tall grasses become dominant (*Molinia* stand)	6	*Molinia* grassland	Grant *et al.*, 1996
	Woodland formation	30	Upland heath	Hester *et al.*, 1991
	Varied grazing pressure			
6.	Increased grazing – increase in sedges, forbs, decrease in *Molinia*, dwarf shrubs	?	Lowland wet heath	Evans, 1989
7.	*Calluna*, *Eriophorum* decreased with increasing grazing pressure, bare ground increased	11	Upland blanket bog	Grant *et al.*, 1995
8.	Light grazing – ericoids, lichens & bryophytes increased; heavy grazing – ericoids decreased, graminoids & forbs increased	20	Upland heath	Welch & Scott, 1995

The precise impact of livestock activity on heathland vegetation is determined by the initial condition of the vegetation plus the type and density of stock and the length and timing of grazing season, and may be further influenced by climatic conditions. However, some generalisations can be made. Table 5 summarises the general trends observed in a number of studies of grazing impact on heathland throughout Europe. In general, livestock activity on heathlands is shown to reduce vegetation cover and re-establish earlier seral stages, creating an uneven aged mosaic in the dominant heathland species. Succession can be slowed, or the successional pathway changed, generally through a shift from ericaceous shrubs to graminoids (Welch, 1984, Grant *et al.*, 1985, Bullock & Pakeman, 1997; Hartley, 1997; Alonso *et al.*, 2001) and the inhibition of scrub growth (Marrs *et al.*, 1986, Tubbs, 1991, 1997). The creation of bare ground can lead to an increase in leaching of soluble nutrients and help maintain low nutrient levels (Marrs, *et al.*, 1986), although dunging may lead to local enrichment (Bakker *et al.*, 1983). These processes may be expressed differently across the spectrum of heathland vegetation types from dry through humid and wet heath to valley mire.

8.2.3 Impacts on dry heath communities

Management of dry heath affects primarily the dominant ericoid species, generally heather *Calluna vulgaris*. Since dry heath communities are intrinsically species poor (Rodwell, 1991), the main conservation aim in grazing is to increase structural diversity. Much work has been done in the uplands concerning the effects of grazing on *Calluna*, and MacDonald (1990) gives a detailed review of these. In general, degenerate stands of heather are less tolerant of grazing than younger stands, and take longer to recover from overgrazing (Grant & Armstrong, 1993). A 40% removal of annual production over several years will damage even young vigorous heather sward (Grant *et al.*, 1978; Grant *et al.*, 1982). Removal of over 80% will lead to shoot death and a decline in stand density. Changes in *Calluna* cover and structure through grazing depend on grazing intensity. Welch (1984) showed that heather cover, height and biomass declined on upland sites with heavy livestock presence, but increased under lighter grazing. Light grazing may stimulate young growth while not adversely affecting mature or degenerate plants (e.g. Demopoulos, 1996), thus maximising structural diversity. Heavier grazing may damage both younger and older heather by repeated grazing of new shoots, uprooting of shoots (Grant *et al.*, 1978) and trampling (Bayfield, 1979). Absence of grazing may eventually lead to *Calluna* degeneration, scrub and tree encroachment (Hester, 1991). The effects of grazing on *Calluna* also depend on soil type and soil moisture content (see below): generally *Calluna* is less damaged by grazing on dry soils than wetter ones (Welch, 1986), whilst grasses invade more easily on mineral soils than on deep peat (Hartley, 1997; Hartley 2001).

The effects of grazing on interactions between *Calluna* and the other dwarf shrub species *Erica cinerea* bell heather and *E. tetralix* cross-leaved heath (the latter is found on wetter heaths, but is considered here) have not been so well studied. *Erica* spp. tend to be grazed only lightly (Bannister, 1966; Rose *et al*, 1996) or avoided altogether (Putman, 1987; Tubbs, 1991) and are therefore less vulnerable to grazing. However changes in cover may not reflect this. *Calluna* can respond to grazing by assuming a prostrate growth form, so increasing cover, whereas for example *Erica cinerea* continues vertical growth if cut (Gimingham, 1972). This response may make *Erica* spp. more susceptible to damage by trampling. In general, intermediate grazing is likely to favour *Erica* spp. in a mixed sward, while heavier grazing will decrease both *Erica* spp. and *Calluna*. However no examples of this process have been reported for lowland heathland.

Grazing also affects the relative proportions of dwarf shrubs and graminoids on heathland swards (Bakker *et al*., 1983; Welch, 1984; Bullock & Pakeman, 1997). Generally, light grazing leads to an increase in dwarf shrub cover and heavy grazing leads to the replacement of *Calluna* with grassland species (Hartley, 1997; Alonso *et al*. 2001). The most detailed work is from the uplands where Welch (1984) found that light grazing favoured small increases in the cover of ericoids and lichens, e.g. *Erica cinerea, E. tetralix, Cladonia impexa,* and *Parmelia physodes*. Heavy grazing favoured graminoids and forbs, particularly sheep's fescue *Festuca ovina*, but also common bent *Agrostis capillaris*, sweet vernal-grass *Anthoxanthum odoratum*, smooth meadow-grass *Poa pratensis*, sheep's sorrel *Rumex acetosella* and white clover *Trifolium repens*. Mosses showed variable responses, with *Hypnum cupressiforme* favoured by light grazing and *Pohlia nutans* and *Rhytidiadelphus* spp. by heavy grazing. Once grassland areas become established within heathland, preferential grazing of *Calluna* at their periphery may further encourage their expansion as dwarf shrub species are more vulnerable to trampling and heavy grazing than grasses (Clarke & Scott, 1995).

Much of the work on graminoids in dry heath communities has been carried out in the uplands, where invasion by grasses, often in over-grazed areas, is considered a conservation problem. In contrast, on lowland heathlands these grassland communities are often of considerable nature conservation interest in their own right (Sanderson, 1998). Although work has been carried out on the impacts of grazing on the vegetation dynamics within these communities (see below), there is little published work on how grazing may alter the dynamic between grassland and lowland heathland communities.

The increase in graminoids and forbs in dry heath communities is facilitated by dung deposition. Welch (1984) found seed of 88 species in dung on upland heathland, although only seven of these germinated in any numbers. Grasses most likely to be introduced via dung were *Anthoxanthum odoratum*, Yorkshire-fog *Holcus lanatus,* annual meadow-grass *Poa annua* and *Poa pratensis* while species such as common mouse-ear *Cerastium fontanum,* perennial rye-grass *Lolium perenne,* annual meadow-grass *Poa annua, Poa pratensis,* sheep's sorrel *Rumex acetosella,* chickweed *Stellaria media* and thyme-leaved speedwell *Veronica serpyllifolia* were likely to attain greater cover than in the previously existing vegetation. Vreugdenhill & Wieren (1979) also found viable *Calluna* seeds in dung on grassland. More grassland species are likely to be transferred to heathland communities that *vice versa* due to differential patterns in habitat use by livestock for dunging and grazing. This was observed in Dorset, where species characterising adjacent acid grassland (*Rumex acetosella,* speedwell *Veronica* sp., field wood-rush *Luzula campestris,* common bent *Agrostis capillaris, Poa pratensis*) have been observed germinating in cow dung on *Calluna* dominated mature dry heath (S. Lake unpub. data). No work has been carried out on how long species introduced in dung persist in dry heath communities.

Livestock activity on dry lowland heathland increases the number of species and structural diversity when at intermediate densities. However, dry heath communities are botanically intrinsically species poor (Rodwell, 1991). Where the grazing unit includes more mesotrophic communities, the increase in species diversity may be due to the introduction of species not generally characteristic of nutrient-poor heath communities (e.g. daisy *Bellis perennis,* dandelion *Taraxacum* agg, *Lolium perenne*, (Vreugdenhill & Wieren, 1979) and not necessarily considered desirable by conservation managers. Therefore the main beneficial impacts of intermediate grazing pressures are to increase structural diversity with benefits for animal communities (see below). Little detailed information concerning livestock activity and structural diversity on lowland heathland is available. Site managers asked by Bacon (1998) if grazing was achieving the aim of maintaining or improving structural diversity on their sites reported a satisfaction level of between 40-100%. In contrast, when asked about objectives for grazing management, only two of 40 site managers during this review mentioned vegetation structure.

8.2.4 Impacts on grass heath and acid grassland communities

The impacts of grazing on heathland have received most attention on the Breckland grass heaths, where lichen and ephemeral acid and chalk grassland form mosaics with *Calluna* dominated swards (Watt, 1940; Rodwell, 1991; Rodwell, 1992). The loss of traditional sheep grazing during the 20th century and massive reductions in the rabbit population through myxomatosis are considered critical in the degeneration of open lichen-rich grass heath and the spread of rank grassland and scrub (Marrs *et al.*, 1986). Dolman & Sutherland (1992) linked an over 75% decline in abundance of several characteristic Breckland plant species (such as perennial knawel *Scleranthus perennis* sbsp. *prostratus*, field wormwood *Artemisia campestris*, small alison *Alyssium alyssoides*, spiked speedwell *Veronica spicata*) with a reduction in disturbance including both sheep and, more crucially, rabbit grazing. While rabbit grazing produces the characteristic lichen-rich and ephemeral-rich grass heath sub-communities on which many of the Breckland rarities depend, sheep grazing tends to produce herb-rich grasslands with a greater abundance of rank grasses. However, sheep grazing may be necessary to graze down more rank vegetation and make it accessible to rabbits.

Acid grassland communities also form an important component of heathlands in other heathland areas, and are of national significance their own right (Sanderson, 1998). The main *Festuca-Agrostis-Rumex* community is considered dependent on grazing for its survival (e.g. Rodwell, 1992). Grazing is considered to keep the vegetation short, maintaining a balance between rosette species, perennial grasses, light demanding chamaephytes and ephemerals and cryptograms able to take advantage of areas of bare ground (e.g. Watt, 1938). Acid grassland supports uncommon and rare species such as mossy stonecrop *Crassula tillaea*, smooth cat's-ear *Hypochaeris glabra*, hairy birds-foot-trefoil *Lotus subbiflorus*, hoary cinquefoil *Potentilla argentea* clustered clover *Trifolium glomeratum*, and suffocated clover *T. suffocatum*. These species are all reliant on a short sward or bare ground (Stewart & Pearman, 1994) and are easily displaced by more competitive grasses. The effects of grazing on invasive grasses are considered below.

8.2.5 Impacts on wet heath communities

There has been comparatively little work on the effects of grazing on wet heath communities, which include humid heath, valley mire, associated damp grassland and seasonal pools. However, various conservation agencies and other organisations have compiled observational reports that form a consensus regarding the effects of grazing on wet lowland heathland communities.

Ungrazed lowland wet heath tends to become dominated by purple moor-grass *Molinia caerulea* (Clarke, 1988; Evans, 1989), and a primary conservation aim is to reduce this dominance (Wright & Westerhoff, 2001). A number of studies have correlated a decrease in plant richness in valley mires with an increase in *Molinia* cover following cessation of grazing (and vice versa) over time scales varying between three and 40 years. Byfield & Pearman (1995) described the presence of desirable species in grazed wet heathland communities in the New Forest and suggested the cessation of grazing on the Dorset heaths has led to a decline in this vegetation type and associated species. They described grazed wet heath in the New Forest as comprising a medium length turf offering ideal conditions for species such as heath lobelia *Lobelia urens*, lesser butterfly orchid *Platanthera bifolia* and pale dog violet *Viola lactea*. Grazing (or other forms of disturbance) is cited as essential to the long-term survival of species such as marsh clubmoss *Lycopodiella inundata* which seems to colonise sites very slowly and is therefore reliant on the long-term continuity of favourable conditions. Poaching provides areas of bare ground needed for the establishment of new individuals in the population, especially of the more short-lived species such as slender centaury *Cicendia filiformis*, and coral necklace *Illecebrium verticillatum* (Chatters, 1996). *C. filiformis* and pale butterwort *Pinguicula lusitanica* are both known to grow within hoof prints (Neil Sanderson, pers. comm., Evans, 1989). Although Byfield & Pearman (1995) suggested that the open seepage flushes around the periphery of valley mires (which provide the principle habitat for bog orchid *Hammarbya paludosa*) can remain in good condition long after the cessation of grazing, grazing is nonetheless cited as playing an important role in their long-term survival. Grazing is also considered to be important in maintaining the open conditions of bog communities characterised by species such as great sundew *Drosera anglica* and slender cotton-grass *Eriophorum gracile*, although livestock penetrate these areas to a limited degree (Pratt *et al.*, 1986).

In the early 1990s, Byfield & Pearman (1995) re-surveyed stands of vegetation in Dorset surveyed by R. Good in the 1930s and recorded the presence or absence of 41 indicator species of conservation interest recorded by Good. Table 6 lists the proportion of populations of species found on wet heath and associated habitats that had declined on extant heathland sites.

Table 6 Proportion of extant stands where populations of indicator species have been lost in Dorset since the 1930s (after Byfield & Pearman, 1995)

No indicator species were chosen for dry heath.

Habitat	% populations lost since 1930s
Humid grassland	75
Lawns and greens	92.9
Seasonal ponds	81.6
Wet heaths	40.5
Valley mires	50

Since the biggest losses were in the three more fertile habitats, Byfield & Pearman (1995) conjectured that these losses were due to faster rates of successional change than occurred on less fertile habitats following the cessation of traditional management practices, including grazing. They compared the decline with the situation in the New Forest, which is broadly comparable in terms of soils, climate and flora but has a continuous history of grazing. 71% of species for which the comparison was possible were considered to be surviving better in the New Forest. Therefore it was suggested that lack of grazing in Dorset was accountable for the disproportionate decline in wet heath and associated species.

Grazing has now been reintroduced as a conservation management tool to a number of sites in Dorset. This begs the question of whether any of the species are now re-colonising or increasing. No systematic re-survey has been undertaken. However, some species have reappeared at sites where they were thought extinct since grazing has been reintroduced e.g. *Pinguicula lusitanica* and petty whin *Genista anglica* (S. Lake, unpub. data). Data from a single 25m x 27m monitoring plot where grazing has been reintroduced (Cox, 1998) shows an increase in characteristic mire species such as bog asphodel *Narthecium ossifragum,* oblong-leaved sundew *Drosera intermedia,* round-leaved sundew *Drosera rotundifolia*, cotton grass *Eriophorum angustifolium* and some *Sphagnum* species, together with a decrease in *Molinia caerulea* and dwarf gorse *Ulex minor* after three years. Replicated grazing exclosures on a nearby site show a decrease in sward height, and an increase in bare ground and species with extensive seed banks such as *Drosera* spp. following grazing (S. Lake, unpub. data).

These findings are corroborated by two studies in Dorset and the New Forest (Clarke, 1988; Sanderson, 1994). In both data were collected from a limited number of quadrats on either side of a fence excluding or reducing grazing on mire habitat at three or four sites. Sanderson (1994) found a large average increase in species number of 240% where grazing occurred, while Clarke (1988) found an average increase of 70% with increased grazing pressure. In both cases the main contribution to increased species richness was the bryophyte and Cyperaceae groups although herbs also increased. The main decrease was in the abundance of *Molinia*, although it remained present. Clarke (1988) found that ericoids decreased, whereas Sanderson (1994) noted a slight increase. Sanderson (1994) also noted that while the ungrazed areas were described by just one NVC community type, the grazed areas comprised a mosaic of two contrasting communities.

Similar trends in wet heath vegetation dynamics have been observed in other UK heathland areas. Species abundance data from stands of grazed and ungrazed wet heath communities on a number of sites in Pembrokeshire (Evans, 1989) show increased cover of sedges and forbs and a decrease in *Molinia* tussocks after grazing. Evans (1989) also found that while changes in species composition were slight after the first season, vegetation structure continued to change for at least six years, mainly through a continuing decrease in the abundance of dwarf shrub species.

As with dry heath, wet heath and mire communities are generally grazed more intensely in the uplands than in the lowlands, and so give an indication of possible changes to lowland communities should stocking densities be higher. Work on the effects of increasing stocking densities in the uplands (Rawes, 1983; Grant *et al*, 1985) shows that compositional changes differ between studies, and, as with dry heath (Hartley, 1997; Alonso et al., 2001), sensitivity of communities to grazing appears to be strongly influenced by the condition and the age of the stand (Grant *et al.*, 1985).

There are, however, drawbacks to the methodologies used in some of this work, most frequently a lack of replication between, in addition to within, monitored plots (e.g. Clarke, 1988; Sanderson, 1994; Cox, 1998). Byfield & Pearman (1995) based their conclusions on a comparison between survey work carried out by R. Good in the 1930s and a repeat carried out in the 1990s. Differences in the two methodologies allow for an over-estimation of the decreases recorded in the damp heath species targeted, although this is not likely to alter significantly the overall decline described.

8.2.6 Impacts on maritime heath communities

Maritime heath differs from the other heathland habitats discussed so far in a number of ways. Most importantly, it can be maintained by exposure and is in places unlikely to undergo succession to scrub or woodland communities. It has a higher percentage of grasses and forbs than the other heathland community types discussed so far, and often occurs in an intimate mosaic with cliff-top grassland communities, combining the characteristics of species-rich grasslands with mixed heath vegetation. Conservation management is aimed at maximising botanical diversity without impoverishing the dwarf shrub element of the community. Maintaining flower-rich swards in the summer is generally a key consideration (Harris & Jones, 1998; Harris & Jones, 2000, Simon Ford pers. comm.). Published information concerning the impacts of grazing on this community is available from two sites, both in Scotland, although there is much observational data from some of the Cornish heaths.

In 1957, the Nature Conservancy removed 4000 sheep and 40 cattle from the Isle of Rhum, leaving 1600 red deer and some goats and ponies to graze the species-rich maritime grassland and heath. The species diversity had declined dramatically by 1970, as red deer grazing did not prevent the invasion of tussock forming grasses *Molinia caerulea* and mat grass *Nardus stricta*. Highland cattle were introduced subsequently and the decline was reversed (Ball, 1972). At the opposite end of the spectrum, a long-term grazing project on Orkney has been designed to reduce grazing pressure and produce favourable conditions for Scottish primrose *Primula scotica*. A significant amount of monitoring has been undertaken at this site (Ray Harris, pers. comm.) but much remains to be analysed. Some general trends have been observed. Heavy grazing after a period of unrestricted summer growth was found to produce an open-structured sward allowing increases in the abundance and flowering of some 40 species. A high grazing pressure, added to the physical constraints of exposure and salt-spray can eliminate the dwarf shrub element of the community. Low grazing pressure allows the dwarf shrub canopy to become dominant and exclude the fine grasses and small broad-leaved herbs. In grassier areas a mat of litter and rank growth of the dominant grasses also reduces the abundance of finer grasses and forbs. The absence of grazing can sometimes lead to the development of a lichen dominated heath (Harris, 1998).

While grazing is not always required to slow successional changes on maritime heath, it can be used to maintain high species diversity. Intermediate grazing pressure will maintain a mosaic of species rich grassland and dwarf shrubs. Grassland diversity is likely to decrease with lighter grazing intensities, while heavier ones will significantly reduce the cover of dwarf shrubs.

8.2.7 Impacts on invasive grass species

Both over and under-grazing can lead to a dominance of grasses. On under-grazed lowland heathlands dominance of relatively palatable species leads to a reduction in species and structural diversity and can be problematic for conservation managers. Two vigorously competitive species grasses that replace dwarf shrub species if growth is unchecked are wavy hair-grass *Deschampsia flexuosa* and purple moor-grass *Molinia caerulea*. However, differing responses to grazing have been observed in these two species under different circumstances.

Deschampsia flexuosa can become dominant on dry heath, particularly following nutrient enrichment. Evidence from the Netherlands suggests that grazing has a limited ability to allow heather recovery in *D. flexuosa*-dominated fertilised (including those suffering from aerial nutrient deposition) former heaths (e.g. Bakker *et al*, 1983; Vandenbos & Bakker, 1990; Bokdam & Gleichman, 2000). However a grazing-induced decrease in *D. flexuosa* on unfertilised heaths is reported in Denmark, the Netherlands, England and Scotland (Buttenschøn & Buttenschøn, 1982; Welch & Scott, 1995; Bullock & Pakeman, 1997; Bokdam & Gleichman, 2000). In upland systems, *D. flexuosa* performed best when fertilised and protected from grazing; on grazed unfertilised plots plants decreased in size (Alonso *et al*. 2001). Grazing appears to be successful in both reducing the amount of *D. flexuosa* litter (which can inhibit other species, Bülow-Olsen, 1980) and creating gaps in the sward that allow *Calluna* regeneration from the seedbank (van Wieren, 1989). Thus, grazing may be effective in reducing dominance of this species provided there is no nutrient input into the heathland system.

Molinia caerulea becomes dominant on wetter heathland if not inhibited by some form of disturbance (e.g. Clarke, 1988). Grazing is generally considered an appropriate tool to reduce *Molina* cover, although in the uplands *Molinia* replaces *Calluna* under heavy grazing on wet soils (Welch 1984c). In contrast, in the lowlands Edwards (1985) and Tubbs (1986) suggested heavy grazing greatly reduces *Molinia* in damp heath communities. The studies on wet heath communities discussed above (see *Impacts on wet heath*) generally showed declines in the abundance of *Molinia* after grazing. This is supported by observational information from site managers: 11 out of 11 who gave *Molinia* control as an aim in conservation grazing lowland heathland sites felt this aim was being achieved. Since *Molinia* stands have greater agricultural interest than *D. flexuosa*, more is known about utilization rates (e.g. Grant *et al*, 1996; Common *et al*., 1997; Wright *et al*, 2000). Grant *et al*. (1996) found that *Molinia* was retained within the sward when utilization rates were below 33% of the lamina length. Newbourne *et al*. (1993) found that Hebridean sheep controlled *Molinia* in an upland sward through an offtake of more than 33% of the vegetation. Although this figure is sometimes quoted in conservation literature as being a utilization threshold below which grazing will not effect *Molinia*, Grant *et al*. (1996) only compared two utilization rates (33% and 66%) and so the threshold could be lower.

8.2.8 Impacts on bracken *Pteridium aquilinum*

The problem of bracken *Pteridium aquilinum* invasion of heathland has generated a considerable amount of research (e.g. Lowday, 1984; Pakeman & Hay, 1996; Marrs & Britton, 2000) and conservation effort (e.g. Wright, 1993; Rutter, 2001). However, little research has been carried out into the effects of livestock grazing on bracken dynamics. Livestock will consume small amounts of bracken (Putman *et al*., 1987) but not in sufficient quantity to reduce cover significantly. A spatial simulation model of vegetation dynamics applied to relationships between expansion of bracken patches and grazing found that small bracken patches could be controlled by grazing, but not the expansion of large patches (Birch *et al*., 2000). However, control of bracken by grazing depended on the impact of trampling. Pakeman et al. (1997) found that where livestock activity was sufficiently high, bracken regeneration on upland heathland following herbicide (asulam) treatment was slowed. Again this was due to disturbance through trampling.

Cattle and ponies push through areas of bracken and can reduce density by damaging plants. Pigs have been used to manage bracken (Read, 1994; Kennedy, 1998) and proved effective in reducing stand density if used in conjunction with cutting or spraying (Read & Williams, 1997). However the pig foraging strategy of digging for rhizomes is likely to result in significant loss of all vegetation cover. Livestock grazing may in some cases allow the spread of bracken because it is avoided and competition from other species is reduced (Davies *et al.*, 1979).

Bracken is toxic to livestock when consumed in quantity, and evidently welfare concerns will prevent the use of livestock grazing (as opposed to trampling or digging) as a tool for bracken management. No data are available on the impact of livestock presence on bracken on lowland heathland.

8.2.9 Impacts on scrub and tree species

Scrub invasion is considered a key factor in the reduction of lowland heathland habitat quality and area (Webb & Haskins, 1980; Marrs *et al.*, 1986; Webb, 1990; UK Steering Group, 1995; Rose *et al*, 2000). Although it is unclear to what extent domestic livestock grazing can be used to manage regenerating tree and scrub species, grazing has excited much interest as an alternative to mechanical and chemical control techniques, which can be both expensive and time consuming. For example the current Tomorrow's Heathland Heritage project in Dorset allows from £700 ha^{-1} (<25% scrub cover) to £2500 ha^{-1} (>75% scrub cover) for scrub clearance (Moore, 2000) whereas approximate costs for using 10 goats over two years to clear scrub from 10ha on a heath in Surrey were £1217 ha^{-1} (Rob McGibbon, pers. comm.). A break down of costs is given in Appendix 9.

Studies in the uplands have shown that Scots pine *Pinus sylvatica*, birch *Betula* spp. and juniper *Juniperus communis* regeneration can be controlled by high grazing intensities (Miles, 1979), and that upland heath may succeed to woodland if grazing is excluded (Hester *et al.*, 1991; French *et al.*, 1997). Similar studies have not been carried out in the lowlands although circumstantial evidence suggests that heavy grazing may inhibit the growth of scrub and trees on lowland heaths (Marrs *et al.*, 1986, Tubbs, 1991; Dolman & Sutherland, 1992; Tubbs, 1997).

Livestock which are predominantly grazers will have some effect in removing or reducing the size of tree seedlings (Bakker *et al.*, 1983; Pratt *et al.*, 1986) and have been reported to open areas of scrub by pushing through it and eating growing tips (Read & Williams, 1997; Jon Brooks, Haydn Garlik, Rue Ekins, pers. comm.). Tubbs (1991) noted that pony browsing in the New Forest can kill gorse regeneration following burning. However, Bokdam & Gleichman (2000) found that free-ranging cattle grazing on a Dutch heathland did not stop birch and pine invasion. Livestock species and breeds that are predominantly browsers may have more of an impact (Oates & Bullock, 1997). In Denmark, Buttenschøn & Buttenschøn (1982) found that Icelandic sheep removed all above ground growth of bramble *Rubus fruticosus* agg. Studies carried out on lowland grassland suggest that both goats (Oliver, in prep.) and Hebridean sheep (Wilkinson, 2000) can significantly reduce scrub and tree species. These species are also considered to have significantly reduced extant scrub and/or controlled regeneration on a number of lowland heathland sites (Rob McGibbon, Caroline Fitzgerald, pers. comm.). While it is clear that in some cases livestock presence can prevent scrub encroachment and may reduce scrub cover, further research is needed.

8.2.10 Impacts on individual plants species of conservation concern

The potential effects of livestock grazing on individual species of conservation concern occurring on heathlands are summarised in Appendices 2-3. Species included are higher and lower plant species for which action plants have been prepared under the UK Biodiversity Action Plan (HMSO, 1995), plus vascular plants listed in the British Red Data Book for vascular plants (Wigginton, 1999) or considered nationally scarce (Stewart & Pearman, 1994).

Vascular plants

The impact livestock presence on a number of plant species have been discussed above. In addition, all species with conservation concern status which occur on heathland and related habitats are considered in Appendix 1 . For this purpose, species have been divided into four groups species due to their similar requirements and response to grazing pressure: (i) dry and wet heath and mire species, (ii) damp and acid grassland species, (iii) seasonal pool edge species, (iv) maritime heath species and (v) Breckland heath. The groups are intended to include species which occur on these habitats within a heathland context, and are not comprehensive in their own right. Therefore some species commonly associated with those included have been omitted (such as the rare suite of species found on rocky outcrops on cliffs on the Lizard which may be associated with maritime heath species).

Lichens

Evidence for the impact of livestock on lichen species is conflicting. Rawes & Hobbs (1979) showed that excluding sheep from blanket bog resulted in an increase in both cover and biomass of lichens after 21 year, while intense grazing (3.4 sheep ha^{-1}) caused a decline. Trampling in mire communities can destroy larger *Cladonia* species and favour an increase in crustose lichens (Rodwell, 1991). However Welch (1994c) and Bullock & Pakeman (1997) found that lichen cover increased with light grazing pressure. Lichen-rich grass heaths in the Brecks are dependent on a short nutrient poor sward that is maintained by heavy rabbit and sheep grazing (e.g. Dolman & Sutherland, 1992). The heavily grazed prostrate *Calluna* heaths of the New Forest are among some of the richest sites for lichens including species such as *Cladonia strepsilis* and *Pycnothelia papillaria*, that have seriously declined in the lowlands although are still abundant in the uplands (Sanderson, 1994; Wright & Westerhoff, 2001). Sanderson (1996) considers such lichens to be dependant on constant low-level disturbance such as grazing or periodic heavy disturbance such as fire to prevent dominance by dwarf shrubs. Similarly, Saunders (1997) noted the critically endangered lichen *Cladonia peziziformison* bare patches resulting from grazing and burning on Dowrog Common in Pembrokeshire. Lichen monitoring has recently been initiated on a number of heathland sites in Dorset where grazing has subsequently been reintroduced, (Bryan Edwards, pers. comm.) but no results are yet available.

Bryophytes

In general, bryophytes may benefit from grazing when it reduces competition from vascular plants and provides patches of bare substrate, but may be damaged by heavily trampling. Some of the richest bryophyte sites in the New Forest are the heavily grazed prostrate *Calluna* heaths, both humid and dry, where rare species such as *Dicranum spurium* and *Hypnum imponens* occur (Sanderson, 1994). Trampling on bogs can lead to an increase in *Sphagnum tenellum*, acrocarpous mosses such as *Campylopus introflexus* and leafy hepatics on peat surfaces exposed by trampling (Rawes, 1983; Rodwell, 1991). Marrs et al. (1988) found that *Sphagnum capillifolium* was most abundant in grazed plots throughout a 20-year experiment. *Sphagnum* also has impressive powers of regeneration, and can shoot from apparently dead material after many years (e.g. Lindsay & Ross, 1994) so may recover well from trampling damage. However, trampling can also disrupt the *Sphagnum* carpet, damaging the typical microtopography associated with hummock forming species such as *Sphagnum papillosum* (Shaw et al, 1994). Three nationally scarce epiphytic liverworts *Cephalozia macrostchya macrostchya*, *Cephalozia plenicpes* and *Cephaloziella elachista* and are found only on sphagnum in undamaged bogs (e.g. Wright & Westerhoff, 2001). The intensity and duration of tramping will dictate whether or not it is beneficial for bryophyte species.

Fungi

Dung is a key factor in changes in the abundance fungi species following (re)introduction of grazing – there are at least 388 species that grow and fruit on herbivore dung (Richardson & Watling, 1997). An example is nail fungus *Poronia punctata*, listed on the provisional Red Data List of endangered British fungi (Ing, 1992). This species was largely confined to the New Forest, but has recently appeared at sites in Dorset following reintroduction on livestock (Cox & Pickess, 1999). Interestingly, *Poronia punctata* is not only dependent on pony dung, but there is some indication that it occurs on dung on predominantly short vegetation. This species, which only persists in grassy or heathy habitats, is probably dispersed by ponies which have eaten spore-bearing vegetation (Whalley & Dickson, 1986).

Work in the Netherlands in wood pastures suggests that grazing increases the abundance and diversity of fungi through vegetation removal and soil compaction (Baars & Kuyper, 1993). However, fungal diversity is much greater in wood pasture than open heathland habitats, and similar trends may not be observed on heathland where fungi diversity is considerably lower (although this will be relevant where extensive grazing systems include semi-natural woodland). Where veteran trees occur on heathland a number of fungi species may be present which depend on the continuity of these trees – a factor that should be born in mind when considering the impact of grazing on regeneration. Grassland species such as waxcaps and species of *Entoloma* and *Geoglossum* prefer heavily grazed swards. In the New Forest grazing is considered essential in the maintenance of suitable conditions for grassland species (Wright & Westerhoff, 2001).

8.2.11 Conclusions

a. Impacts of livestock presence on lowland heathland vegetation will vary according to stocking density, livestock type, grazing season, vegetation start point, site characteristics and climate.

b. In general, at intermediate stocking densities grazing is likely to produce maximum species and structural diversity on all heathland vegetation types. High and low extremes will both lead to an increase in grass cover and reduction in dwarf shrub cover; low density will generally allow an increase in scrub cover.

c. Data are lacking on the degree of structural diversity and the scale of vegetation mosaics created by livestock presence, particularly for wet vegetation types. The impact of livestock on the interactions between dwarf shrub cover and desirable acid grassland communities has not been explored on lowland heaths.

d. Livestock presence can control and reduce invasive species such as *Deschampsia flexuosa* (provided the sward is not nutrient enriched) and *Molinia caerulea*. The effects of livestock on bracken and in particular scrub merit further research.

e. Livestock presence will benefit individual plant species provided they are not selectively grazed or dominant in the vegetation community. Populations of many characteristic heathland species will benefit from an increase in bare ground and reduction of competitive grasses. However, variables such as livestock breed, grazing intensity and grazing season will have individualistic effects on species depending on their ecology and phenology.

8.3 Impacts on invertebrates

8.3.1 The conservation of invertebrates

The conservation management of invertebrates presents difficulties in comparison with most other taxa and this is perhaps one reason why they have been relatively neglected compared with plants or vertebrates. The small size, restricted distribution and sometimes cryptic habit of invertebrates mean they are often overlooked. Even experienced entomologists hunting thoroughly for species in specific locations often have to admit defeat (Edwards, 1994)! Thus the status of many invertebrates of conservation importance is far from certain, as experts are unsure whether a lack of sightings means a population has become extinct or individuals have just been missed. Similarly, it is hard to be sure whether other populations exist but have not been recorded. This problem is exacerbated by the fact that the life cycle of many species means they are only active or obvious for very short periods of time. For example, the spider-hunting wasp *Homontus sanguinolentus* (an endangered RDB species) has only ever been observed in late July/early August (Edwards, 1994). Secondly, almost nothing is known of the ecology and habitat requirements of many species, including some BAP and RDB species (see Appendices 4 and 5) and even the identification of some species may be problematic. Without better information, is hard to be sure where to look for species of concern, never mind how to protect them in whatever habitat we think they may need.

Despite these difficulties, the conservation of invertebrates is vitally important for several reasons. Firstly, invertebrates are the most species rich group present on lowland heath. In fact, the heaths of Southern England are one of the most important habitats for invertebrates, supporting more than 50% of the British species in some orders (e.g. Odonata and Heteroptera). Secondly, many heathland invertebrate species are already rare, or at the edge of their range in the lowland heaths of the south (Kirby, 1992). Hence, 15% of the British insect fauna are RDB species and for some groups, e.g. Hymenoptera, this figure rises to almost 30% (Shirt, 1987). Thirdly, the position of invertebrates is made even more precarious because their small size means that their abundances are very variable but they often have limited dispersal capability (Dempster, 1991). Populations fluctuate markedly in response to environmental factors such as climate (Harrington & Stork, 1995), yet they have little "buffering capacity". Add to this their often highly specialised requirements (e.g. the Purbeck mason wasp *Pseudepipona herrichii*, a BAP species, needs bare clay soil for burrows and the caterpillar of a particular moth species to provision the nest), and it means that a sudden deterioration in habitat can push a species over the edge to extinction very rapidly.

8.3.2 The impacts of grazing

It is clear from the above that factors like grazing have the potential to have very pronounced effects on the populations of heathland invertebrates, many of which are vulnerable or endangered. Thus it is important to ask how the use of grazing as a management tool in lowland heaths will alter the abundance and viability of invertebrate populations. There are three main ways in which grazing could influence invertebrate populations: indirectly by habitat alteration, either by changing the structure of the vegetation, or by altering the species composition of the vegetation; or directly by their presence (e.g. some species, such as the beetle *Aphodius niger* are dependant on animal, usually cattle, dung. Thus, grazing could have positive or negative effects on heathland invertebrates depending on their precise habitat requirements. This may explain why some studies have found no effect of grazing on heathlands in terms of species richness because, for example, species requiring bare ground appeared whilst those requiring the presence of tall grasses were lost (Denton 2001).

The key to successful conservation of invertebrates using grazing is an accurate knowledge of the habitat preferences of the species of most concern. However, this knowledge is lacking for many species, although for some better-studied species it is now possible to make predictions about the likely impacts of grazing. This has been attempted in table form in Appendix 4, which examines the most important BAP species found on heathland and identifies those species for which grazing could be expected to influence their abundance. Appendix 5 attempts this for selected heathland RDB species, although this is rather more difficult because far less is known about many of these species. However, these tables clearly indicate that one of the most common reasons given for the decline of heathland invertebrates (excluding obvious and major habitat loss due to afforestation or urban development) is scrub encroachment, often associated with "inappropriate management". This should give us cause for optimism that better grazing management could have a beneficial effect on many species of conservation interest. However, we still need to understand the best method (e.g. which livestock species) and duration of grazing to allow us to maximise these benefits. In the next section of the report we try to address this by focusing on specific habitat requirements and the rare species associated with them.

8.3.3 Grazing and vegetation structure: scrub management vs. bare ground

Many lowland heaths are in poor condition in terms of habitat structure for invertebrates. Without sustained management lowland heaths are colonised by scrub, trees or “undesirable species” such as bracken. In addition, the heather canopy becomes extremely even aged. However, it is now well known that the optimum arrangement for invertebrates is a matrix of different ages of heather, some bare ground and sandy areas and a small number of trees and shrubs (Kirby, 1992; Edwards, 1994).

Within this general strategy, particular invertebrate species have specific requirements and this knowledge is crucial if we are to understand fully the impacts of grazing on their abundance. This is particularly important for BAP or RDB species. Some of these species of high conservation importance can only exist where there is a substantial amount of bare ground and sparse vegetation. These include: species which require access to the sandy soil for their nests (e.g. the heath bee fly, *Bombylius minor*); thermophilus species which need bare sandy areas with a warm microclimate (e.g. larvae of silver-studded blue, *Plebejus argus*); or predators, which need open country in which to hunt effectively (e.g. *Cicindela sylvatica*, the heath tiger beetle). Many key BAP species and RDB species fall into this category and decreases in their abundance have been blamed on poor management leading to a loss of bare ground, open areas or short vegetation. Examples, in addition to the species mentioned above, include the beetles *Amara famelica*, *Anisodactylus nemorivagus* and *Lycoperdina succincta*; the ants *Formica exsecta* and *Formica rufibarbis*; the spider hunting wasp *Homonotus sanguinolentus*; the Southern damselfly *Coenagrion mercuriale*; the hover-fly *Chrysotoxum octomaculatum*; the robber fly *Eutolmus rufibaris*; the mottled bee-fly *Thyridanthrax fenestratus*; and the ladybird spider *Eresus sandaliatus*.

In contrast, there are a number of species for which scrub encroachment is not a problem; rather they are dependant on scrub or tree species for either food or shelter. Some scrub species support very rich invertebrate faunas; broom *Cytisus scoparius* has been found to have 35 herbivorous insects, in turn supporting 130 predators and parasites (Kirkby, 1992), whilst birch *Betula* spp. and willow *Salix* spp. are second only to oak *Quercus robur* in the number of insect species which feed on them (Southwood, 1961). Some species of conservation importance are dependant on the presence of scrub and trees: the beetle *Cryptocephalus coryli* feeds on young birch on the Coversand heaths; the dingy mocha moth, *Cyclophora pednularia*, feeds on willow in heath; and the endangered cranefly *Nephrotoma sullingtonesis* occurs only on open heath with pine *Pinus sylvestris*. Two RDB species, the endangered cuckoo bee *Stelis breviuscula* and the hoverfly *Callicera aenca*, are only found at the heathland/woodland edge. As well as trees and scrub, a range of heather structures is beneficial. Some BAP/RDB species require tall mature heather; for example, the spider *Uloborus walckenaerius* builds its web in tall heather plants. Invertebrate preferences for particular ages of heather mean that grazing can produce marked shifts in invertebrate community composition. For examples, in upland systems it has been shown that some carabid species were characteristic of mature heather stands, whilst others only occurred in areas with open ground; heavy grazing shifted the composition of the carabid assemblage favouring the latter at the expense of the latter (Gardner *et al*., 1998).

Although particular species clearly differ in their habitat requirements, the optimum management strategy for the conservation of lowland heath invertebrates is clear: to maintain a varied vegetation and habitat structure which includes some bare ground but also some tall heath with scrub. How can this best be achieved with grazing? Cattle grazing is one way to help prevent scrub encroachment, and cattle are also effective at trampling bracken. However, their large feet, so useful at flattening “nuisance” species, can pose a hazard for some invertebrate species because they compact the ground or trample on nests (see below).

One of the key problems for heathland managers is that the use of grazing has declined and in many areas has not been replaced by alternatives for maintaining structural diversity, such as cutting and scrub clearance. Even in locations where heathland managers are attempting these management practices, they are labour intensive and hence expensive, and on wet heath they may also be impractical as the ground becomes too churned up with the use of heavy machinery. Again livestock, that are prepared to graze wet areas, may be the best option.

Whatever species of livestock is used, a key aim will be to maintain habitat variability e.g. different heights of heather. However, the effectiveness of livestock grazing in achieving structural diversity has not been studied (see 8.2 Impacts on plants). If grazing alone is found inadequate to create the necessary mosaic of habitats, it may be complemented by cutting some areas of heather, and scraping by hand to clear bare ground on suitable sand/clay banks to provide nest sites for bees. Certainly for many areas, substantial scrub and tree clearance may be necessary and this is far beyond what herbivores can achieve! However, once the clearance has been done, grazing will be able to help prevent succession to woodland.

8.3.4 Grazing and plant species composition

As described above, heavy grazing pressure generally decreases the cover of palatable grasses, herbs and heather in favour of more unpalatable or grazing tolerant grasses. These changes in species composition can have adverse effects on some species which have specific requirements in terms of feeding on these palatable species. For example, the BAP species the heath bee-fly *Bombylius minor* feeds on flower-rich path edges (verge heath), a vegetation type also favoured by herbivores. In fact, grazing by ponies on roadside verges and other grassy areas is thought to be at least partly responsible for the decline in two RDB species, the cuckoo bee *Melecta luctosa* (which is endangered and requires good flower cover) and the weevil *Tychis qunquepuctatus*, whose existence in the New Forest is threatened by grazing of its food plant, the bitter vetch *Lathyrus linifolius* var. *montanus*.

A more common problem on lowland heaths is a lack of grazing leading to tree and scrub encroachment (see above). However, even with good grazing management, difficulties arise because herbivores will only prevent encroachment by species they can eat. Thus although many tree and scrub species are palatable (rowan *Sorbus acuparia*, birch *Betula* spp., sallow *Salix* spp.), other encroaching species (bracken *Pteridium aquilinum*, *Rhododendron ponticum*) are less so, and these unpalatable species are difficult to keep in check by grazing almost by definition. Hence mechanical means are necessary. However, even some “problem” species, with the exception of *Rhododendron* spp. and *Gaultheria shallon*, are home to some notable invertebrates (e.g. the beetle *Exapion genistae* which feeds on the seed pods of gorse). Thus it may be beneficial to maintain areas of native scrub species.

8.3.5 Dung and trampling

Some key species are dependant on dung. For example, the beetle *Aphodius niger*, a BAP species only recorded from the New Forest, requires cattle dung trodden in at the edge of ponds. Insects so dependent on dung are threatened by changes in grazing practice, but also by the introduction of helminthicides in cattle. Hence the species action plan for this species requires the development of an alternative policy for the use of helminthicides. Some species are not directly dependant on dung, but prey on insects that feed on dung. A good example is the larvae of the hornet robber fly *Asilus crabroniformis*, another BAP species, which are believed to prey on the larvae of dung beetles. Other species are dependant on the presence of livestock for different reasons. For example, the fly *Hippobosca equina* (a RDB species) is, as the name suggests, parasitic on horses.

The presence of large animals is not always beneficial for invertebrates. For example, trampling by cattle, so useful at preventing the spread of bracken, can be very detrimental for ground nesting species. Cattle can compact the ground so wasps cannot burrow and they can destroy ants nests. In many cases species may need an intermediate grazing pressure, and will suffer from both over and under grazing. For example, the black bog ant *Formica candida*, a BAP species, is considered to be threatened by too much grazing pressure leading to trampling of nests and too little grazing leading to encroachment of scrub and bracken. This illustrates the difficult balancing act conservation managers have in trying to create optimum habitat conditions for invertebrates. This balance may be hard to achieve in practice. One approach is to intensively manage small areas on a rotational basis. An alternative is to use more extensive systems, where a lower density of livestock over much larger areas may achieve the degree of vegetational diversity required.

8.3.6 Conclusions

a. Invertebrates have very specific habitat requirements and variable population sizes, so many species are vulnerable.

b. Not enough is known about the ecology and life histories of many key species, to predict how management techniques including livestock grazing may affect populations.

c. Invertebrates often respond rapidly to changes in environmental conditions, which increases their vulnerability but may also mean they can be rescued by appropriate management which modifies the habitat to better suit their needs.

d. To maximise invertebrate diversity, a heathland should have a range of vegetation types and a varied habitat structure from bare ground to small trees; in addition, adjacent habitats, such as roadside verges, may be crucial for some heathland invertebrates.

e. Habitat mosaics are vital; many species need range of habitats available within a small area, e.g. wasps may need sandy areas for nests and nearby heather flowers as nectar sources.

f. Grazing is a key determinant of habitat structure, and so is one of the main influences on invertebrates. Appropriate grazing management may achieve the required habitat diversity. Equally, over or undergrazing may lead to loss of the habitats required by particular invertebrate species.

8.4 Impacts on vertebrates

The presence of livestock on heathland sites may affect other vertebrate species both directly e.g. disturbance, and indirectly e.g. habitat change. Very little work has been carried out on the effects of grazing on heathland vertebrates. However, a comparison of the requirements of vertebrates with the possible effects of grazing on heathland vegetation gives an indication of the effects grazing may have on these species. In some cases, changes in vertebrate populations can be correlated with changes in grazing management e.g. (Denton *et al.*, 1996 Hitchings, 1996; Wotton & Gillings, 2000). Many vertebrate species require a diversity of vegetation types and structures within their range and these may be achieved through appropriate livestock grazing (see above). However, the degree and spatial scale of this required diversity is likely to differ between species - whether and how quickly it can be produced through livestock grazing will depend on a number of factors including livestock type, stocking rate and season and the start-point of the vegetation. Species-specific grazing management may not meet the requirements of other species present. Species listed as being of conservation concern (Biodiversity Information Group, 2001) that may be affected by livestock presence are presented in Appendices 6 and 7 together with the known and potential impacts of livestock grazing on each species.

8.4.1 Impacts on birds

There has been little work directly relating grazing management on lowland heaths with changes in bird population sizes. However, there are a number of ways in which livestock presence on heathland sites may affect birds. Appendix 6 lists bird species of conservation concern (Gibbons *et al.*, 1996) that occur on UK lowland heathland and may potentially be affected by grazing. The Appendix lists relevant aspects of species' behaviour and habitat requirements and suggests which species may be favourably, or unfavourably affected by grazing.

Livestock presence may directly impact bird species through disturbance and damage to nests and indirectly through habitat alteration. Direct impacts will affect mainly ground nesting species, while indirect impacts may affect all heathland species to a varying degree. Direct impacts will be seasonal and can be avoided by removing livestock in the nesting season (usually May - June). Indirect impacts could have an influence all year, for example the consequences of structural changes will not necessarily be limited to the season they occur in.

Direct impacts of grazing. Ground nesting species are known to mob livestock approaching the nest site. For example, stone curlew *Burhinus oedicnemus* have been observed attempting to drive sheep away from nest sites on Breckland heaths (Bev Nichols, pers. comm.) and as consequence sheep are generally not grazed on such sites during the nesting period. Livestock presence may also detrimentally affect birds through nest trampling, as has been shown for both passerines and waders on lowland wet grassland (Green, 1986; Green, 1988; Wilson *et al.*, 1997). There is no published work on nest trampling on heathland sites, but it has been reported for woodlark *Lullula arborea* (John Mallord, pers. comm.). The extent of any impact at the population level is not known but is unlikely to be high. Ground nesting species on which livestock presence may directly impact are highlighted in Appendix 6 (ground nesting is defined here as nesting on the ground, generally in an open scrape, and does not include species nesting in burrows or on cliffs). A distinction is also made between nidifugous young (f), who can move away from potential danger, and nidicolous young (c) who remain in the nest after hatching.

Indirect impacts of grazing. Livestock presence on heathland habitats has been shown to have a varying effect on vegetation diversity (see above) and may affect heathland birds in a number of ways. For example, the greater abundance of bare ground and the fine scale mosaic of different sward heights likely to be a product of appropriate grazing management will benefit many heathland bird species. Species such as woodlark require open sites with bare ground and a short sward and Wotton & Gillings (2000) suggest that in providing these conditions the current increase in lowland heathland grazing will benefit woodlark populations in both the long and short term. However, the reduction in dwarf shrub cover and structural diversity characteristic of very high grazing pressure may adversely affect species such as Dartford Warbler *Sylvia undata* which require dwarf shrubs for foraging, shelter from predators and nest sites (van den Berg *et al.*, 2001). Similarly, changes in structural diversity on wetter habitats will affect the nesting opportunities of species such as snipe *Gallinago gallinago*, curlew *Numenius aquartus*. Circumstantial evidence suggests that breeding waders benefit from grazing on the New Forest valley mires (Tubbs, 1997). It is important to consider the spatial scale of habitat diversity when discussing its benefits. Smaller-scale habitat diversity may suit species such as woodlark *Lullula arborea* but is inappropriate for species such as stone curlew *Burhinus oedicnemus* and chough *Pyrrhocorax pyrrhocorax*, which require larger areas of open heathland with extremely short swards for feeding.

Habitat characteristics will also influence the abundance and diversity of prey species such as invertebrates and where these increase the impact on bird diversity and abundance will be beneficial. Declines in prey species will evidently have a detrimental effect, and this has been shown for buzzards *Buteo buteo* in the New Forest. Tubbs & Tubbs (1985) showed a clear negative correlation between breeding success of buzzards and increased grazing pressure in the New Forest which was linked to a decline in small mammal population. Comparatively low breeding populations of kestrel *Falco tinnunculus* and tawny owl *Strix aluco* in the New Forest have also been attributed to the lack of small mammal prey (Tubbs, 1997).

8.4.2 Impacts on reptiles

Appendix 7 lists reptile and amphibian species of conservation concern found on lowland heathlands, and provides summary information about how they may be affected by livestock presence. Heathlands are the only habitat in Britain where all six native reptiles can be found. Sand lizard *Lacerta agilis* and smooth snake *Coronella austriaca* are confined to the southern English heaths. Adder *Vipera berus,* and to a lesser extent common lizard *Lacerta vivipara* and slow-worm *Anguis fragilis,* are strongly associated with heathlands, and may also be affected by livestock. Being at the north-western limit of their range, both sand lizards and smooth snake have narrow habitat requirements. For example, House & Spellerberg (1983) found that sand lizards occur at highest densities where variation in vegetation structure is greatest and the interface with other vegetation types is high. Deep heather litter is required for invertebrate prey. Both hot open areas with micro-topographical variation in the exposed sand surface and cool shaded areas are needed for temperature regulation, while open soil is required for egg laying.

Livestock grazing does not necessarily prejudice these requirements. However, grazing at high intensity has the potential to damage reptile sites. Mechanisms through which this may potentially occur include repeated trampling or grazing of mature or degenerate heather stands where this reduces structural diversity, heavy grazing of *Molinia* tussocks, again affecting structure, and trampling of egg laying and hibernation sites (Keith Corbett, Chris Reading, pers. comm.). The Herpetological Conservation Trust (pers. comm.) considers livestock grazing to have caused habitat changes which have damaged reptile populations in a few cases. Reported problems included changes in the structure of *Molinia* swards used by adders and damage to sand lizard egg-laying sites on dry heath. However, many sites are also grazed without any reported damage to reptile populations. It is not known whether there are circumstances where grazing may enhance structural diversity in the vegetation (including the creation of bare ground patches) and create a mosaic of vegetation types more suitable for reptiles.

In general, livestock largely avoid areas of dry heath favoured by sand lizard and smooth snake, except for lying-up areas (a few spots are habitually used), paths, and in the autumn when they may disperse over dry heath searching for dwarf gorse *Ulex minor*. However, on some sites small-scale habitat features may be particularly important for reptiles and in these cases, damage to these features may have a disproportionate effect - for example, a single visit by a herd to an egg-laying site during the incubation period may destroy the clutch. On other sites, features of importance may be larger with reptiles more widespread and so there is less risk of such an effect.

In contrast to dry heath communities, *Molinia* swards are likely to be preferentially selected by livestock. *Molinia* swards can support high densities of smooth snake, common lizard and adder. Grazing will alter the structure of the vegetation but the effects are clearly dependent on the grazing intensity and may be patchy across a site.

Grazing may also change patterns of site use by reptiles. Denton *et al.* (1996) suggested that low density livestock grazing can change site use by species such as adder and grass snake - preferential use of wetter more productive habitats by grazing livestock makes this vegetation less attractive to snakes, while the less preferred vegetation elsewhere in the heathland system remains attractive to snakes.

The impacts of livestock presence on reptile populations need to be more fully understood particularly where grazing is proposed at higher intensities on sites with vulnerable reptile populations. However, various factors make it extremely difficult to evaluate any potential effects on reptiles – changes in population size are very hard to measure with any confidence and reptiles are relatively long-lived so effects on populations may be gradual (Andrew Nicholson, pers. comm.).

Conservation opinion currently ranges from considering the exclusion of livestock from some key reptile areas to be necessary to safeguard reptile populations, to considering that low intensity grazing on large, extensively grazed sites poses no threat to reptile populations. There are currently no published data to back up either approach. On the Dorset heathlands, the area where rare reptiles are most affected by grazing, the approach taken when first introducing grazing has been to start at low intensity allowing potential effects or risks from grazing to be assessed.

8.4.3 Impacts on amphibians

Of the six UK amphibians, only natterjack toad *Bufo calamita*, common toad *Bufo bufo* and palmate newt *Triturus helveticus* occur frequently on heathland. Frog *Rana temporaria*, common newt *Triturus vulgaris* and crested newt *Triturus cristatus* are not strongly associated with heathland habitats, although frogs in particular may occur. The impact of grazing on toads is of particular interest. The natterjack suffered a substantial decline across its range during the 20th century. One of the major factors in this decline was scrub encroachment on heaths and dunes (Beebee, 1977), creating conditions suitable for superior competitors (such as the common toad and frog) and tadpole predators (such as the great-crested newt). Recent work by Denton & Hitchings (1996) on a heathland site where grazing has been reintroduced suggests that grazed habitat is at least as suitable as un-grazed habitat for both adult natterjacks and toadlets, and has the advantage of being highly unattractive to common toads. In addition, grazing around natterjack pools discouraged grass snakes, a predator of toads.

8.4.4 Impacts on small mammals

The key impact of livestock grazing on small mammals is through changes in vegetative cover. Small mammals show differences in their preferences for cover e.g. field voles *Microtus agrestis* prefer open unshaded communities of short uniform vegetation, while wood mice *Apodemus sylvaticus*, although essentially a woodland species, may use more open habitats where population densities are low. Species most likely to occur on heathland communities are field voles, wood mice and harvest mice *Micromys minutes* (Putman, 1986). The harvest mouse is a species of conservation concern, (IUCN Red list - lower risk). The impacts of livestock presence on these species have been studied in the New Forest by Hill (1985). The only small mammals found on grazed heathlands were a very few wood mice. Adjacent ungrazed heaths were found to contain large populations of wood mice and also harvest mice. Within acid grassland communities wood mice were more abundant than on the heathland but were found to use the area only irregularly in the summer. Very few field voles were found and only within areas of thick permanent bracken litter on acid grassland.

These findings suggest that grazing may have a severe impact on small mammal population on heathlands. However, no small mammal studies are known from other heathland areas. A lower grazing pressure and thus greater structural diversity may allow larger populations to be supported on other heaths.

8.4.5 Conclusions

a. Several bird species of conservation concern may be affected favourably by appropriate levels of livestock grazing on heathlands, particularly through increased structural diversity and potential increase in invertebrate prey. Over or under-grazing may lead to population declines.

b. There is controversy over the impacts of livestock on reptile species. Research is needed to clarify the interaction between livestock-induced habitat change and population changes in key species.

c. High grazing pressure reduces small mammal diversity in the New Forest, including a Red Data book species. It is not known whether this is likely to occur under lighter grazing regimes and further research is recommended.

d. In general, direct impacts are seasonal, while the consequences of indirect impacts will not be limited to the season they occur in. Therefore direct impacts will be more easily controlled through the timing of livestock grazing.

e. The spatial scale of indirect impacts on vertebrate species through changes in habitat structure is important. Livestock husbandry may need to be tailored towards creating different scales of habitat diversity for different species.

9. Practicalities of heathland grazing management

The impact of domestic livestock grazing on lowland heathland sites will be affected by the particulars of how the grazing system is set up and management is implemented. Ecological practicalities, such as livestock type and grazing season, have been discussed above. Other aspects which can influence the impact of livestock on heathland vegetation are reviewed briefly here. The practicalities of introducing grazing to semi-natural sites are being increasingly discussed in the public arena (e.g. Simpson & Gee, 1997; Oates & Tolhurst, 2000; Grayson, 2000). Key issues relevant to heathlands are outlined below and sources of further information given where appropriate.

9.1 Infrastructure

9.1.1 Site structure - fencing

Clearly heathland sites must be fenced to contain grazing livestock. A number of alternatives are available. One approach is to fence habitats within the site separately so that the timing and density of stock grazing can be carefully controlled in each. An alternative is to use a more extensive system with only a perimeter fence, allowing stock to move between habitats at will. The first obviously requires a greater time input, both in monitoring changes in the vegetation and moving stock. Fencing is also expensive and visually intrusive, and in upland systems has proved problematic in terms of birds flying into them. This approach is most appropriate where a high degree of control is needed, generally where livestock presence may impact detrimentally on other species of conservation concern such as ground nesting birds, or where a site manager wants precisely timed impacts on the vegetation such as flower-rich maritime heath. Electric fencing may also be used, either where permanent fencing is not permitted or not appropriate, or to concentrate grazing impact on a small area, such as invading scrub.

More extensive systems tend to be used where there are no such requirements, and offer a more natural grazing system as livestock behaviour is not inhibited. They may lead to a greater range of grazing pressures at a given stocking rate and therefore increased ecological diversity (see section on Livestock Behaviour and Stocking Rates). Work in the Netherlands (Bokdam & WallisDeVries, 1992) has also shown that cattle perform better where they have a greater choice of habitat types. The inclusion of adjacent habitat (e.g. grassland, saltings, woodland) may therefore be beneficial on sites where extensive grazing is planned. For sites dissected by roads extensive grazing systems may still be implemented by installing cattle grids where perimeter fencing crosses roads. In some cases road fencing may still be preferred to reduce the danger to livestock and drivers. On extensively grazed sites more time may be required for checking and if necessary catching livestock.

Layback land (back-up land) is also a vital part of a grazing scheme, whether extensive or not. Provision of layback land allows livestock to be removed from the principle grazing areas if vegetation becomes overgrazed or stock loose condition or become ill.

Fencing is a key issue on many sites which are common land. Permission from the Secretary for State has to be sought for fencing common land and, if there is sufficient public opposition, the case must go to a public inquiry where there is of course no guarantee that the verdict will be in favour of fencing. Temporary electric fencing is used on sites such as Chobham Common where permission to erect permanent fencing has been refused (Andy Wragg, pers. comm.). The National Trust considers fencing to be the main constraint in adequately managing their lowland heathland sites, many of which are commons (Katherine Hearn, pers. comm.).

For a review of the suitability of different types of fencing and gates see Simpson & Gee (1997) and Read & Williams (1997). Harris & Jones (1998c) discuss the importance of enclosure shape and the positioning of fence lines.

9.1.2 Other aspects of infrastructure

Adequate water sources need to be supplied where these are not naturally available. Care must be taken in siting these, as watering areas can become heavily disturbed by trampling. Artificial water supplies that are not mains fed may take a significant amount of staff time in refilling. Handling facilities are essential in moving stock and for routine and veterinary attention. Both permanent corrals and transportable hurdles can be used.

9.2 Husbandry

9.2.1 Welfare issues

Animal welfare issues must be addressed in nature conservation grazing projects. Livestock managers need to be particularly aware of these as there may be conflicts between animal welfare and grazing requirements – for example when grazing particularly nutrient poor swards. Tolhurst (2001) provides a comprehensive review of welfare requirements and legal obligations in the context of nature conservation grazing. The MAFF/DEFRA welfare code requires five ‘freedoms’ – freedom from hunger, thirst and malnutrition, freedom from discomfort (shelter), freedom from injury or disease, freedom from fear, and freedom to express natural patterns of behaviour (MAFF, 2000). Conservation organisation may also have their own codes of conduct. For example, English Nature have issued a code of conduct addressing stock inspection (recommended daily), veterinary inspection (at least every 12 months), sward condition (checked weekly), fencing (checked regularly), water (daily access to fresh water) and public access (public access requirements to be addressed on grazed sites).

The concept of extensive grazing schemes where the aim is to allow free-ranging stock to be as self-maintaining as possible and replicate the ecological role of extinct large wild herbivores (e.g. Van Wieren, 1989; WallisDeVries, 1993; WallisDeVries, 1995), raises welfare concerns. This system has been tried in the Netherlands (e.g. Bruinderink & Kuiters, 2000), and it seems unlikely that the welfare compromises would currently be found acceptable in Britain. Further discussion on the Dutch model can be found in Kampf (2000). However, extensive grazing schemes on large sites where stock are by no means wild but are nonetheless free to behave naturally are carried out in Britain. On these sites it is not necessarily possible to check stock every day, and some compromise may be necessary.

9.2.2 Supplementary feeding

It is common farming practice to provide supplementary food for livestock maintained outdoors through the winter. However, in most cases supplementary feeding is undesirable when grazing is carried out on lowland heathland for conservation benefits (discussed in section 8: Impacts of grazing). Supplementary feed may also offer a poorer quality alternative to forage present on site (such as *Ulex* spp in winter), but encourages livestock to linger in the feeding areas rather than forage elsewhere (Rue Ekins, pers. comm.). Despite this there may be cases where site managers wish grazing to continue to reduce vegetation whose nutritive value is however insufficient to maintain the well being of livestock. In such situations supplementary feeding does occur. The problems of intensified trampling and nutrient input may be minimised by restricting feeding to an area of limited conservation interest. Mineral supplements in the form of licks are often used due to the low mineral status of heathlands (e.g. Bokdam & WallisDeVries, 1992) and protein feed blocks (such as Rumevite) can be used to stimulate stock to increase their intake of roughage. The presence of such supplement blocks may alter behavioural patterns, but there is the potential for this to be used beneficially to manipulate patterns of site use (Harris & Jones, 1998).

9.2.3 Avermectins

Avermectins (e.g. Ivermectin) are a group of veterinary medicines widely used to control parasites in livestock since the early 1980s. Avermectins are excreted in the dung for several weeks after dosing, and remain active in the dung against all invertebrate species. This is obviously a cause for concern on heathland sites which support many rare invertebrate (see above in section 8.3). Direct dunging by stock into pools or small water courses may also pose a threat to aquatic invertebrates, and insectivorous vertebrates e.g. chough *Pyrrhocorax*

pyrrhocorax can suffer as a result of a decline in insect abundance (Lamacraft & Muirhead, 2001). Alternative products are available which appear to be more benign (Cooke, 1997; McCracken & Bignal, 2001), and these should be used for livestock grazed on heathlands.

9.3 Stock source: ownership *vs*. grazier

Grazing can be arranged through grazing licenses or informal agreements with local farmers, or by owning stock. There are advantages and disadvantages to both. Grazing managers using their own stock will have more control over the animal type used, stocking density, season and husbandry (e.g. supplementary feeding, use of avermectins). However, staff are legally required to have training in stock husbandry, and moving and checking stock can take considerable staff time. Handling facilities and layback land must be provided. Using a grazier precludes the necessity of buying stock and equipment, and there may be financial gain if the grazier pays a grazing fee. However the grazing manager will have far less control over the grazing regime, and this may be a problem where graziers' commercial objectives are in conflict with conservation objectives for the site. As an alternative, some conservation organisation manage their own 'flying flocks' which can be moved between different conservation sites in an area as required (e.g. Tolhurst, 1994).

9.4 Public response to grazing

Gaining public support for grazing projects is important for sites with public access and crucial on common land. The main problems related to the public present are:

- uncontrolled dogs harassing livestock;
- dog-walkers objecting to using leads. Robust ponies may also occasionally attack overly interested dogs;
- horse riders objecting to the attentions of stallions and young bullocks;
- the perception of fencing as being intrusive on sites which have a tradition of being open and where there is a strong sense of common ownership (even if not by law);
- welfare issues – particularly in areas with large populations of riding horses, the condition of ponies grazing heathlands is often considered unacceptable by the public.

However, many visitors also find livestock attractive and may even visit primarily to see the stock (e.g. Read & Williams, 1997). This may in itself be a problem where the condition of livestock is not viewed favourably by visitors – for example New Forest ponies tend to look 'ribby' by late winter, and although this is generally perceived of as natural and acceptable by conservation managers, the public may not agree (Bullock & Armstrong, 2000). Informing the public is an important step in reducing problems on grazed sites with public access. Possible techniques include using posters and leaflets, holding public meeting, and door-to-door canvassing. In some areas managers have held referenda following such consultations, enabling the public to register their support for the management plans for particular sites. This sort of "ownership" of decisions ensures a high level of public support, even for potentially controversial schemes (S. Hartley, pers. obs.). Some site managers have considerable experience of such issues, and there is the potential to produce a set of guidelines which would be useful to other sites managers facing similar problems.

Grazing can be more problematic in urban areas where there is less understanding of livestock and often greater public pressure on sites. Vandalism is generally greater in urban areas, and this is a serious problem if damage to fencing results in stock being set loose in urban areas, particularly in the vicinity of busy roads and smart gardens. Fires may also be a serious threat to animal welfare, particularly on small sites if animals cannot get away from smoke.

9.5 Funding options

Heathlands, particularly in the lowlands have become economically and culturally dislocated from the landscapes they sit within (see section 4, History and Context). They need human management to persist, but few current management practices are ecologically and economically sustainable. Heathland grazing is rarely economically viable in the current agricultural climate, certainly not in comparison with other land uses such a as forestry or urban development. Live-weight increases are relatively slow on nutrient-poor heathland vegetation for all stock, and the 1996 BSE restriction that beef cattle must reach a marketable condition within 30 months makes viable beef production difficult to achieve on heathlands.

There currently appear to be two alternative responses to these economic constraints. The first (most relevant to large sites) is to use extensive grazing schemes working on the basis of minimum inputs and minimum outputs with no effort put into linking heathlands back into a wider economic context. Such projects have to be funded entirely from the nature conservation sector, and have the greatest potential in restoring areas where natural large-scale ecosystem processes can occur. The second approach is to try and reintegrate heathland livestock grazing into an agricultural context. There are a number of ways this could be done. Current agri-environment payments offer financial compensation to producers for foregoing the economic benefits of aspects of intensification in order to maintain the less intensive grazing systems beneficial to semi-natural communities. In addition, support payments are possible through MAFF/DEFRA’s Organic Aid scheme and English Nature’s Wildlife Enhancement Scheme. However, such payments are not necessarily sufficient to ensure financial viability (e.g. Grayson, 2000). Therefore a key part of agricultural reintegration must be adding value to heathland-raised livestock. For example, there is a growing interest in organic and sourced products (e.g. those reared locally or on nature-conservation sites), which may attract a significant price premium. Local farmers’ markets, such as those set up under local rural development schemes, and farm-gate sales are likely to be appropriate outlets. In addition, regional grazing schemes (Grayson, 1999) provide a co-ordinated approach to conservation grazing schemes that may help financial viability (Oates & Tolhurst, 2000).

In reality, heathland grazing is likely to reflect a combination of these two approaches. The first offers greatest potential in allowing large-scale natural processes to occur in lowland Britain but involves a net financial loss to conservation agencies. The second approach resonates more with traditional uses of heathlands and may help re-establish both sustainable heathland management and a more “holistic” cultural view of heathland landscapes. The newly established Department of Environment and Rural Affairs may provide a framework for integrating environmental protection with other aspects of rural life, including both leisure and agriculture, is an interesting development in this regard.

9.6 Conclusions

a. There are a number of practical issues that need to be addressed when considering the reintroduction of grazing to any nature-conservation site, including heathland. Since there is now a considerable body of experience in this field it would be beneficial to prospective grazing projects if the information combined into a set of guidance notes.

b. Heathland grazing is inhibited by its lack of financial viability unless funding by the conservation sector can be sustained. Socio-economic research into re-establishing the links between agricultural exploitation and other uses of a “cultural” landscape may offer a way forward.

10. Comparisons with other practices and other systems

10.1 Other management practices

Management of lowland heathland is aimed at removing or controlling invasive grass and scrub species, preventing accumulation of soil nutrients, maintaining dwarf shrub plants in vigorous growth stages, decreasing fuel load and thus risk of wild fires, and creating a diversity of habitats for characteristic heathland species. Alternative management practices to grazing used on lowland heath are controlled burning, mowing or forage harvesting, scrub clearance, and herbicide applications against such species as bracken *Pteridium aquilinum*. As with grazing, there are no definitive studies of the impacts of these activities on the biota of lowland heaths (and it is not our aim to review the information on this!), but overviews such as Webb (1986) and Gimingham (1992) illustrate the main impacts. Controlled burning removes most above-ground living biomass, but leaves the litter layer largely intact. Thus it creates areas bare of vegetation which are re-colonised mostly by species that can resprout from underground organs. It also can cause net loss of nutrients in smoke and in run-off. The aim of burning is to remove invading species, to remove degenerate heather growth, and, at the larger scale, to create a mosaic of stands of different ages since burning. Mowing simply removes all vegetation to a uniform height. It is a less severe management than burning, but again can remove invading shrubs, open up the vegetation, and can be used to create a patchwork of stands of different heights. Removal or poisoning of invasive species are very targeted types of management with no impact on the heathland habitat besides slowing the encroachment of scrub, bracken etc.

The choice of which management practice to use will not be based purely on ecological and conservation considerations. Costs vary hugely (again it is not our aim to review these). Although grazing, mowing and burning all result in biomass removal, this is virtually the limit of what can be achieved with the latter two practices. This review has shown that grazing will have a huge range of impacts on heathland biota through direct effects and the many indirect consequences of these. Burning and mowing cannot provide the diversity created, for example by selective grazing and habitat use, dunging, or trampling and poaching. Indeed, the very nature of these practices is to create a uniformity within the managed area. Although a degree of heterogeneity can be achieved by rotational mowing or burning, grazing provides heterogeneity from the scale of a few centimetres up to that of hectares. Burning and mowing may not be practical for very wet areas of heath, although some livestock (e.g. cattle) will graze in these areas.

The impacts of grazing management have rarely been compared within the same heath system to those of other management practices, but Pywell *et al.* (1995) compared the impacts of grazing, mowing and burning at a range of heathland sites across southern England. They found large vegetation differences among areas managed in different ways. In particular grazed areas had greater botanical species richness than areas mown or recovering from burns. The former had a higher incidence of low-growing and small forbs and grasses.

Burning and mowing may be combined with grazing. Bullock & Pakeman (1997) found site managers doing this in Devon and the New Forest. Areas were burnt or mown to remove degenerate heather or tall, dead *Molinia* and so provide fresh growth for ponies or cattle. Thus, burning or mowing was used as a one-off 'pre-treatment' to make subsequent grazing possible. Large effects of this initial removal of unpalatable biomass were seen, with the pre-treated areas being much preferred by livestock and thus developing more species-rich plant communities. Our interviews with site managers revealed that many combined grazing with various other pre-treatments. For example, cutting of scrub before grazing with sheep (Steve Clarke, Sutton Heath, Suffolk), burning before grazing with cows (Pete Gotham Aylesbere, Devon), adding cattle after bracken control to graze the aftermath and trample regenerating frond (Chris Marrable, Ashdown Forest), or forage harvesting being combined with grazing to control growth (Rob Macklin, North Warren, Suffolk).

10.2 Comparison with UK upland heaths

Throughout the report we have tried to highlight key results from studies carried out on upland moors which may be relevant to the conservation management of lowland heathlands. To highlight a few examples here:

- long-term observational studies of grazing impacts which demonstrate the stocking rates above which *Calluna* cover is lost (Welch, 1994; Welch & Scott, 1995);
- the use of aerial photographs and parish/estate livestock records to detect long-term effects of grazing on vegetation dynamics (Hester *et al.*, 1996);
- investigations of sheep foraging behaviour in response to plant quality (Duncan *et al.*, 1994) or vegetation structure (Clarke *et al.*, 1995a, b; Hester & Baillie, 1998; Hester *et al.*, 1999);
- use of exclosures and experimental manipulations to demonstrate the role of environmental factors interacting with grazing in vegetation change (e.g. soil type) and show capacity for recovery (Hartley *et al.*, 1997; Alonso *et al.*, 2001);

- the development of foraging models to predict impacts on vegetation at a range of spatial scales including farm-scale level (Armstrong *et al.*, 1997a, b; Milne & Sibbald, 1998).

However, these examples have also highlighted some of the key differences between upland and lowland heaths in terms of both management history and underlying ecology. These differences may severely limit the applicability of the results of upland studies to the lowlands. There are two main ways in which the two habitats differ: in the way they are (and have been) managed, and in their ecological characteristics.

10.2.1 Management

Upland heaths have long been managed as a resource for grazing animals, whether hill sheep for farming, or red deer for sport. Both sheep (in some areas) and particularly deer numbers have increased in recent years (Clutton-Brock & Albon, 1992). Consequently, the usual management problem in the uplands is degradation or loss of habitats important for conservation (Mackey *et al.*, 1998), often ascribed to over-grazing (Welch & Scott, 1995; Bardgett *et al.*, 1995). Heather cover has been lost to grasses and tree regeneration is virtually non-existent. In contrast, in lowland heaths the use of small areas of poor quality forage for grazing is not considered economic and the main management problem is thus a lack of grazing leading vegetation changes. A possible exception to this is areas of the New Forest where commoners have rights to graze relatively high numbers of ponies and cattle, which has a substantial impact on the vegetation. Another difference between upland and lowland heaths with respect to grazing is that in the uplands herbivores are often unenclosed wild species with large range sizes, whereas management of lowland heaths by grazing usually involves a much more intensive approach with domestic livestock grazing smaller fenced areas.

10.2.2 Ecology

Management techniques have differed between the two systems because they differ substantially in terms of their ecology. For example, upland systems can be considered as rather less complex than lowland ones: they are less species rich, there are fewer vegetation and habitat types, and the habitat is less fragmented and structurally variable. This means that many of the results from upland studies, such as foraging models which have herbivores choosing between two vegetation types, will not be appropriate for the more complex situations in lowland heathland.

There are also fundamental differences in the abiotic environment between the two types of heath: the uplands are wetter, colder and have peaty soils, but have greater soil nutrient concentrations (phosphorus, nitrogen, potassium, magnesium, calcium) (Chapman & Clarke, 1980). Vegetation types which are adapted to grow slowly on nutrient-poor soils will be more vulnerable to damage from eutrophication than upland ones, as has been found in the Netherlands (Brunsting and Heil, 1989; Aerts *et al.*, 1990).

The much smaller area of most lowland heaths compared to uplands makes them, and the species dependant on them, more vulnerable to land use change. Habitat fragmentation is a problem for many species of conservation importance, particularly poor dispersers such as many invertebrates and is probably a bigger problem in the lowlands. Overall, in Scotland, 25% of the upland heath has been lost since 1940 (although this figure is over 40% in some regions) (Mackey *et al.*, 1998), but over 50% of lowland heath has been lost over the same period. This can also be seen from the figures for losses of upland Scottish mires (27%) as compared to lowland mire (44%) – greater accessibility means lowland areas are a bigger conservation challenge.

10.3 Comparison with other European countries

We have also drawn on studies of grazing on lowland heath in other European countries. These included the Netherlands, Denmark, Germany, France and Northern Spain. This is valuable, because the general impacts of grazing will be similar, as will the fundamentals of animal grazing and ranging behaviour. Specific comparisons with the Netherlands and Northern France are the most valuable, as these countries have heath systems most similar to lowland Britain, with a similar species pools, climate and soils. Scandinavian heaths resemble British upland heaths and southern European systems are very different (e.g. the species pool, soil types, seasons, hydrology, etc) (Gimingham *et al.*, 1981; Webb, 1986). However, the specifics of stocking densities, the appropriate livestock to use and even the responses of certain species to a particular management may vary among countries. Indeed, as we have seen, these variables can change across and within the lowland heathland Natural Areas in Britain. Therefore, it is unlikely that studies in other countries will be used to draw any but the most general conclusions about heathland and species' responses to grazing.

11. Methodologies for studying heathland grazing

Studies designed to extend our knowledge of how to manage lowland heaths by grazing, must be both to be scientifically rigorous and to provide relevant information for site managers. These can be contradictory requirements. Scientific and statistical rigour demands replication and good sample sizes, which allow clear and general conclusions. However, this may be at the expense of plot sizes and the number of taxa sampled. Rare taxa may be excluded in particular because sample sizes are necessarily small. Conservation managers may require information at relevant (i.e. large) spatial scales and for many taxa, especially rare species. However, because large plots take a long time to sample and detection of rare taxa requires very intensive sampling, such information may come at the expense of replication and suitable sample sizes and therefore in a loss of generality. Different parties may believe one extreme is more important than the other, but ideally both rigour and relevance must be achieved. This section will review methodologies for studying lowland heathland grazing and to what extent they meet these criteria. As a precursor to this review we will consider several key elements of grazing studies.

11.1 The aims of a grazing study

Different grazing studies may have different aims. It is important both to be clear what the aims are when setting up the study, but also to be aware of such differences when comparing studies. Here we highlight two issues important when making between-study comparisons.

11.1.1 Comparisons of alternative managements

These fall into three types.

Grazing *vs* no management is the commonest comparison. As with such studies in grasslands, this comparison is of limited value (see Bullock *et al.*, 2001), because heathlands are successional and will develop towards scrub and woodland in the absence of management. Scientifically, such comparisons give us an extremely coarse understanding of the effects of grazing (e.g. vegetation becomes shorter and more open). Practically, as we know heathland must be managed in some way, it is more relevant to compare alternative management practices.

Grazing can be compared to other practices such as burning or mowing.

Comparison of different grazing practices is more relevant to this review. Ideally, stocking rates, livestock species and breeds, grazing season, etc can be varied and their effects compared.

11.1.2 Types of measurements

These may include: the impacts on different taxa such as dwarf shrubs, scrub, the herb and bryophyte layer, invertebrates and vertebrates; vegetation structure and height; abiotic variables such as hydrology, microtopography, soil structure and soil nutrient status; livestock foraging and behaviour and livestock performance. Different studies, with different aims and priorities, often use alternative methods to make these sorts of measurements and hence, even if the same parameter has been recorded, direct comparisons may not be appropriate.

11.2 Issues of scale

The spatial scale of the study must be considered, particularly in terms of the plot size or the area over which the grazing treatment is applied. Two factors severely limit the minimum size of treatment plots. First, the area of vegetation required by a reasonably sized group of livestock may be very large in nutritionally poor heathland habitats. Bacon's (1998) review of lowland heathland grazing projects showed livestock were grazed in groups of 3-50 cows, 2-20 ponies and 20-400 sheep (excluding followers), over areas of 12-400 ha for cattle and ponies and 1.5-200 ha for sheep. These heathlands supported 0.1-0.4 cows ha^{-1}, 0.015-3 ponies ha^{-1} and 0.8-2 sheep ha^{-1} (NB these are stocking densities during the grazing period, not stocking rates). Mathematically, this would allow, e.g., plots of 2.5-10 ha^{-1} each with one cow. However, domestic livestock are herding animals and their grazing behaviour can affected by the numbers of animals in a group (e.g. Penning *et al.*, 1993; Rind & Phillips, 1999). Therefore, it is dangerous to extrapolate the consequences of the behaviour of a small group of grazers used in an experiment to that of a larger 'normal' herd which would be used in the grazing management of a heathland. It is not clear what the minimum size of an experimental herd should be for each livestock species, but a herd of 10 cattle would, by Bacon's (1998) data, require a plot of 25-100 ha.

Second, one must consider the areas that populations of target taxa may occupy. While the populations of many small heathland herbs may occupy only a few square metres (S. Lake, unpub. data), other taxa may require much larger areas to maintain viable populations. A population of the silver-studded blue butterfly *Plebejus argus* requires at least 0.1 ha, and up to 1 ha, of heathland and this range probably applies to many flying invertebrates (Thomas 1984, Jeremy Thomas, pers. comm.). Similarly, ground-dwelling heathland invertebrates such as ants require between 0.05 ha (*Myrmica* spp.) and 0.5 ha (*Lasius* spp.) to maintain a viable population of 20-30 colonies (Graham Elmes pers. comm.). Heathland herpetofauna are considered to need at least 1-2 ha for a population to persist (Herpetological Conservation Trust, pers. comm.) and a Dorset population of the smooth snake *Coronella austriaca* which has been monitored for several years covers an area of 12.5 ha (Chris Reading, pers. comm.). Heathland birds exhibit a variety of territory sizes. The Dartford warbler *Sylvia undata* has territories of 1-10 ha (van den Berg *et al.*, 2001), while the nightjar *Caprimulgus europaeus* has densities of 6-12 ha per male (Burgess *et al.*, 1989). In order to truly measure the impacts of a grazing regime on a species, the treated area must encompass at least one population. If a population extends beyond the treatment boundaries (or falls within more than one treatment plot), then positive or negative treatment effects may obscured: 1) by source-sink dynamics, whereby patches in which the population is declining are supplemented by immigration from patches with positive population growth; or 2) by active habitat selection in mobile species such as birds and flying insects.

These figures suggest that accurate assessment of the impacts of a grazing regime on the populations of most taxa would require treatment plots/areas of at least 5-10 ha (although this may not be big enough to accommodate a reasonable livestock herd). Certain very mobile taxa such as birds have populations which may extend over several heaths, and so studies could never be sufficiently large scale to accommodate these (see van den Berg *et al.*, 2001). The same problems may apply to species with metapopulation dynamics, such as the silver-studded blue butterfly (Webb & Thomas 1994), in which larger scale source-sink dynamics may obscure responses at the plot level. However, the use of plot sizes large enough to accommodate one bird territory or one population in a metapopulation could be combined with mechanistic demographic and dispersal studies (see below) to understand the impacts of grazing on these species.

Practical difficulties thus mean that our experiments and monitoring activities are often not on a large enough scale and we need a variety of methods to “scale-up” our understanding of grazing impacts from plot scale to management plan scale. We have several methods at our disposal: firstly, we can use mechanistic demographic and dispersal studies (see below), secondly we can use foraging models (see below). Both of these scale-up spatially, but we can also scale-up temporally by using long term observational studies to inform our extrapolation from experiments. For example, a study of over 20 years on upland heath allowed Welch *et al.* (1994) to determine the critical stocking level above which heather cover declined.

Long-term studies also allow us to estimate the minimum time necessary for manipulative studies to be informative. Grazing studies of up to 12 years on improved grassland (Bullock *et al.*, 2001), 33 years on Welsh hill pasture (Hill *et al.*, 1992) and 10 years on lowland heath (Bokdam & Gleichman, 2000) showed continuing vegetational changes. These changes did slow over time, with most changes happening over the first seven years in the hill pasture and over the first five years in the heathland. This suggests that grazing studies examining vegetation impacts should run for at least five years, and probably for 10 years. Again mechanistic population and foraging may allow extrapolation and prediction of species' responses into the future (see below).

11.3 Monitoring methods

As this review has shown, most information on the impacts of lowland heathland grazing comes from non-quantified observations (usually following addition of grazing animals not within an experimental framework, see below). Thus, occasional visits to a site may suggest, e.g., that a certain plant or reptile species is increasing or declining or that the dwarf shrub vegetation is more open. This form of information gathering is easy and cheap, and it has provided useful indicators as to the possible impacts of certain grazing practices. However, this does not provide objective information for analysis or quantification of responses. It is also notoriously subject to bias, in that the observer may see what they want to see. This method is often combined with a lack of monitoring before grazing was implemented, meaning it is not clear whether apparently new species have colonised or have been found as a consequence of increased vigilance. For example, petty whin *Genista anglica* seemed to have gone extinct at a heath in Dorset, but plants were found following the reintroduction of grazing. The initial impression that the species had re-colonised was soon dispelled as the gnarled woody stems of the plants showed they were many years old and had simply re-emerged as the grazers reduced the vegetation height (S. Lake unpub. data).

Quantitative monitoring of grazing impacts is vital to provide accurate information for managers. This can be of several types, and the choice of which to use depends on the aims of the study:

Abundance of different taxa can be assessed using standard methods such as quadrats for plants or vacuum sampling for invertebrates (see Sutherland, 1996 for a guide to methods for all taxa).

Mapping of vegetation types (e.g. dwarf shrub, scrub, bare ground, grass) within large treatment plots will indicate gross vegetation changes such as retraction of scrub or the expansion of grass-dominated vegetation (e.g. Bakker *et al.* 1983, Rose *et al.*, 2000).

Demographic and dispersal studies on selected taxa will provide information for predicting long-term consequences with population and metapopulation models (see below).

Habitat changes can be monitored and related to the requirements of specific taxa. Variables include; vegetation height and vertical structure, light intensity and temperature at the soil surface, microtopography, hydrology, soil structure, soil nutrients, and heterogeneity in all of these measures.

Large-scale monitoring using remote sensing, land cover mapping and aerial photography can be used to map vegetation changes in terms of vegetation boundaries, extent of invasive species, and heather structure (Marrs *et al*, 1986; Hester *et al.*, 1996).

It may also be necessary to study aspects of the ecology and performance of livestock.

Habitat use by livestock can be assessed using counts along transects (Pratt & Putman, 1986; Gordon and Illius, 1989), total counts within fixed areas (Osborne, 1984), following animals (Pollock, 1980), dung density (Bakker & de Bie, 1983), or radio-tracking over larger areas (Catt & Staines, 1987). Preference indices (Hunter, 1962; Pianka, 1973; Jacobs, 1974) can then be used to determine habitat preferences.

Diet selection can be measured by faecal analysis (Bakker & de Bie, 1983; Putman & Pratt, 1987; Baker, 1993), alkane analysis of rumen contents (Fraser & Gordon, 1997), heather utilisation rates (Clarke *et al*., 1995) or direct observation of grazing behaviour (S. Lake unpub. data). The latter can be supplemented by 'pluck samples' whereby the vegetation within a few centimetres of the grazed vegetation is plucked by hand and its composition analysed (e.g. WallisDeVries, 1996).

Livestock performance can be assessed over a season or shorter periods by measures of live weight gain, condition score, fat reserves, etc (e.g. WallisDeVries, 1996).

It is also important to consider the frequency of monitoring. Monitoring before management treatments are applied is vital for non-replicated designs (see below) in order to determine initial differences among plots. Ideally, such pre-treatment monitoring should extend over several years (e.g. three years) in order to establish the natural variation in population numbers and other variables. Apparent changes under the treatments can then be compared statistically with this natural variation. Pre-treatment monitoring would also aid interpretation of results from replicated designs, although variation among replicates would normally be used to assess the significance of treatment differences.

11.4 Randomisation, replication and controls

In setting up grazing experiments and studies it is vital to ensure treatments are allocated randomly to plots or sites. In practice, site managers apply grazing regimes to certain areas and not others for particular reasons and this usually means the grazed and ungrazed (or differently gazed) areas show initial differences. While this is acceptable when done for site management reasons, when done to understand the impacts of certain grazing regimes this is bad experimental practice and severely undermines any conclusions one may draw. Initial differences are acceptable to some degree if they are random, and more acceptable in replicated designs, because replication will iron out initial differences among the differently treated plots. However, systematic initial differences (through non-random allocation of treatments) may lead to immeasurable errors in assessing treatment effects. The most usual error may arise through 'non-additive' effects, whereby plots with different initial conditions respond differently to the same grazing regime. For example, upland studies showed responses of *Calluna* to grazing varied among soil types; heather was more resilient on wetter and peat soils (Hartley, 1997; 2001).

Unreplicated designs will lead to similar problems; that treatment effects will always be confounded with historical and environmental differences among the treated plots or sites. Thus, some degree of replication will vastly improve our ability to interpret grazing studies. Earlier we recommended that pre-treatment monitoring would aid in over-coming problems arising from a lack of replication. However, this assumes effects are non-additive, i.e. that we can simply subtract initial differences among plots to arrive at the treatment effects.

It is worth mentioning controls here. Classical ecological experimentation has usually involved the use of 'controls', plots or sites within which no treatment (e.g. no grazing) is applied. In studies of the management of successional systems, the idea that no management (e.g. no grazing) is a 'control' is a mistake. The systems do not remain static under no management, but undergo succession, e.g. from dwarf shrub heath to scrub. Thus, no management is a treatment as much as any other and does not provide a baseline against which to judge other treatment effects.. However, unmanaged plots may be useful if considered as a type of treatment, particularly when considering grazing effects on less studied taxa.

11.5 Study methods

The range of possible methods for studying the impact of grazing on heathlands is assessed below.

Within-site replicated plot experiments

This is the classical approach to assessing the impact of grazing and other management practices on ecological communities. The use of replicates, usually by blocking (i.e. replicates are spatially segregated to allow spatial variation in ecological processes to be assessed), allows the use of statistical techniques such as analysis of variance (ANOVA) which give rigorous and clear results. For example, Hulme *et al.* (1999) investigated the effects of three grazing intensities on the vegetation of a hill grassland, using two blocks. Vegetation changes in improved grassland were studied by Bullock *et al.* (2001) in an experiment using two grazing levels in each of three seasons replicated in two blocks. In theory this is the best approach to use, but practical problems limit its usefulness for studying grazing of lowland heath.

To allow replication within a single site (and to limit costs associated with replication), plot sizes have usually been relatively small. Grazing studies have used plots of 0.25 ha in improved grassland (sheep, Bullock *et al.*, 2001), 0.3 ha in upland *Festuca* grassland (sheep, Hulme *et al.* 1999), and 1.2 ha (for sheep) and 3.7 ha (for cattle, but this plot was not replicated) in upland *Molinia* grassland (Grant *et al.* 1996). As discussed above, much larger plot sizes would be needed to accommodate reasonable groups of cattle or ponies and to encompass populations of key invertebrates and vertebrates. It is not a coincidence that most studies of this type have looked only at the vegetation responses (some have studied invertebrates as well, despite small plot sizes; Gibson *et al.*, 1992; Treweek *et al.*, 1997). It seems unlikely that one could achieve realistic grazing treatments using replicated plots within a heathland site, unless one was only to look at effects on plant species and habitat structure.

11.5.1 Exclosures

Exclosures were used in some of the first ecological experiments. Tansley & Adamson (1925) used exclosures to study the effects of rabbit grazing on the South Downs. The method involves establishing a grazing regime over a site and erecting fenced exclosures against the grazing animals. Replicate exclosures can be used. A good example of this method is at Arne

Nature Reserve (RSPB) in Dorset. Exclosures have been set up in each of two heathland vegetation types, with five replicates in each type. Each exclosure is 20m × 10m; one half is fenced against cattle only and one half against cattle and (wild) deer. Vegetation and structural changes are being monitored within the exclosures and in permanent plots in the adjacent grazed heath.

As shown by the interviews with site managers some exclosures have been set up within heathland grazing systems. These have a number of problems in that: they are usually small (many have dimensions of 5-10 m); only a few are set up, i.e. replication is poor; monitoring is often irregular and cursory, or even non-quantitative; and they provide a simple comparison of no grazing *vs*. a single grazing regime. The first three problems could be overcome by a greater investment of money and time. However, exclosure studies would thus come to resemble the replicated plot design, with the associated impracticalities discussed above. The Arne example maintained a fairly small plot size by restricting the study to that of impacts on plants and habitat structure. The last problem, that exclosures allow only a no grazing treatment rather than alternative grazing treatments, is more insurmountable. However, comparisons between grazed and ungrazed areas can be valuable. For example, in the uplands, exclosures on heather moorlands have been compared with matched unenclosed areas to demonstrate a range of important parameters which can inform grazing management (Hartley 1997; Gardner *et al.* 1997; Alonso *et al.* 2001; Hartley 2001). Firstly such experiments have shown the consequences of particular grazing impact levels in terms of vegetation change, secondly they have shown how grazing impacts are modified by other environmental factors such as soil type, and thirdly, perhaps most importantly, they demonstrate whether and how quickly a given vegetation type can recover if it has been damaged by inappropriate grazing management. In addition, it may be possible to develop the use of exclosures further: 1) to study effects of seasonal grazing, by opening up the exclosures at certain times of year (while livestock graze for longer periods outside the exclosures); or 2) to compare different livestock species, for example by using sheep (which can use smaller plot sizes) in exclosures and cattle or ponies in the open heath.

11.5.2 Using sites as replicates/blocks

Spatial scale problems can be overcome by using individual sites as replicates. Thus a number of grazing treatments are applied within one heathland system and these are repeated across a number of heathlands. This would allow grazing regimes to be applied virtually as they would be in a heathland management programme and thus allows realism. The number of treatments would have to be limited to accommodate this scale. Plots would be designed according to the landscape, and should be as similar as possible. At this scale plots would show initial differences, but random allocation of treatments and replication across sites would allow the consequences of these differences to be minimised. Replication should be within the natural boundaries of a group of heathlands, perhaps within a ‘Natural Area’, as the replicates should be as similar as possible. Use of, e.g., a Purbeck heath and a Devon heath as two replicates would be of limited value due to the large differences among these regions (and thus non-additive effects). Replication within Natural Areas could be combined with comparison among Natural Areas to determine similarities and differences among Natural Areas. Analysis of the impacts of the grazing treatments would follow an ANOVA structure.

11.5.3 Addition of livestock on a single site

A number of studies of single sites have monitored a heath before grazing was implemented and then over time subsequent to livestock addition (e.g. Bakker *et al.*, 1983; Buttenschøn & Buttenschøn, 1985). Changes over time are analysed, e.g., by ordination techniques, and these are assumed to be caused by the grazing regime. In such studies changes over time may be due to other environmental changes such as atmospheric deposition or climate change and the consequence is that only large changes which seem to be explained sensibly by grazing are detected. These studies may be improved by using exclosures (e.g. Buttenschøn & Buttenschøn, 1985; Bokdam & Gleichman, 2000) to provide a baseline of changes not due to grazing. Of course, these assume non-additive effects. Further, the comparison is only of grazed with non-grazed.

11.5.4 Use of existing grazing programmes

These can be used in three ways. Where managers graze only part of a site, or different parts of the site have different grazing regimes, these different areas can be visited and surveyed (e.g. Bullock & Pakeman, 1997). Similar grazing regimes in different parts of the site may provide replication. Different sites may provide a form of replication, but if regimes have not been co-ordinated, comparisons will usually be coarse, such as not grazed *vs* grazed or heavy *vs* light grazing (e.g. Bullock & Pakeman, 1997). Such an approach is extremely problematical, although it offers a cheap way of studying grazing with no costs in setting up treatments. Grazing regimes will rarely have been assigned randomly and there is no real replication.

A second approach is to assess a large area which has been open to livestock, but the grazing and ranging behaviour of the animals has created patches which have been grazed at different intensities. These patches are identified, usually in terms of vegetation height, dung density, or observation of animals, and then surveyed and compared (e.g. Putman, 1986; Bakker, 1989; Bullock & Pakeman, 1997). Again different sites can be used as replicates. However, the grazing intensities will not be randomly assigned. Livestock show preferences for good, non-random, reasons. Short, grassy areas (e.g. created by fire or mowing) may be preferred to tall, woody vegetation and differential grazing by animals will merely exacerbate such differences, whereas this method would assume they are all due to grazing.

Hester *et al.* (1996) demonstrated a third approach. This involved analysis of aerial photographs taken over 42 years and covering 1000 km^2 of Scottish moorland. Changes in vegetation were related to records of changes in land use and grazing management over this time period.

11.5.5 Meta-analysis of existing studies

In the above we have assessed each study approach on its own merits and whether it is rigorous or practical to use this approach in setting up a new study. While many approaches have limited value, they are being used in ongoing studies and certain methods (e.g. exclosures or monitoring over time) could be used in conjunction with new practical management schemes. Meta-analysis of data collected in this way could provide valuable, general information as to the effects of different grazing regimes. This involves development of an appropriate statistical methodology to combine the results from a range of different studies (see Gurevitch & Hedges, 1993). A range of statistics are possible, but when many non-experimental datasets are available ordination techniques such as Canonical Correspondence Analysis can be used to separate effects of grazing treatments from those of other environmental variables.

Meta-analysis can be used for existing data, but if new data are to be collected from existing and new grazing projects (i.e. aside from proper experiments), these should be collected according to an agreed protocol in order to extract most information. A data collection protocol could be linked to standardised procedures for such methods as the use of exclosures.

11.6 Generalising and extrapolating from grazing studies

A major aim of grazing studies is not just to find appropriate management strategies for a particular heath, but to generalise to allow the design of grazing regimes for whole regions. Good experimental studies across a variety of sites, and meta-analyses of different studies will provide general information as to the impacts of grazing on ecological processes. However, further studies to achieve a mechanistic understanding of grazing impacts can supplement this phenomenological information and greatly aid generalisation and prediction, as can the use of various modelling approaches.

11.6.1 Demographic and population modelling studies

These can be used to perform Population Viability Analyses (Beissinger & Westphal, 1998; Menges, 2000) and assess the fate of species' populations under a grazing regime. This involves measuring the effects of grazing on different life history stages and using theses to parameterise simple models which calculate population growth rates (e.g. Bullock *et al.*, 1994). Knowledge of the mechanisms by which a species responds to grazing may allow manipulation of grazing to better benefit (or control) the species. Even if full demographic studies are not done, targeted studies may be useful. The regeneration ecology of several rare heathland herbs is being studied in order to predict their responses to grazing (S. Lake, unpub. data). Dispersal studies can be carried out as well, particularly of how livestock may affect dispersal and thus the ability of species to spread (e.g. Coulson *et al.*, 2001). Metapopulation studies and models can be used to predict species responses to a changed suitability of heathland habitat (e.g. Webb & Thomas, 1994). Key species which could be targeted for such studies are suggested in Appendix 8.

11.6.2 Mechanistic approaches to species responses

The habitat requirements of key species can be analysed, particularly in relation to habitat structure. This can provide predictions of how a species will respond to grazing. To be valuable, these should use behavioural/ecological studies rather than simple observations of the type of habitat a species is generally seen in. For example the habitat requirements of a number of lowland heathland species have been well characterised; the silver-studded blue butterfly *Plebejus argus*, a red ant *Myrmica sabuleti*, the heath grasshopper *Chorthippus vagans*, the sand lizard *Lacerta agilis* (Thomas *et al.*, 1999) and the Dartford warbler *Sylvia undata* (van den Berg *et al.* 2001).

Livestock habitat and grazing preferences will suggest which heathland areas (e.g. wet heath rather than dry heath) and which species may be most affected by grazing. Simple grazing preferences will not tell the whole story however, as plant species differ in their tolerance to grazing as well as their attractiveness to livestock.

Species' traits and functional groups can be used to understand responses to grazing and to compare a variety of grazing studies. Plant traits include species ability to colonise gaps, palatability to grazers, competitive ability, regrowth ability, etc. Regression techniques can be used to test hypotheses about the impacts of grazing (e.g. is grazing affecting the community by changing the gap dynamics or by preferential grazing?) and to predict species responses to grazing; even of species not studied (e.g. Bullock *et al.*, 2001.). Plant functional groups can be classified, e.g., by life history (e.g. annual/short-lived perennial/long-lived perennial), morphology (e.g. rosette/short/tall or shrub/dwarf *vs.* shrub/herb), taxonomy (grasses/forb/legume) and regeneration traits (e.g. seed bank type, clonal or not) (Lavorel *et al.*, 1997; 1999). These are useful for less well studied species and again can be used to analyse and then predict responses to grazing.

11.6.3 Forage utilisation and vegetation change models

This sort of modelling approach aims to use knowledge of grazing behaviour to predict vegetation changes. A particular difficulty in predicting the impacts of grazing on vegetation change is the spatial variability in herbivore densities and patterns of habitat use. This means that the local grazing pressure on a "patch" of vegetation cannot necessarily be inferred just from the overall numbers of animals in an area. It was in response to this problem that models were developed which attempt to use knowledge of foraging behaviour (e.g. habitat and species preferences) to predict the grazing pressure by herbivores with respect to season and vegetation availability. One such model (HILLPLAN, by Macaulay Land Use Research Institute) predicts the relative sheep grazing time and intensity on a range of vegetation types and hence the relative change in biomass of these vegetation type (Armstrong *et al.*, 1997a, b). This model has now been given a spatial component to allow predictions to be made at the level of the whole farm (Milne & Sibbald, 1998).

Models like this are undoubtedly useful but they are forced to rely on simplistic assumptions and often lack data to validate them. For example, the vegetation categories are over simplified (patches are categorised as *Calluna*, *Nardus*, *Molinia* or *Agrostis-Festuca*) and plant growth is calculated using average temperatures and rainfall whilst not including a parameter for soil nutrient levels. Similarly, whilst foraging is almost certainly the major determinant of movement of hill sheep, the model relies on sheep always choosing the area of highest plant quality, whereas they may in fact use areas of poorer quality forage, if they are seeking shelter for example. In fact, forage quality is defined on the basis of dry matter digestibility alone, a rather limited assessment which may be inaccurate if for example the vegetation patch includes plants of different ages (Armstrong *et al.*, 1997a, b).

Thus although these models are reasonably accurate for predicting the behaviour of hill sheep at a coarse scale, they have been less successful at predicting vegetation change, partly because of problems predicting the growth of plants, but also because of small scale variation in both herbivore behaviour and vegetation type. Vegetation is usually a mosaic not a patch.

These problems have led to more intensive investigations of herbivore behaviour in mixtures of vegetation. These experiments have shown that stocking rate alone does not accurately predict grazing impacts because of factors like sheep preferring to graze on small rather than large grass patches, on heather at the edge of grass patches not the main canopy and facing uphill (Clarke *et al*. 1995a, b; Hester & Baillie, 1998; Hester *et al.*, 1999). These more recent studies indicate both the importance of habitat structure in determining grazing impacts and the future direction models should take if they are to make accurate predictions. In response to this, a new modelling approach for predicting the impacts of herbivores grazing a mosaic of heather and grass has been developed (Palmer & Hester, 2000), but as no field data were available to validate this model, it was developed purely by simulation within a GIS. Thus its applicability and accuracy remain uncertain.

Of course another difficulty is that all the above models were developed in relatively "simple" upland systems. How useful they will prove to be in the more structurally complex lowland heaths, where the habitat is more fragmented, more species rich and plant growth is quicker must be open to question!

11.6.4 Conclusions

a. Comparisons between the effects of different grazing regimes on the heathland habitat and biota are essential to allow management to be planned to achieve particular biodiversity objectives.

b. Unfortunately, much of the data collected on the effects of grazing on lowland heathland is not easily interpretable, having been collected from sites with no baseline monitoring, or from studies which were insufficiently replicated. In general, monitoring is not conducted frequently enough, is non-quantitative and/or does not consider all the relevant taxa. The importance of good design of experiments or other forms of study and the monitoring programme cannot be over-emphasised.

c. A meta-analysis of existing data from lowland heathland grazing studies would yield information of some value. However, the design and implementation of a comprehensive monitoring programme to be applied to ongoing and new grazing programmes would yield information of much greater value and rigour. This should involve monitoring before grazing is initiated, to provide a baseline.

d. More experimental studies would yield important information. Many different techniques are available for carrying out such studies. Exclosures are one of the most popular, although it can be difficult to extrapolate from the results obtained by excluding grazing to those which may be obtained by manipulating grazing intensities.

e. It is difficult to extrapolate from the results of small plot/exclosure studies to a scale more appropriate for grazing managers who may need to manage taxa with populations that range over large areas. Scaling-up can be achieved using long-term or large-scale observational studies, by using a mechanistic approach to understanding species responses, or by modelling.

f. The most valuable, and resource-hungry, approach to solve scale and replication problems would be to set up replicated experiments in which different heaths in a region are used as replicate blocks. Each heath would be divided into plots of several hectares and different grazing regimes would be applied to different plots. Monitoring of a range of habitat variables and taxa would supply extremely rigorous information on the effects of different grazing regimes.

g. Modelling grazing impacts is a useful way forward, but many models have been developed for upland systems and may be an oversimplification for lowland systems; in addition models often lack good data to validate them.

12. Conclusions and recommendations

In general we can conclude the following.

- Grazing by livestock is an appropriate management for lowland heathland, to deliver biodiversity objectives.

- Appropriate grazing can produce a greater diversity of habitats and thus a greater biological diversity than other management types such as burning or cutting.

- Grazing impacts must always be considered in terms of the intensity of grazing and the livestock types used; negative effects, or poor achievement of targets can arise from inappropriate grazing. The negative impacts of grazing on biodiversity over much of upland heathland in Britain illustrates the consequences of overgrazing.

12.1 The current state of knowledge about lowland heathland grazing

12.1.1 Grazing impacts

We can conclude definitely that heathland grazing *per se* has the following impacts.

- It opens up vegetation and decreases the height of dwarf shrubs and rank vegetation (e.g. *Molinia caerulea* dominated mire, *Deschampsia flexuosa* dominated grass heath).

- It shifts vegetation towards a greater representation of fine grass and herbs.

- It increases plant species diversity.

- It can control some invasive species such as *Molinia caerulea*.

Further, our knowledge of species' ecology and comparisons with other better-studied systems suggests the following:

- Many of the lowland heath plant species of conservation concern (e.g. BAP and RDB) will be benefited by some degree of grazing.

- Many lowland heath invertebrates and vertebrates of conservation concern have a clear need for grazed habitat, although the necessary grazing intensity is species specific.

- Many other plant and animal species require tall, scrubby habitat characteristic of low levels of grazing or no grazing at all.

- Therefore, grazing management should aim to maintain a heterogeneity of vegetation types and structures to provide habitat for a diversity of key heathland species.

Knowledge of how to manage lowland heathland by grazing is hampered by poor information on the following.

- The habitat requirements of many heathland plants, invertebrate and vertebrate species.
- How these habitat requirements might be met by grazing management.
- The effects of different grazing regimes (stocking density, grazing season, livestock species and breed) on heathland vegetation, species of conservation concern or invasive species.
- How different grazing regimes may affect the range of vegetation structures and habitats present on a heathland system as a whole, and thus how to best provide habitat for a diversity of taxa.

12.1.2 Livestock behaviour and performance

An understanding of this is essential in order to plan grazing management and choose the livestock which will achieve management objectives.

- Livestock species differences in diet selection are reasonably well characterised and knowledge of these can be used to help select appropriate species for a management regime.
- Knowledge of diet selection differences among breeds is observational and poorly quantified and these are not well distinguished from the learning history ('background') of animals.
- Knowledge of differences due to other aspects of livestock type (age, gender) is more limited.
- The effect of learning history on diet selection is virtually unknown, but may be an important factor.
- Habitat choice and ranging behaviour differences among livestock types are not well understood.
- The effect of the size and geography of the heathland site on habitat choice and ranging behaviour is poorly studied.
- Knowledge about the performance of different livestock types on lowland heathland and the consequence of this for animal welfare or meat production is limited.
- Stocking density is a poor measure of grazing intensity. Utilisation rate of dominant plants may be the best measure and is used for such studies in the uplands.

12.1.3 Socio-economic aspects of heathland grazing

It was not in the remit of this review to address the socio-economic considerations of heathland grazing, and debate has been focussed on the conservation management aspects rather than its economic sustainability. However, socio-economic research into ways of integrating environmental protection of heathland with other uses, particularly agriculture and leisure, may be beneficial to the expansion and long-term viability of heathland grazing projects. Research should explore ways of maximising returns from livestock by considering the agricultural and marketing implications of using different management regimes (e.g. rare breeds) and marketing strategies (e.g. sourced products, local sales). Such a study would be timely in the broader context, at a time when UK agricultural policy and economics are changing rapidly.

12.2 Recommendations

There is an urgent need for more information to guide the use of grazing as a management tool for lowland heathland. This can be obtained by the following five methods, ordered in terms of the value and rigour of the information that will be gained. However, Method 1) would require a substantial effort in terms of time and money. Therefore, Methods 2) and 3) would be achieved more easily and provide important information in a relatively short time. Methods 4)-6) could be carried out within studies of the type suggested in Method 2), and would substantially add to the value of these studies. In studying grazing regimes, the variables that need to be considered in terms of the impact on biota are: grazing intensity; timing and duration of grazing season; type of livestock, including species, breed, gender, age, origin, and husbandry. Because stocking density is a poor measure of grazing intensity, so use of a surrogate is recommended; e.g. utilisation rate of heather in drier heaths, or of other dominant plants such as *Molinia caerulea* in wetter heaths or coarse grasses in grass heaths.

Method 1. *Establish full grazing experiments using the 'Sites as replicates' approach. These would be best targeted at assessing the effects of different grazing intensities and/or grazing seasons, and should use the following protocol:*

a. within a site, set up treatments comparing 2-3 (a realistic number) different grazing intensities (i.e. plant utilisation rates, achieved by manipulating grazing densities) or seasons;

b. carry out at a minimum of 5 sites within a region (possibly a Natural Area), to achieve replication;

c. repeat across regions (e.g. Natural Areas), but adapting the treatments to each region;

d. monitor before grazing is imposed and then yearly by, mapping changes in the extent of each heathland vegetation type, and measuring vegetation structure and monitoring selected plant, invertebrate and vertebrate species in representatives of each vegetation type;

e. to better achieve generalisation, carry out further studies of habitat and diet selection by animals, demography of key species (e.g. Appendix 8), changes in functional groups, and adaptation of forage utilisation models;

f. monitor performance and welfare of the livestock.

Method 2. *Establish detailed monitoring on ongoing and new grazing projects, using the following protocol:*

a. select a subset of grazing projects, representing the full geographical and geological range of lowland heaths and the variety of grazing regimes used;

b. match each grazed area with an adjacent ungrazed area within the same heathland site;

c. for new project begin monitoring before the onset of grazing;

d. monitor (yearly) by, mapping changes in the extent of each heathland vegetation type, and measuring vegetation structure and monitoring key plant, invertebrate and vertebrate species (e.g. Appendix 8) in representatives of each vegetation type;

e. ideally, carry out additional studies of the range and diet selection behaviour of livestock and by establishing and carrying out monitoring within large exclosures in representative vegetation types;

f. monitor performance and welfare of the livestock.

Method 3. *Carry out a meta-analysis of existing data from monitoring of heathland grazing projects. This would be of limited value because of the low intensity of monitoring and the small range of taxa studied.*

Method 4. *Study the potential impacts of different livestock breeds by carrying out studies on established and new grazing projects. These would assess in detail what different breeds are eating, and their intake rates, habitat selection and ranging behaviour. These data could be used to extrapolate the breeds' different impacts on vegetation structure and composition. This could include examination of sites where negative impacts of grazing on particular species has been reported (e.g. by observation), to determine the causes of such effects.*

Method 5. *Carry out autecological studies of key species to precisely understand their habitat requirements.*

Aside from these studies, a socio-economic study of heathland grazing would provide better information on how to make this management more cost effective and thus feasible over a greater number of heathlands.

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Appendices

Appendix 1. Summarising studies of habitat and diet selection in domestic livestock on heathland

Stock type	Time spent on habitat - habitat preference (as shown by preference index e.g. Hunter, 1962	Dietary preference	Seasonal change in habitat/diet selection	Area	Study
Sheep	N/A	*Molinia* – preferred *Trichosphorum casepitsoum* – preferred *Carex* spp – preferred *Calluna* – preferred *Eriophorum* – preferred	Use of *Calluna* & *Eriophorum* increases as other spp die off, peaking Jan –Mar, also Aug – Oct for *Calluna*	Scotland	Grant et al., 1976
Sheep	Heathland – preferred during winter Pasture- preferred July-Oct	See seasonal change	Switch from heath and woodland to pasture in summer	Netherlands	Bakker et al., 1983
Sheep	Mesotrophic communities - Strong preference Oligotrophic communities – Strong avoidance	See seasonal change	*Agrostis –Festuca*, *Calluna— Trichophorum* and *Nardus* swards less in winter, *Molinia* grassland more used in winter	West Highlands	Osborne, 1984
Sheep	N/A	*Calluna* utilisation in grass/heather mosaic increased with fragmentation	*Calluna* use increase in autumn	N.E. Scotland	Clarke, et al., 1995
Sheep	N/A	*Erica* sp – preferred *Calluna vulgaris* –preferred Other woody spp – avoided Graminoids – preferred Forbs – lightly preferred	Winter increase in *Calluna*	NE Spain	Bartolome et al., 1998
Cattle Sheep	N/A	See seasonal change	Ericoids most heavily used Oct-Dec, less than graminoids in spring & summer. *Molinia* & *Trichophorum* most heavily used in spring & summer	North east Scotland	Welch, 1984

Stock type	Time spent on habitat - habitat preference (as shown by preference index e.g. Hunter, 1962	Dietary preference	Seasonal change in habitat/diet selection	Area	Study
Cattle	Grasslands Wet and dry dwarf shrub heath Woodland	0-1.2% *Molinia* 65-80% other grasses 9-27% *Calluna*	Most use made of *Calluna* in winter, *Molinia* in summer.	New Forest S. England	Putman et al., 1987
Cattle	60-70 % grasslands –strong preference 10-20% wet and dry dwarf shrub heath -underexploited 10-20% woodland -avoided gorsebrake -no preference	See above	Little variation in use of habitat – artefact of supplementary feeding	New Forest, S. England	Pratt et al., 1986
Stock type	Time spent on habitat - habitat preference (as shown by preference index e.g. Hunter, 1962	Dietary preference	Seasonal change in habitat/diet selection	Area	Study
Cattle	Grassland communities	N/A	Moved from mesotrophic to oligotrophic grasslands in winter	Isle of Rhum, Scotland	Gordon, 1989b
Cattle - Meuse-Rhine-Issel	63.8 % heathland - Under exploited	N/A	Less use of heathland in winter	Netherlands	WallisDeVries, 1991
New Forest ponies	35-67% grasslands – Strong preference <15% wet heathland - Under exploited <10% valley mire - Preferred in summer <37% woodland & gorse brake - Preferred in winter	See above	Ponies show greatest used of grassland in spring, wet and dry heathlands in late summer, gorse brake and woodland in winter	New Forest, S. England	Pratt et al., 1986
New Forest ponies	grasslands wet heathland valley mire woodland & gorse brake	0.3-23.3% *Molinia* 36-75% other grasses 0.5-27% *Calluna* 6-10% *Pteridium* 0-13% *Ulex* spp.	Use of grass max. in summer, *Agrostis curtisii* replacing *Molinia* in autumn. Corresponding increase in *Ulex* spp. & *Ilex aquifolium*. *Pteridium* max in autumn	New Forest, S. England	Putnam et al., 1987
Ponies	Grassland communities	N/A	Increased use of *Molinia* grassland in summer	Isle of Rhum, Scotland	Gordon, 1989b
Exmoor ponies	Upland heath	*Calluna* – avoided *Juncus* spp.– preferred *Ulex* spp. Preferred	Grasses form majority of diet in spring to autumn, gorse increases in autumn, maximum use in winter, *Juncus* max. in	Exmoor, SW England	Baker, 1993

Stock type	Time spent on habitat - habitat preference (as shown by preference index e.g. Hunter, 1962	Dietary preference	Seasonal change in habitat/diet selection	Area	Study
		Upland heath *Pteridium* – no preference *Molinia* – preference unknown	spring, min. in winter, *Calluna* max in winter, min in summer, intermediate spring & autumn		
Goats	Dwarf shrub heath	N/A	Females use mesotrophic grasslands and dry heath in summer, heath in winter. Males use dry heath, increasing use of mesotrophic grassland in spring & autumn	Isle of Rhum, Scotland	Gordon, 1989b
Goats	N/A	*Erica* sp –strongly preferred *Calluna vulgaris* – preferred Woody spp. – preferred Graminoids – avoided Forbs – avoided	Spring decrease, summer increase in *Calluna*	NE Spain	Bartolome et al., 1998
Stock type	Time spent on habitat - habitat preference (as shown by preference index e.g. Hunter, 1962	Dietary preference	Seasonal change in habitat/diet selection	Area	Study
Goats	Scrub and woodland invaded chalk grassland	*Sambucus nigra* –strongly preferred *Fraxinus excelsior* weakly preferred *Crataegus monogyna* –avoided *Prunus spinosa*, *Acer campestris*, *A. pseusoplatanus*, *Ros*a spp. – no preference	Winter grazing	England	Oliver et al., in prep

Appendix 2. Vascular plants species of conservation concern which occur on lowland heathland communities and may be affected by livestock presence.

Reasons for decline are given where relevant to grazing. Species which may suffer a decline through inappropriate grazing are in **bold**

Species		UK status	Habitat within heathland	Known/potential impact of livestock	UK distribution
Heath and mire					
Erica ciliaris	Dorset heath	RDB	Wet heath.	Unpalatable, unlikely to be greatly affected by grazing. Seedling growth restricted to bare soil which can be provided through livestock trampling	SW England
Erica vagans	Cornish heath	RDB	Species-rich heaths	Unpalatable, unlikely to be greatly affected by grazing	Confined to the Lizard, Cornwall
Eriophorum gracile	Slender cotton-grass	RDB	Transitional mires on *Sphagnum* tufts and the sides of *Molinia* tussocks	Decline partially attributed to successional changes on ungrazed mires.	Confined to Surrey, New Forest & Glamorgan
Gentiana pneumonanthe	Marsh gentian	NS	Damp acid grassland and heathlands.	Decline partially attributed to reduction of grazing. Open conditions required for flowering, may persist in a non flowering state in sub-optimal conditions.	S & E England
Hammarbya paludosa	Bog orchid	NS	Valley mires, boggy areas in sphagnum and peaty mud and among grasses on runnel edges.	Depends on grazing to provide open runnels flushes and *Molina* free mires. Tiny shallow rooted plant very vulnerable to trampling	Southern England, Cumbria & Scottish Highlands
Lobelia urens	Heath lobelia	RDB	Grassy heath, often seasonally waterlogged.	Livestock activity can provide open ground necessary for establishment from seed (forms viable seed bank). Adult plants vulnerable to disturbance.	Southern coastal counties
Lycopodiella inundata	Marsh clubmoss	NS BAP	Bare peaty soil on wet heaths, mires which is inundated in winter	Decline partially attributed to cessation of grazing Poaching of tracks and peat cutting provide ideal habitat	Hants, Dorset, Cornwall and W coast up into N Scotland

Species		UK status	Habitat within heathland	Known/potential impact of livestock	UK distribution
Rhynchosphora fusca	Brown beak-sedge	NS	Wet heaths, margins of acid bogs, often on bare peat. Spreads by rhizomes, will readily colonise bare peat. Evidence of colonisation from old seed bank	Threatened by loss of habitat through succession. Grazing and trampling provide good conditions.	Cluster of sites in S England & W. Wales, scattered throughout W Scotland.
Viola lactea	Pale heath violet	NS	Patchy humid heath grasslands – cannot compete with taller veg. Vigorous vegetative spread	Decline due to cessation of traditional heathland pastoralism	Southern, SW England, W coast Wales
Damp and acid grassland					
Chamaemelum nobile	Chamomile	NS	Close grazed, acid – neutral grasslands, sometimes damp. Prostate form when grazed (principal host for noctuid *Cucullia chamomillae*)	Decline due to neglect of old grazed greens, commons. Requires grazing to prevent competition.	S England, E. Anglia, S.Wales.
Cicendia filiformis	Slender centaury	NS	Damp short grasslands, associated with flooded pools and ruts.	Declined due to cessation of traditional pastoral practices. Grazing critical to maintain short open sward and bare ground with microtopographical variation	Pembrokeshire, Cornwall, Dorset, New Forest
Crassula tillaea	Mossy stonecrop	NS	Open bare sandy soils with some compaction and therefore occasional flooding in winter.	Trampling can provide bare ground	Norfolk, Suffolk, Dorset, New Forest & Channel Islands
Hypericum undulatum	Wavy St. John's wort	NS	Damp heath and rush pasture. Known to forms viable seed bank.	Increased rapidly in Pembrokeshire when grazing reinstated	SW England, W Wales
Hypochaeris glabra	Smooth cat's ear	NS	Disturbed nutrient poor soils in acidic sandy, heathy gravely grasslands. Can be bare ground pioneer	Requires grazing and trampling to maintain short sward and bare ground	S England, Wales, E. Anglia.
Illecebrum verticillatum	Coral necklace	NS	Heavily grazed lawns and heathy swards, winter wet hollows and ruts.	Grazing vital to maintain short sward. Trampling may provide microtopographical variation	Cornwall, New Forest
Lotus subbiflorus	Hairy bird's-foot-trefoil	NS	Sandy heath grasslands.	Decline due to scrub encroachment following cessation of traditional management including grazing.	Hants, Dorset, Devon, Cornwall, Scillies, Pembs. Channels

Species		UK status	Habitat within heathland	Known/potential impact of livestock	UK distribution
Moenchia erecta	Upright chickweed	NS	Sandy heath grasslands, often broken and seasonally parched.	Sward maintained by exposure and occasional grazing, heavier grazing on wetter sites in New Forest	Southern England, Wales
Potentilla argentea	Hoary cinquefoil	NS	Short open turf on light heathland soils	May be reliant of grazing to reduce competitors	Southern, south-east England
Trifolium ornithopoides	Bird's-foot clover	NS	Short turf, often parched in summer, waterlogged in winter	Does well on heavily trampled sites. Grazing maintains short sward	Local largely coastal spp of S. Britain.
Trifolium suffocatum	Suffocated clover	NS	Short dry turf.	Grazing and trampling provide sparse short sward.	Submaritime, Suffolk to Cornwall, inland in Brecks
Pool edges, seasonally inundated hollows					
Deschampsia setacea	Bog hair-grass	NS	Bare margins of shallow pools, seasonally wet hollows.	Grazing prevents pools growing over and poaching increases bare ground. May be grazed.	New Forest, Dorset, Highlands & Islands of Scotland
Juncus pygmaeus	Pygmy rush	RDB BAP	Seasonally flooded ruts and pans on dry-wet ericaceous heath transition	Disturbance such as cattle poaching in gateways essential	Lizard
Ludwigia palustris	Hampshire purslane	RDB	Heavily grazed seasonally inundated pools. May occur as pioneer annual on exposed mud	Grazing prevents pools growing over and poaching increases bare ground.	New Forest
Mentha pulegium	Pennyroyal	RDB BAP	Seasonally inundated grassland around ephemeral pools and runnels.	Decline due to changes in traditional management including grazing. Currently persists on heavily grazed, trampled and dunged sites	New Forest & Lizard.
Pilularia globulifera	Pillwort	RDB BAP	Slightly acid to neutral silty/peaty lake, pond margins, pans, seasonal pools	Livestock provide poaching for bare ground. May rely on vector for dispersal e.g. ponies, cattle	New Forest, Dorset, Cornwall, central S Wales and W coast up into N Scotland+
Pulicaria vulgaris	Lesser flea-bane	RDB	Winter flooded hollows in grassy places.	Decline due to changes in traditional management of greens. Favoured by heavy poaching, grazing and some nutrient input	New Forest, Surrey
Ranunculus tripartitus	Three-lobed crowfoot	RDB	Shallow seasonal pools on heath and related communities.	Intolerant of competition, requires grazing and poaching in addition to fluctuating water levels.	Lizard, Cornwall & W. Wales.

Species		UK status	Habitat within heathland	Known/potential impact of livestock	UK distribution
Maritime heath & grassland					
Genista pilosa	Hairy greenweed	RDB	Maritime heath.	Intense grazing may prevent flowering and seeding	Lizard, N.Cornwall, St. Davids head & Cader Idris
Herniaria ciliata	Fringed rupturewort	RDB	Maritime heath, short grassy swards	Lack of grazing may have caused some losses	Lizard
Primula scotica	Scottish primrose	NS	Maritime heath/grassland	Vulnerable to under and overgrazing according to exposure	Lizard, W. Wales occasionally inland
Scilla autumnalis	Autumn squill	NS	Maritime heath/grassland, also damp acid grass heath.	Grazing necessary on deeper soils to reduce competitive species.	Cornwall & Thames Valley
Breckland grass heath					
Artemisia campetris	Field wormwood	RDB	Short grass heath	Needs short sward, but species is sensitive to grazing and only persists where it is excluded	E. Anglia
Phleum phleoides	Purple-stemmed cat's-tail	RDB	Short chalky grass heath	A short open sward through grazing is a primary requirement. Bare ground needed for seedling establishment. Intense rabbit grazing may prevent flowering.	E. Anglia
Silene otites	Spanish catchfly	RDB	Short grass heath	Grazing essential to reduce competition	E. Anglia
Thymus serpyllum	Breckland thyme	RDB	Short grass heath	Grazing essential to reduce competition	E. Anglia
Veronica spicata sbsp. *Spicata*	Spiked speedwell	RDB	Short grass heath	Grazing essential to reduce competition, but may reduce flowering spikes	E. Anglia
Veronica verna	Spring speedwell	RDB	Short grass heath	Grazing essential to reduce competition	E. Anglia

Appendix 3. Lichen, bryophytes and fungi for which there are Biodiversity Action Plans which occur on heathland habitats

Reasons for decline are given where relevant to grazing. Species which may suffer a decline through inappropriate grazing habitat are in bold

Species		UK status	Habitat within heathland	Known/potential impact of livestock	UK distribution
Lichens					
Buellia asterella	Starry breck-lichen	RDB BAP	Calcareous sandy lichen heath.	Threats include lack of rabbit grazing and scrub encroachment. Livestock grazing and trampling will maintain appropriate sward. May be vulnerable to trampling.	Breckland
Cladonia mediterranea	A reindeer moss	BAP RDB	Basic serpentine heath, also boulder scree and damp areas between *Calluna*	Trampling by livestock poses a threat due to small size of populations.	Lizard, Pembrokeshire, Lundy
Cladonia peziziformis	A reindeer moss	BAP RDB	Peaty soils, mostly on coastal heath	Reasons for decline include inappropriate grazing and loss of sites through succession May favour undisturbed *Calluna*, but has also been recorded from bare patches created by livestock.	Pembrokeshire
Pseudocyphellaria aurata	A lichen	BAP RDB	Occurs on trees, rocks and heather stems	Trampling, nutrient enrichment and over-grazing are some current factors causing decline.	Channel Islands
Squamarina lentigera	Scaly breck-lichen	BAP RDB	Sandy calcareous lichen heath	Disturbance essential to maintain open sward	Breckland
Bryophytes					
Atrichum angustatum	Lesser smoothcap	BAP RDB	Old records from heaths, now confined to damp sandy rides and tracks in woods	Increased shading may be a cause of decline	High Weald (Sussex, Kent)
Jamesoniella undulifolis	Marsh earwort	BAP RDB	Sphagnum mires	Decline due to loss of good quality habitat. Livestock poaching may cause decline	Cornwall, Argyll

Species		UK status	Habitat within heathland	Known/potential impact of livestock	UK distribution
Leptodontium gemmascens	Thatchwort	BAP RDB	Decaying vegetation in areas of ungrazed heath and acid grassland	Both overgrazing and scrub encroachment are considered as reasons for decline. Extensive grazing may be suitable.	Scattered across southern England
Pallavivinia lyellii	Veilwort	BAP RDB	Bare acid, peaty soils in lowland bogs and damp woodland, often associated with tussocks of *Molinia* and *Juncus*.	Overshading due to scrub encroachment may be a cause of decline. Grazing may help prevent this.	Mainly southern England and West Wales
Fungi					
Poronia punctata	Nail fungus	BAP RDB	Occurs on acid habitat on dung of equines.	Decline due to changes in agricultural practise and loss of unimproved grasslands. Livestock (equine) presence vital	Confined to New Forest and Dorset

Appendix 4. Invertebrates for which there are Biodiversity Action Plans and which occur on lowland heathland communities.

Data are taken from the species action plans – all species mentioned as occurring in lowland heath are included, even if their principal habitat is non-heath e.g. acidic bogs or temporary pools. Species where inappropriate grazing management could cause further decline are in bold.

1. ORTHOPTERA

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Chorthippus vagans (Heath Grasshopper) Rare	New Forest	dry heathland; requires bare ground and *Calluna*		NB this species listed as a BAP species in New Forest SAC literature but no BAP is available at present
Decticus verrucivorus (Wart-biter) Vulnerable	currently five populations, two in East Sussex and one each in Dorset, Wiltshire and Kent	species of calcareous grassland, although one extant UK colony occupies a heathland/ grassland site	inappropriate grassland management, leading to loss of habitat quality; small population sizes; predation, particularly by birds, is a significant problem at some sites. Inapproporiate grazing will lead to further declines (D.Sheppard, pers.comm..).	a species of calcareous grassland but the plan aims to ensure that all occupied and nearby potential habitat is appropriately managed
Stethophyma grossum (Large marsh grasshopper)	currently a number of populations in Dorset and the New Forest, but little information on their size is available other than to suggest that most are small	restricted to very wet, marshy areas, commonly quaking acidic bogs	drainage of wetlands for land reclamation and peat extraction has had a major impact Inappropriate grazing will lead to further declines (D. Sheppard, pers.comm.)	a mire rather than heathland species but populations concentrated in areas important for lowland heath; implementation of plan could benefit other species of lowland mire

2. LEPIDOPTERA

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Mellicta athalia (Heath fritillary) Vulnerable	declined severely during this century, just 43 colonies known in 1989; main centres are Exmoor, east Cornwall and Blean Woods of Kent	breeds on heathland, species-rich grassland and coppiced woodland	reduction of coppice area and increased isolation of new clearings in Kent; abandonment or inappropriate management of species-rich grasslands in the south-west	trial habitat management being conducted by National Trust on heathland habitat on Exmoor
Plebejus argus (Silver-studded blue) Nationally scarce	undergone a severe decline in range this century, estimated at 80%;remains widespread only on the heaths of Dorset and Hampshire,	lowland heathland, calcareous grassland, single peatland site in Wales; requires presence of ants of the genus *Lasius*, open ground for breeding, and either bare soil or short vegetation; preferred conditions produce warm microclimates at ground level for the larvae: early successional stages are preferred, particularly where succession is held in check by grazing	loss of heathland to development and agriculture; fragmentation and isolation of habitat; inappropriate heathland and grassland management; increased quarrying activities, particularly on the Isle of Portland, Dorset	without traditional management (e.g. cutting of scrub, grazing of domestic animals, or burning to encourage young growth for livestock), suitable conditions on heathlands are short-lived (5-10 years); implementation of action plan could benefit other species of lowland heathland; consider with lowland heathland BAP
Acosmetia caliginosa (Reddish buff) Endangered	lost from the New Forest and from Hampshire; now only single native population remains on Isle of White	preferred breeding habitat is open grassy, often heathy, swards rich in saw-wort, but neither strongly acidic nor strongly alkaline. Most larvae have been found in sward heights of 5-15 cm	establishment of conifer plantations on open heathland; scrub encroachment due to insufficient browsing, grazing and clearance	consider with lowland heathland BAP
Coscinia cribraria (Speckled footman moth) Vulnerable	all records from heathlands in the Wareham area of south-east Dorset; no strong colony is currently known	bogs but ecology unknown	the loss of suitable habitat due to development, plantation forestry and subsequent encroachment of conifer seedlings, drainage work, extensive heathland fires, scrub encroachment and changes in the heathland resulting from inappropriate management	ensure landowners and managers are aware of the presence and importance of conserving this species, and appropriate methods of management for its conservation

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Cyclophora pendularia (Dingy mocha) Rare	very local species, confined to Dorset and western Hampshire	larvae of the dingy mocha require 1-3 m tall willow bushes, such as *Salix aurita* and *S. cinerea*, in open heathy situations	loss of heathland to development, forestry, agricultural improvement and road construction; succession to woodland on unmanaged heathland; unplanned heathland fires; scrub clearance during heathland restoration	consider with lowland heathland BAP
Hemaris tityus (Narrow-bordered bee hawk-moth) Nationally scarce	has retreated to western Britain, especially south-west England from Cornwall to Wiltshire	a wide range of unimproved grasslands, including wet, acidic grassland and chalk downland; also on acid bogs, peat cuttings and drier heathland; larval foodplant is *Succissa pratensis*	agricultural improvement of unimproved grassland and heathland; inappropriate management of grassland, heathland and bogs	consider with lowland heathland BAP
Noctua orbona (Lunar yellow underwing) Nationally scarce	once widespread in Britain but has been steadily declining; post-1980 records from about 40 ten km squares, mostly in Breckland	now mainly associated with open, sandy, heathy or calcareous sites and open grassy areas within woodland feed on a range of grasses and small herbaceous plants	Inappropriate grazing is thought to be causing declines in populations in the Brecks.	likely that implementation of this action plan will benefit other species of lowland heaths and grasslands; consider with lowland heathland BAP

3. ODONATA

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Coenagrion mercuriale (Southern damselfly) Rare	recorded from 24 ten km squares in Devon, Dorset, Hampshire and sites in Wales; largest populations in New Forest and Pembrokeshire	wet heaths; breeds in heathland streams and runnels and, more rarely, rhos pasture, chalk streams and calcareous mires	loss of suitable habitat due to lack of appropriate heathland management, including reduced grazing and over-deepening of shallow breeding streams	encourage the sympathetic management of all occupied and nearby sites, especially appropriate grazing management; use this species to promote awareness of the importance of heathland

4. COLEOPTERA

Name and status	Location	Preferred habitat	Reasons for decline	Mmanagement action
Amara famelica Rare	Ashdown Forest 2 locations (single records)	open sandy or gravelly heaths; flat, partly vegetated sites	loss of heathland; inappropriate management leading to scrub encroachment	consider with lowland heathland BAP; encourage S-facing open areas
Anisodactylus nemorivagus Nationally Scarce	New Forest (Hampshire) Wiltshire Surrey	open, sandy heathland	loss and fragmentation of heathland; inappropriate management leading to scrub encroachment	consider with lowland heathland BAP; monitoring only
Aphodius niger Endangered	only ever been found in New Forest, Hampshire, all records from edge of single pond	cattle dung trodden into the water`s edge	changes in grazing and the introduction of helminthicides to cattle	develop policy on the use of helminthicides in the New Forest
Cicindela sylvatica (Heath Tiger beetle) Nationally scarce	very localised in Surrey, Sussex, Hampshire and Dorset	open, dry and sandy soils with heather	loss of heathland; inappropriate management leading to scrub encroachment and loss of open sand	consider with lowland heathland BAP; provision of south-facing patches of bare ground
Cryptocephalus coryli Endangered	single sites in Surrey and Berkshire; number of sites on the Lincolnshire Coversand Heaths	in the south occurs on hazel in woodland edges; in the north lives on young birch in heathland	at risk from clearance of birch from heathland	ensure Wildlife Enhancement Scheme on Coversand Heaths takes into account importance of birch scrub for this species
Graphoderus zonatus (Spangled Diving Beetle) Endangered	Woolmer Forest, Hampshire	pools dug as breeding sites for natterjack toads; ponds created by peat cutting	dessication and pollution of ponds; loss of open water and scrub encroachment	consider with lowland heathland BAP; re-excavate ponds
Helophorus laticollis Vulnerable	only from the New Forest since the 1960s	shallow, exposed, grassy pools on heathland	reduction in grazing resulting in scrub encroachment; water abstraction and drainage for roads	reintroduce to two heathland sites, in Surrey and in Hampshire; consider with lowland heathland BAP
Hydroporus cantabricus Rare	Isle of Purbeck and neighbouring heathland south of the River Frome, Dorset; last record from Studland Heath NNR in 1993	shallow pools on peat on exposed heathland in southern England	loss of heathland by agricultural improvement, afforestation, urban encroachment; climate change resulting in loss of temporary pools	consider with lowland heathland BAP; monitoring only

Name and status	Location	Preferred habitat	Reasons for decline	Mmanagement action
Pterostichus kugelanni Endangered	since 1970 found only at three sites in the New Forest and at a single site on Dartmoor	on heathland with sandy or gravelly soil, but with wet areas present	inappropriate management of heathland; loss of habitat	provision of south-facing patches of bare ground; consider with lowland heathland BAP

5. HYMENOPTERA

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Anergates atratulus (Dark guest ant) Insufficiently known	heathlands of Purbeck and Wareham in Dorset, near Burley in the New Forest and the heaths at Longmoor in Hampshire	obligate parasite in colonies of another ant, *Tetramorium caespitum*, a lowland heath spp.	host species occurs on short dry acid grassland and is declining due to habitat loss through development, agricultural improvement, afforestation; inappropriate management; changes in grazing practice	ensure that known sites for the dark guest ant are appropriately managed, implementation of this action plan will benefit other species of lowland heaths e.g. ground beetles; consider with lowland heathland BAP
Formica candida (Black bog ant) Endangered	Dorset and Hampshire; lost from former strongholds in New Forest.	bogs, wet heaths and mossy stream sides	loss of bog habitat through land drainage; overgrowth of scrub; excessive grazing and trampling of nests; pollution and eutrophication of watercourses; drought.	review management in the New Forest (particularly stocking/grazing levels and forest management practice);
Formica exsecta (Narrow-headed ant) Endangered	Bovey valley, Devon, thriving in Scotland		loss of suitable heathland due to destruction and inappropriate management; encroachment by scrub, trees and bracken leading to shading of nests; excessive grazing and inadequate browsing by inappropriate equine breeds in the New Forest, and production of dense, single-age heather monoculture with reduced marginal scrub	re-establish 10 self-sustaining populations in appropriate locations in Dorset or the New Forest by 2005
Formica pratensis (Black-backed meadow ant) Endangered	probably extinct – last known sites in Dorset heaths around Bournemouth and Wareham (no sightings since 1980s)	dry heathland	urban development on heaths around Bournemouth; inappropriate management and excessive encroachment of scrub on open heath	if colonies are re-discovered, encourage the restoration or enhancement of suitable heathland in areas adjacent to known, or restored, colonies

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Formica rufibarbis (Red barbed ant) Endangered	Surrey heathlands: now restricted to two sites, Chobham Common and the Bisley ranges and the Scilly Isles	requires an open habitat: short, lowland grass and heather or maritime heath overlying loose or sandy soils	loss of suitable heathland habitat through urban or industrial development, agricultural improvement and afforestation; inappropriate heathland management; disturbance of nests by inappropriate mechanised scrub or heather clearance; untimely or intensive heathland fires	implementation of this action plan could benefit other species of lowland heaths; consider with lowland heathland BAP
Chrysis fulgida (Ruby-tailed wasp) Endangered	small concentration of records from the Surrey/north Hampshire heaths; old records from Portland, Dorset	preference for heathland although occurs in a variety of habitat types; little information	Thought to be a brood parasite of *Symmorphus crassicornis* which preys on *Chrysomela populi* feeding on low growing *Populus tremula* growing in damp areas on heathland. Inappropriate grazing could hinder the recovery of this species	implementation of this action plan could benefit other heathland species - the ground beetles and wasps; consider with lowland heathland BAP
Homonotus sanguinolentus (Spider-hunting wasp) Endangered	8 records from lowland heathland in Dorset, Hampshire and Surrey, (to 1962); only recent (1990) record is single male, Cranes Moor in New Forest	predator of spiders of the clubionid genus *Cheiracantheum* that construct retreats in aerial locations, including grass flower heads and heather inflorescences; prefers ungrazed wet heath	loss of southern heathland, especially grass-heath; scrub and bracken development	implementation of this action plan could benefit other species of lowland heathland, including ground beetles, wasps and flies; consider with lowland heathland BAP

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Pseudepipona herrichii (Purbeck mason wasp) Vulnerable	Poole basin only; restricted to Godlingston Heath NNR and six other heathlands (1997 monitoring)	dry, open sandy heathland, needs areas for nests and sparse cover of heather; provisions its nest with the caterpillars of a tortricid moth which feeds on heathers; the host is commonest on bell heather Erica cinerea in early to mid successional heathland; the flowers are the major nectar source for the adult wasps; nest is dug in areas of bare, clayey ground within heathlands	succession on heathland; heathland fires; loss of habitat to afforestation and building	implementation of this action plan could benefit for other species of lowland heath, including: the ground beetles wasps and flies; consider with lowland heathland BAP

6. DIPTERA

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Asilus crabroniformis (Hornet robberfly) Notable	unimproved grassland and heath in southern England and Wales; habitats declined in range/quality and fragmented; since 1970 has been recorded from only 40 ten km squares	open areas with herbivore dung; larvae believed to prey on dung beetle larvae and adults feed on a variety of insects; requires suitable grassland to support its prey community	loss of unimproved grassland and heath leading to habitat fragmentation; use of persistent parasite treatments for stock which kill dung beetle hosts; changes in stock management	encourage monitoring of known sites; include information on the history of site management and the effects of ivermectin treatments

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Bombylius minor (Heath bee-fly) Vulnerable	mainly confined to southern heathland, where it has suffered a contraction in range; currently known from only a few sites in Dorset; highly localised and at low population levels	on open heathland; parasitoid of solitary bees of the genus *Colletes*; the bees nest in vertical sand-banks; strong association with nectar sources on flower-rich path edges (verge heath) but also visits *Erica cinerea*	loss and fragmentation of heathland habitat including verge heath, due to development and scrub encroachment; inappropriate heathland management; loss or shading of vertical sand banks, causing decline in numbers of host bees	implementation of this action plan could benefit other species of lowland heathland, including other bee-flies, tiger beetles and sand lizard; consider in conjunction with lowland heathland BAP
Chrysotoxum octomaculatum (Hoverfly) Vulnerable	confined to southern England; historic records from dry heaths of east Dorset, New Forest and western Weald; undergoing a dramatic decline within all known sites: only 6 records since 1980 from four 10 km squares, mostly in Surrey	dry heaths; ecology virtually unknown; larvae of aphid-feeding type but in New Forest believed to be associated with ants	not well understood, may include habitat destruction due to afforestation, tourism or increased recreation, lack of heathland management leading to loss of bare ground or disturbed soil, and unplanned summer fires	promote the sympathetic management of current and former sites to aid conservation of this species Use this species to highlight the effects heathland management may have on resident fauna and flora
Eristalis cryptarum Vulnerable	suffered a major contraction in range: lost strong populations in New Forest and Dorset; last remaining British location is small cluster of sites on Dartmoor	valley mire on heathland and moorland; its aquatic larvae are assumed to live in saturated peat in flushes, pools or stream edges	not known	ensure that there are viable populations at five sites within the historic range, including Cornwall, the New Forest and east Dorset by 2010
Thyridanthrax fenestratus Mottled bee-fly Rare	confined to southern heathland in Dorset, New Forest and the Weald in Hampshire, Surrey, West Sussex; has gone from some former sites, such as mid Surrey and has become scarce on many other sites	species of open, heather-dominated heathland; found along sandy paths and other sparsely vegetated sandy areas; considered to be a parasitoid of the sand wasp, although this requires confirmation; has requirement for hot microclimates and for flowers which the adults visit to feed on nectar	distribution has become much more restricted as heaths have become smaller, more fragmented and management problems increased; inappropriate heathland management; encroachment by scrub and trees; uncontrolled heathland fires; damage to paths and open areas by increasing recreational use, especially horse riding, or by intense military use	ensure all occupied sites are appropriately managed, including provision and maintenance of bare, compacted sand, and the avoidance of excessive disturbance; implementation of this action plan could benefit other species of dry heathland: sand lizard, other bee files and hover –flies and tiger beetles; consider with lowland heathland BAP

7. NON-INSECTS

Name and status	Location	Preferred habitat	Reasons for decline	Management action
Eresus sandaliatus = cinnaberinus (Ladybird spider) Endangered	until 1920s recorded from several sites in Dorset, then thought to have become extinct in Britain; rediscovered in 1979, but known from only a single site, Wareham Forest, where the population is very small (<300 adults)	found on dry sandy heaths with bare or lichen covered patches; forms burrows in sandy substrates protected from the wind by the surrounding heather; needs very warm, dry conditions; has a life cycle of up to 8 years so may be slow to respond to improved habitat conditions	encroachment and shading by Rhododendron, pine and bracken	remove encroaching pine, Rhododendron, bracken and scrub at appropriate intervals to maintain areas of bare ground and to encourage the regeneration of heather; continue to use this species as a flagship to inform and popularise the problems faced by heathland invertebrates; consider with lowland heathland BAP
Uloborus walckenaerius Spider Rare	found in large numbers on heathland at a few sites in the south of England, particularly New Forest, and Chobham and Thursley Commons (Surrey); has disappeared from several former strongholds and is declining as area of heathland declines	inhabits lowland heathland where it spins an almost horizontal orb web about midway between the ground and the top of mature heather plants	loss of heathland due to development and afforestation; inappropriate heathland management	likely that this species will benefit from the action plans for other species of lowland heathland; requirements of this species should be taken into account in the implementation of the action plan for lowland heathland.

Appendix 5. Selected Red Data book invertebrates which occur on lowland heathland communities

All Endangered or Vulnerable (RDB1 and 2) heathland species which have accounts in the Red Data Book are included; species where inappropriate grazing management could cause further decline are in **bold type**, although reasons for population declines are often not known.

1. LEPIDOPTERA

Name and status	Location	Preferred habitat	Reasons for decline
Pachythelia villosella Vulnerable	confined to single locality on Dorset/Hampshire border	heathy part of New Forest	no evidence for a decline
Stenoptilia graphodactyla Vulnerable	Dorset/Hampshire border; no confirmed recent sightings	boggy heaths	
Hadena irregularis (Vipers bugloss) Endangered (may be extinct)	Breckland (SW Norfolk, W Suffolk)	feeds on Spanish catchfly only, *Silene otites*	food plant is also rare and requires disturbed ground

2. COLEOPTERA

Name and status	Location	Preferred habitat	Reasons for decline
Graptodytes flavipes (Water beetle) Vulnerable	Dorset, New Forest, Surrey	pools and slow running water on heathland	loss heathland habitat due to disturbance and urbanisation
Ochthebius aeneus (Water beetle) Endangered (possibly extinct)	Surrey, Isle of Wight; last record in 1913	brackish water on lowland heath	loss of wet heath habitat in Southern England
Diastictus vulneratus Vulnerable	Breckland	only open areas – sandy situations in dry open heathy areas	
Lycoperdina succincta Vulnerable	confined to Breckland; now probably a single population of limited size	feeds on puffball fungus	threats to remaining areas of open ground in Breckland
Cryptocephalus biguttatus (Chrysomelid) Vulnerable	very localised, widely separated populations, last record 1983 (Chobham common, also Dorset, West Sussex, Surrey)	boggy heaths and moors, food plant *Erica tetralix*; possibly associated with ants	

Name and status	Location	Preferred habitat	Reasons for decline
Bagous brevis *(Weevil)* Endangered	2 recent records in New Forest	ecology virtually unknown, occurs on banks of ponds associated with lesser spearwort (*Ranunculus flammula*)	Drainage of ponds and other land use changes; succession
Bagous czwalinai (Weevil) Endangered	known only from one site in New Forest	small Sphagnum bogs; ecology unknown	drainage, land use change, drying out and succession: trees overgrowing bogs
Bagous frit *(Weevil)* *Endangered*	known only from 2 small sites in New Forest; site in Studland, Dorset destroyed;	small Sphagnum bogs; ecology unknown	drainage, forestry operations, natural succession
Tychius quinquepuctatus (Weevil) Vulnerable	Devon, Sussex, Norfolk; not in New Forest since 1967	feeds on bitter vetch (Lathyrus linifolius var. montanus)	overgrazing of food plant by ponies in New Forest – unrestrained grazing has threatened species existence at this site

3. HYMENOPTERA

Name and status	Location	Preferred habitat	Reasons for decline
Aracnospila rufa (Spider wasp) Endangered	heaths in SE Dorset	preys on spiders on heathland	afforestation
Homonotus sanguinolentus (Spider wasp) Endangered	a few localities in Dorset, Hampshire, Surrey		loss of heathland habitat
Ceropales variegata (Spider wasp) Endangered	recorded from 1 site in Surrey.	heathland in South, with pine, Calluna/Erica and bog myrtle	loss of heathland habitat suspected but lifecycle unknown. Apparent association with large flowers, so may be susceptible to increases in grazing
Odynerus reniformis (Mason wasp) Endangered, believed extinct	New Forest, Surrey, Hampshire; no records since 1915		decline very abrupt but reason unknown
Philanthus triangulum (Beewolf) Vulnerable	Isle of Wight sand dunes; Nacton heath Suffolk, Norfolk heaths	heathland in East Anglia	

Name and status	Location	Preferred habitat	Reasons for decline
Dufourea minuta (Mining bee) Endangered	Surrey, Dorset	sandy soils	loss of heathland habitat
Melecta luctuosa (Cuckoo bee) Endangered	no recent records; Surrey, Dorset, Hampshire,	New Forest is favoured locality	uncertain, but heavy grazing by ponies may have reduced cover of flowering plants
Stelis breviuscula (Cuckoo bee) Endangered	1 record, 1 individual, W. Sussex	edge of heathland, close to woodland, host bee nests in dead birch wood	very recent addition to UK fauna

4. DIPTERA

Name and status	Location	Preferred habitat	Reasons for decline
Nephrotoma sullingtonesis (Cranefly) Endangered	confined to West Sussex; last recorded in 1983 but only 3 individuals	open heath with pine	pine extending across open areas and other areas lost to grasses
Chrysops sepulcralis (Horsefly) Vulnerable	confined to Dorset (Wareham/ Studland) and 1 record from New Forest	ponds, boggy areas of heath	loss of wet heath to drainage and building
Callicera aenea *(Hoverfly)* *Vulnerable*	scattered records, unpredictable occurrence.	habitat possibly open woods at heath edge, larvae live in dead wood but ecology largely unknown	
Eutolmus rufibarbis (Robber fly) Vulnerable	New Forest (old records), Cobham common Surrey, Sussex (recent records)	large blocks of open dry heath; ecology largely unknown but larvae may be predators of dung beetles	a particularly vulnerable habitat; destruction of heathland, tree and scrub invasion especially pines, frequent fires
Villa circumdata (Bee fly) Vulnerable	Wareham, Dorset; Cobham, Surrey; New Forest	Southern heaths with bare patches and sunny ground; larvae are parasitoids of other insects	

Appendix 6. Bird species of conservation concern occurring on heathland habitats that may be affected by livestock presence

Species	Conserv-ation status	Time of year present on heaths	Ground nesting	Type of Young	Use of heathland habitat	Requirements that may be affected by livestock presence
Circus cyaneus Hen Harrier	Red	Winter visitor, heaths often used as communal roost sites	✓	c	Roosts in mature heather	Requires leggy, mature heather for roosting.
Circus pygarus Montague's Harrier	Amber	Summer visitor, breeding	✓	c	Breeds on dry heath	Grazing may reduce small mammal abundance on heaths
Falco columbarius Merlin	Red	Winter visitor, roosts on heaths	✓	c	Open heath	Maintenance of open heath
Burhinus oedicnemus Stone Curlew	Annex 1 BAP Red	Summer visitor	✓	f	Nests on bare stony ground on grass heath	V. short sward required for breeding and foraging
Charadrius hiaticula Ringed Plover	Amber	Breeding season only	✓	f	Nests on bare shingle or gravel patches	Bare ground for nest sites, invert. prey
Vanellus vanellus Lapwing		Breeding season only	✓	f	Bare stony ground on grass heath or valley mires	Bare ground or tussocks for nesting, invert prey
Gallinago media Snipe	Amber	All year round	✓	f	Mires	
Numenius aquartus Curlew	Amber	Summer visitor	✓	f	Mires	
Caprimulgus europaeus Nightjar	Annex 1 BAP Red	Summer visitor	✓	(f)	Nests on dry heath on patches of bare ground. Forages up to 5 km from nest over uncultivated land.	Grazing important for creating bare patches for nest sites & increasing prey abundance
Picus viridis Green Woodpecker	Amber	All year round		c	Forage on open dry heath, bare ground around ants nest.	Increase in bare ground. Ant prey

Species	Conserv-ation status	Time of year present on heaths	Ground nesting	Type of Young	Use of heathland habitat	Requirements that may be affected by livestock presence
Lullula arborea Woodlark	Annex 1 BAP Red	Summer visitor (sometimes will spend the winter on heathland)	✓	c	Bare ground and a short sward for feeding. Nests close to paths / firebreaks and among tussocks.	Increase bare ground and short sward for foraging. Invert prey
Anthus trivialis Tree Pipit	C. Red	Summer visitor	✓	c	Heath with patches of scrub	Invert prey
Lanius collurio Red-backed Shrike	Annex 1 BAP	Summer visitor			Scattered scrub and open ground	Invert prey
Saxicola torquata Stonechat	Amber	Summer visitor (sometimes will spend the winter on heathland)		c	Open heath, with scrub.	Invert prey
Sylvia undata Dartford Warbler	Annex 1 BAP Red	All year round		c	Open, mature heath. Low, gorse provides best shelter in winter and the highest density of invertebrate prey.	Low scrubby gorse may result from grazing.
Carduelis cannabina Linnet	Red BAP	All year round		c	Nests in gorse and scrub	Grazing may reduce seed availability
Pyrrhocorax pyrrhocorax Chough		All year round		c	Cliff nesting, feeding on short coastal cliff-top grassland.	Short turf & invert. prey

Annex I – species listed under Annex I of the EC Birds Directive (EEC/79/409)
BoCC – species in the Red List species of national conservation concern as listed as red, amber or candidate red (Gibbons *et al.* 1996
BAP – species action plan prepared (HMSO, 1995)
f, c – nidifugous or nidicolous young
✓ - ground nesting species potentially vulnerable to trampling

Appendix 7. Reptile and amphibian species of conservation concern (Biodiversity Information Group, 2001) which may be affected by livestock presence on lowland heathlands

Species	UK status	Potential effect of livestock	UK distribution
Lacerta agilis Sand lizard	BAP Annex II, Annex Iva, Schedule 5	Reduction of required structural diversity of dry heath habitat through trampling Trampling of egg laying and hibernation sites	Confined to southern heathlands
Coronella austriaca Smooth snake	Annex II, Annex Iva, Schedule 5	Reduction of required structural diversity of dry heath habitat through trampling. Possible reduction in populations of prey species, e.g. small mammals and other reptiles.	Confined to southern heathlands
Bufo calamita Natterjack toad	BAP Annex II, Annex Iva, Schedule 5	Grazing may prevent further decline caused by scrub encroachment Grazed swards are unattractive to competitors.	Sand dune and heathland sites in England and Scotland, including reintroduction

Annex II - protected under Annex II of the Berne Convention
Annex IVa - protected under Annex IVa EC Habitats Directive
Schedule 5 – protected under the Wildlife and Countryside Act 1981 (Schedule 5)
BAP- species action plan prepared with within UK Biodiversity Action Plan

Appendix 8. Examples of lowland heathland species of conservation concern which could be targeted in studies of the impacts of grazing

These are thought likely to show responses to grazing management, and together represent a range of possible responses. Each species can also represent a suite of species with similar habitat requirements and each is typical of a particular type of heathland vegetation. Non-vascular plants, lichens and fungi are excluded due to the difficulties in studying the ecology of these taxa.

Species	Habitat
Plants	
Gentiana pneumonanthe Marsh gentian	Wet heath
Lobelia urens Heath lobelia	Grassy heath
Viola lactea Pale heath violet	Humid heath
Cicendia filiformis Slender centaury	Damp grassland
Primula scotica Scottish primrose	Maritime heath
Genista pilosa Hairy greenweed	Maritime heath
Hypochaeris glabra Smooth cat's ear	Dry acid grassland
Veronica spicata subsp *spicata* Spiked speedwell	Breck heath
Phleum phleoides Purple-stemmed cat's-tail	Breck heath
Invertebrates	
Chorthippus vagans Heath grasshopper	Dry heath
Plebejus argus Silver studded blue	Dry heath
Coenagrion mercuriale Southern damselfly	Wet heath
Cicindela sylvatica Heath tiger beetle	Dry heath
Asilus crabroniformis Hornet robberfly	Dry heath & grassland
Birds	
Gallinago media Snipe	Mire (ground-nesting)
Caprimulgus europaeus Nightjar	Dry heath (ground-nesting)
Lullula arborea Woodlark	Dry heath (ground-nesting)
Sylvia undata Dartford warbler	Dry heath (scrub-nesting)
Pyrrhocorax pyrrhocorax Chough	Coastal heath (cliff nesting)
Reptiles	
Lacerta agilis Sand lizard	Dry heath
Coronella austriaca Smooth snake	Dry heath

Appendix 9. Costings for scrub clearance by goats

Supplied by Rob McGibbon.
Assumptions:
10 ha enclosure i.e. 500m x 200m.
40 goats, 2 seasons grazing April – November, 200 days annually
Person day = 7.5h

Item	Cost (ex VAT)
Goats	Assumed free
Supervision	
Assume av 1h per day for 400 days = 53 person days @ £100 per day (inc transport)	£5300
Fencing	
Treadins, polywire and corner posts	£500
Earth stake, sundries	£5
Energiser	£100
4x 12v rechargeable batteries	£280
Total cost of fencing	£885
Life of fencing is c 5 years, therefore cost over 2 years	£354
Fence maintenance, delivery/ collection of goats	
4man days @£100 per day	£400
Support costs for time off heathland	
1 person hour per day for 330 days = 44 person days @ £100 per day (inc transport)	£4400
Wormers, vaccines	£100
Foot trims, worming, vaccinations 12 person days @£100	£1200
Back-up land lease - say 1ha @ £50 per hectare	£100
Winter feed - say 0.1 standard bale per goat per day for 50 days = 50 @ £2	£100
Minerals etc - say-£10 per winter	£20
Organisation / administration / overheads (inc vet)	£200
	£6120
TOTAL	£12174
Cost per hectare	£1217

Appendix 10. Sites and participants included within the review

Note that 'organisation' relates to the person contacted, not necessarily that managing the site. 'Participant' refers to the person able to respond to the telephone questionnaire and is not necessarily the site contact.

Site	Participant	Organisation
Arne RSPB Reserve, Stoborough RSPB Reserve, Grange heath	Neil Gartshore	RSPB
Ash Ranges	Rob McGibbon	Surrey Heathland Project
Ashdown Forest	Chris Marrable	Board of conservators of Ashdown Forest
Aylesbeare, Hawkerland, Venn Ottery, Colaton Raleigh	Lesley Kerry Pete Gotham	Grazier RSPB
Brettenham Heath, Cavenham Heath	Nick Sibbet	EN
Chobham Common	Andy Wragg	Surrey County Council
East Wretham Heath, Weeting Heath	Bev Nichols	Norfolk Wildlife Trust
Foxlease & Ancell's Meadows	Jonathon Mycock	Hampshire Grazing Project
Godlingstone Heath	Geoff Hann	NT
Godrevy	Bill Makin	NT
Goss Moor	Martin Davey	EN
Hartland Moor NNR, Stoborough Heath (EN), Morden Bog	Tim Brodie-James	EN
Deer Park & coastal sites	Haydn Garlik	NT
Minsmere	Andy Needle	RSPB
New Forest	Rue Ekins, Russell Wright	EN
North Warren	Rob Macklin	RSPB
Somerley Close Landfill	Rue Ekins	Grazier
Sutton Heath, Parsnip Hill,	Steve Clarke	Suffolk Wildlife Trust
The Flushes, Frensham	Mike Coates	Waverly Borough Council
The Lizard NNR	Ray Lawman	EN
The Loft & Hill of White Hamars	Roy Harris	Independent grazing advisor
Trevigue	Simon Ford	NT
Weather Heath	Jim Rudderham	Elveden Estate
West Penwith	Jon Brookes	NT
Woolmer Forest	Chris Buckley	HCT

Information was also used from the following sites:

Brookwood	Bacon (1999)
Prey Heath	Bacon (1999)
Upper Hollesley Common	Bacon (1999)
Skipworth Common	Bacon (1999)
Upgate Common	Bacon (1999)