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Relationships Between Grazing and Birds With Particular Reference to Sheep in the British Uplands

Author

Robert J. Fuller

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EXECUTIVE SUMMARY

1. **This review of the relationships between grazing, principally by sheep, and bird populations in open upland habitats has the following aims: (a) to summarise the recent trends in sheep stocking that have occurred throughout Britain, (b) to describe the potential mechanisms by which grazing may affect upland birds, and to consider the evidence available for these mechanisms, (c) to place grazing into context with other factors as possible determinants of changes in bird populations, (d) to outline the ornithological implications of a reduction in grazing, (e) to consider the implications of different grazing intensities for individual species of birds, (f) to identify key areas for future research on the relationships between birds and grazing.**

2. **There have been large overall increases in sheep numbers in most regions of Britain, both upland and lowland, since the mid 1970s. This increase appears to have commenced at the same time in all regions but there is considerable variation in the rate of this increase. In some regions, notably the Scottish Highlands, sheep numbers have remained relatively stable but in the Highlands there has been a net loss of rough grazing, mainly to forestry, so that grazing pressure has probably intensified. In the period 1950 to 1975 there was much regional variation in the trend of sheep numbers; some regions showed stability, others a steady increase but elsewhere there was a drop post 1960. Several regions show a plateau or even a drop in numbers since the late 1980s but in all such cases overall numbers remain far higher than in the mid 1970s. Wales stands out as showing an increase throughout the period since 1950, but this is also evident in Shropshire, Derbyshire and south-west England. These broad national and regional trends conceal much variation at the local scale. There are several major problems in using data on trends in sheep numbers to draw inferences about changes in grazing pressure. In particular, there is a general lack of fine-scale knowledge about how sheep distribution has changed across different habitats. Nonetheless, it appears that many unenclosed areas of the uplands have been increasingly heavily grazed since the mid 1970s, especially in Wales, the Welsh borders, and parts of south-west England, northern England and southern Scotland. These are the regions where recent increases in sheep numbers have been most marked and where the highest densities of sheep now occur.**

3. **Interactions between grazing pressure and bird populations are exceedingly complex. Several mechanisms by which grazing can potentially affect birds operate through modification of the vegetation. Four aspects of changes in habitat structure and vegetation composition are considered in detail: loss of heather, loss of vegetation mosaics, reduction of food resources (fruit, invertebrates, small mammals) and implications for predation rates. Other potential mechanisms do not operate through vegetation, for example trampling, the effect of dunging on food availability, the provision of carrion. It is concluded that three mechanisms are likely to be especially important to a large proportion of ground-nesting upland bird species: (1) loss of preferred vegetation types, (2) alteration of food supplies and (3) alteration of predation pressure. Almost certainly the scale of the recent increases in sheep numbers in many upland areas will have caused reduction in habitat quality through these mechanisms for many upland birds. Firm evidence demonstrating the existence and impact of such mechanisms on upland birds is, however, largely unavailable because there has been so little relevant research.**

4. **Grazing pressure affects different species in different ways. The exact mechanisms are species-specific. Different intensities of grazing will benefit, and conversely disadvantage, different groups of birds. Nonetheless, extremely heavy levels of grazing appear to be disadvantageous to the majority of upland birds. On the other hand, cessation of grazing is equally undesirable for the majority of upland species are adapted to open habitats, and**

often require areas of short vegetation, that are best maintained by light or moderate grazing.

5. The implications of a reduction in grazing are considered, in particular the effect of an expansion of scrub and woodland in the uplands. The effects of scrub development on bird communities will probably depend on the patchiness of the scrub and its regional location. There is a need to explore how moorland birds respond to scrub development.

6. Grazing pressure has undoubtedly been a fundamental influence on upland bird communities both historically and in recent times. Overgrazing should, however, be regarded as one of several inter-related, long-term trends combining with adverse consequences for some of the characteristic upland species. High grazing pressure is likely to compound effects of increasing predators, poor burning and acidification. Deleterious impacts of these trends are likely to be less severe under light grazing pressure. On current evidence it is impossible to assess exactly the relative effects of grazing though this has been better achieved for black grouse than any other species.

7. Recent declines of upland birds appear to be especially severe on Welsh moorland. The circumstantial evidence is reasonably strong that overgrazing is implicated. Upland Wales happens to be the most heavily sheep-stocked area of Britain (Figures 10 & 11) and the rate of increase in sheep there has been steep in recent decades (Figures 2 & 3). Unlike most other parts of Britain, Welsh sheep numbers have been increasing since the 1950s. Collapse in bird populations may be a response to the recent intensification of overgrazing (coupled possibly with increased predation rates) superimposed on a long-term reduction in carrying capacity of the Welsh uplands.

8. During the last two to three decades bird populations, especially of breeding waders, have collapsed in many areas of moorland-edge enclosed pastures. This is thought to be linked with increased grazing pressure by sheep, especially through the associated land improvements including drainage, fertilising and reseeding. Such habitat changes may also have affected moorland birds, many of which use marginal farmland for feeding.

9. This review has established that exceedingly little is known about the ecological relationships between grazing and upland bird populations. Against the background of the huge and recent increase in sheep numbers throughout most of Britain, there is a need for specific research into the ecological implications of heavy grazing by sheep and also of the implications of reduced grazing. Six specific areas of work are needed. First, it is essential that some means of tracking upland bird populations is developed and the BTO/JNCC/RSPB Breeding Bird Survey is an important step in this direction. Second, better information is needed on habitat requirements of birds in different upland areas, both at landscape and territory scales. Third, more information is needed about how grazing can be used to create and maintain the vegetation structures preferred by birds. Fourth, a clear understanding is needed of how grazing pressure interacts with predation rates on ground-nesting birds. Fifth, an experimental approach is highly desirable in which grazing pressure is manipulated, with predation and burning properly controlled, within large areas of moorland. Sixth, studies are needed on upland scrub to determine how invasion of scrub, in the event of reduced grazing, might affect upland bird communities.

1. INTRODUCTION

Grazing by large herbivores and burning are principal factors maintaining the open character of the British uplands. It is now recognised that some heath and moorland landscapes were created through the action of herbivores in the absence of fire (Stevenson & Birks 1995; Thompson & Miles 1995). Subsequent long-term changes in upland vegetation have been closely linked with changes in grazing pressure (Stevenson & Thompson 1993). It has also been argued that in some areas, notably western Scotland, intense grazing and burning have reduced land productivity (McVean & Lockie 1969; see also Mather 1978). More recently, large increases in sheep numbers during the latter half of the 20th century have caused further large-scale vegetation changes, especially an increase in grassland at the expense of heather *Calluna vulgaris* (e.g. Bardgett *et al*. 1995a,b; Thompson *et al*. 1995a). The pattern of grazing has never been static - both in historic and recent periods grazing has been an agent of profound ecological change in the British uplands. Similarly, in western North America, grazing by domestic livestock has fundamentally altered native biological communities and a vigorous debate now centres on this land management issue (Fleischner 1994; Brown & McDonald 1995).

There are obvious dangers in predicting future trends in land-use, nonetheless some reduction in grazing pressure is likely to occur in at least parts of the British uplands over the next few decades. A primary driving force for such change is the widely held perception that overgrazing by deer and sheep is deleteriously affecting upland vegetation and wildlife. Another change in upland land-use in recent decades concerns the management of grouse moors. It is widely believed that many Scottish grouse moors are now burned less frequently and less intricately than once was the case (e.g. Phillips & Watson 1995). However, a study in the Grampian and Borders Regions based on aerial photographs (Hester & Sydes 1992) did not detect a demise in burning since the 1940s but there was evidence that moors were burned less frequently than desirable for maintaining heather. It seems likely that changes in burning practices are locally variable and that the major changes may have occurred since the pre-war decades. These two trends - less grazing and local decline of grouse-moor management - could ultimately lead to large changes in upland vegetation. Already, local reductions in grazing pressure by sheep are taking place within some Environmentally Sensitive Areas and other protected areas. Advice has also proliferated as to what constitute environmentally acceptable stocking rates and practices (see individual ESA prescriptions, but more general recommendations have been made e.g. Cadbury 1993; Thompson *et al*. 1995a,b; Ward *et al*. 1995). Present support for sheep farming in the uplands operates through systems of headage payments - the ewe premium and the Hill Livestock Compensatory Allowance (HLCA). Headage payments are widely considered to have underpinned escalating numbers of sheep in many regions since the 1970s. Reform of these subsidy systems has been frequently advocated in such a way as to generate environmental benefits at the same time as maintaining rural society (e.g. Woods & Cadbury 1987; NCC 1990; Penford & Francis 1990; Haines 1991; Egdell *et al*. 1993; Ward *et al*. 1995). There is a difficult balance to be struck here because much of the present conservation interest of the uplands is perceived to depend on pastoral farming which is viable only with the availability of grants and subsidies. Over much the same period, red deer *Cervus elaphus* populations increased markedly in the Scottish Highlands. The ecological impacts of this increase, the need for reduced deer densities and the likely benefits of this have been reviewed by Staines *et al*. (1995).

This review concerns the relationships between grazing and bird populations, principally in the uplands. Overgrazing has long been perceived as a potential problem for many upland birds. Recently the strongest expression of this concern is the apparently large declines in ground-nesting birds in the Welsh uplands which have been attributed, at least in part, to overgrazing by sheep (Lovegrove *et al*. 1994, 1995). The birds and grazing issue has often been crystallised as one of loss of heather due to intensive grazing by sheep, with consequent impacts on birds associated with heather moorland such as red grouse *Lagopus lagopus*, merlin *Falco columbarius* and hen harrier *Circus cyaneus*. Heather moorland should certainly be a focus of attention because the British

examples are internationally important (Ratcliffe & Thompson 1988; Thompson *et al.* 1995a). The grazing issue is, however, multi-faceted and exceedingly complex. Many upland areas subject to increased grazing actually have rather little heather, perhaps for reasons of climate and past management; changes in grazing pressure within such areas may be highly significant to bird populations, even though there may be little change in heather cover. Within the British uplands there is huge variation in the present vegetation types, geology and soils, climate and land management (Ratcliffe 1977; Nolan & Robertson 1987; Ratcliffe & Thompson 1988; Thompson & Brown 1992). Furthermore, the absolute and relative numbers of deer and sheep in the uplands show much spatial variation. Accordingly, the ecological effects of sheep grazing, and of changes in grazing pressure, will vary substantially from one region to another, even from one moor to another (Grant & Armstrong 1993). This makes it impossible to derive simple prescriptions, incorporating desirable stocking rates, that can be *generally* applied with any confidence. Any given intensity of grazing will disadvantage some species of birds but benefit others; not all species of birds lose out under heavy grazing though it appears that many of the upland species of highest conservation significance do. Finally, it is not a simple matter to isolate the effects of grazing from those of other changes that are occurring in the uplands, for example trends in predation rates and air pollution. Indeed there may be interaction, even synergism, between grazing and these other factors.

The subject of grazing in the uplands and its effects on birds has been addressed in some detail previously by Hudson (1984, 1995), Cadbury (1992) and Harding *et al.* (1994). Original material presented in these earlier reviews is cited here where appropriate. The specific aims of the present review are to:

(1) summarise trends in sheep stocking and grazing, particularly to explore regional variation and to identify the timing of the recent increase in numbers;

(2) identify the potential mechanisms by which grazing may affect birds in open habitats and to summarise the evidence available for the existence of such mechanisms;

(3) discuss the relative importance of grazing and other factors as possible determinants of changes in upland bird populations;

(4) outline the implications of a reduction in grazing pressure for upland bird communities;

(5) consider the implications of different grazing intensities for individual species of birds, focusing on ground-nesting and ground-feeding species;

(6) identify key areas for future research on the relationships between birds and grazing.

The focus of this report is on the implications for bird populations of grazing pressure by sheep within open, unenclosed habitats in upland Britain. This is not to say that grazing issues are of less ecological significance in other habitats. Grazing is also an important factor determining habitat quality for several bird species on lowland heaths and grasslands in Britain though here the problem is generally one of too little, rather than too much, grazing. Habitat quality for stone curlew *Burhinus oedicnemus* and woodlark *Lullula arborea* has deteriorated on some lowland breeding grounds as a consequence of reduction of grazing pressure (Green & Griffiths 1994; Green & Taylor 1995; Sitters *et al.* 1996). Many woods in western and northern Britain have long been heavily grazed by sheep and deer with large impacts on regeneration (Mitchell & Kirby 1990; Staines *et al.* 1995). More recently, deer populations have expanded dramatically in many parts of lowland England creating serious regeneration problems within high forest and coppice woodlands (Kay 1993; Putman 1994). Browsing and grazing within *existing* scrub and woodland are not considered in this report because they are very different ecological issues to those of grazing in the open, treeless uplands.

Overgrazing in the uplands may lead to increased runoff, erosion and flooding in the associated spate river systems (Sanson 1996). This could cause alteration of riparian vegetation and depletion of aquatic invertebrates with implications for birds such as dipper *Cinclus cinclus* and grey wagtail *Motacilla cinerea*. These possible links do not appear to have been explored in any detail but they illustrate that intensive grazing on the hills may have geographically and ecologically far-reaching consequences.

2. SHEEP STOCKING: PATTERNS IN TIME AND SPACE
(by R.J. Fuller & S.J. Gough)

2.1 Historical and Long-term Aspects

Sheep have been present in the British uplands for centuries but hill farming has changed enormously, especially in the last 200 years. The following general account is based on Sydes & Miller (1988). In the early Middle Ages monastic estates kept large sheep flocks in southern Scotland, northern England and Wales. However, much of the uplands were grazed by mixed assemblages of domesticated herbivores - cattle, horses, goats and sheep. Transhumance was probably widespread, with the stock being moved to lower pastures for the winter. Throughout the uplands, but especially in Wales and England, there is a long history of both sheep and cattle being raised for fattening in the lowlands. Sheep did not attain their present ubiquitous and dominant status in the uplands until the 18th and 19th centuries; this situation was reached later (by the mid 19th century) in the Scottish Highlands than elsewhere.

One of the most detailed analyses of historical trends in sheep populations was by Hughes *et al.* (1973) for north-west Wales. The large changes they describe in the overall numbers of different herbivores and in the seasonal pattern of grazing must have had major long-term implications for upland vegetation. Sheep have been farmed on a large scale in north Wales since the arrival of the Cistercians in the 12th century. In early medieval times sheep considerably outnumbered cattle on the Cistercian properties but this was not typical of other areas where numbers of sheep and cattle were more evenly balanced. During the 1600s numbers of sheep started to rise substantially in north Wales and this increase was maintained up to the end of the 19th century. Numbers dropped in the first half of the 20th century but a strong increase has occurred subsequently (see below). The ratios both of sheep to cattle and sheep to goats have increased consistently since 1600 as hill farming in north Wales has become increasingly dominated by the sheep. Cattle are now largely confined to the upland margins and the lowlands. Changes in overall numbers of herbivores tell only part of the story of hill farming systems in north Wales. There have been large changes in the types of sheep and seasonal pattern of grazing. In particular, since the mid 1800s winter grazing has diminished as a result of a massive reduction in wether sheep (mutton sheep) which were kept on the hill throughout the year.

The trends over the last 100 years in total numbers of livestock in England and Wales have been described by Grigg (1989) based on annual agricultural records which start in 1866. Numbers of sheep show more fluctuation than those of cattle and pigs. Cattle increased steadily through the period and pigs increased since approximately 1950. By contrast, sheep gradually decreased since 1875 reaching lowest numbers in the late 1940s, partly as a result of severe losses in the 1947 winter. Over this period sheep numbers approximately halved. Grigg (1989) states that this decline occurred mainly in the lowlands but some upland areas also experienced drops in sheep populations as shown by the work of Hughes *et al.* (1973) in north Wales. Thereafter, numbers of sheep rose to such an extent that by 1980 overall numbers in England and Wales were similar to those one hundred years previously. This strong increase in sheep is not unique to Britain for there have been large increases since the 1970s in other EU countries, especially Spain, Ireland and Italy (Beaufoy *et al.* 1994). The following section focuses on this recent period of increase.

Species and breeds of herbivores differ in their impacts on vegetation through a combination of ranging behaviour, physical size, biting method and food preferences (Oates 1993; Armstrong & Milne 1995; Hearn 1995). It is certain, therefore, that the historical changes described above in upland livestock will have triggered major responses in vegetation. The demise of grazing by wether sheep and cattle in the uplands is thought to have contributed to long-term expansion of *Nardus* grassland (Welch 1986). Controlled grazing studies have recently demonstrated that goats and cattle achieve much greater defoliation of *Nardus* than do sheep (Grant *et al.* 1996) and that *Nardus* cover is more likely to decrease under cattle grazing but increase with sheep grazing.

***Molinia* has also probably been favoured by the decline in cattle (D. Bullock pers. comm.). Spread of bracken *Pteridium aquilinum* may have been facilitated by reduced trampling pressure (Marrs & Pakeman 1995) and by reduced cutting for stock bedding (Taylor 1986).**

2.2 An Analysis of Sheep Numbers Since 1950

In assessing likely ecological implications of the rising numbers of sheep it is important to determine over what period, and exactly where, grazing pressure has intensified. Detailed examination of the June Agricultural Census returns is worthwhile because they point to several interesting regional variations in stocking trends. However, this information must be treated with extreme caution because stocking levels cannot be equated with grazing pressure for several reasons (Grant & Maxwell 1988; Sydes & Miller 1988):

(1) Sheep show great variation in local density even within tracts of unenclosed land. This may be associated with the presence of preferred vegetation types (Hughes *et al.* 1975; Osborne 1984; Welch 1984) or with supplementary feeding sites. Hence one cannot deduce that grazing pressure will have *generally* increased within upland areas, even if overall stock numbers have strongly risen. Statistics are not available at a sufficiently fine spatial resolution even to determine the change in numbers on unenclosed hill land relative to that on in-bye land.

(2) The June census reveals nothing about autumn and winter stocking rates which, in terms of impacts on heather, are the most important. Sheep consume more heather at this time of year when their preferred grasses have died back (Thompson *et al.* 1995b). Supplementary feeding in winter has the effect of concentrating sheep in certain areas, enhancing their impact on heather in the vicinity of the feed sites. In northern England, for example, the trend of increasing numbers of sheep overwintering on moorland has been an important factor contributing to overgrazing (Hudson 1984). The development of big-bale silage in the early 1980s has increased the provision of supplementary hill feeding in Wales and other upland districts (D. Drewett pers. comm.).

(3) There may be local and regional differences in stocking patterns such as the seasonal movements between unenclosed land and in-bye which could cause spatial differences in vegetation. Stock type (breed, age, condition) of animals may also vary locally and regionally with implications for impacts on vegetation.

(4) Temporal changes in type of stock and farming practices have occurred in many regions with consequences for vegetation. These include changes in breeds, age structure and body condition of sheep. Reduction in shepherding will have had the effect of enhancing the selection of sheep for particular areas and vegetation types.

(5) In many parts of the uplands there has been loss of rough grazing (Harding *et al.* 1994) with the consequence that even long-term stability of sheep numbers would imply an increased density of sheep.

(6) The presence of other herbivores needs to be considered. For example, in the Scottish Highlands reduction of sheep numbers may lead to little ameliorative effect on vegetation because high grazing pressure may be sustained by red deer (Hope *et al.* 1996). Indeed the two herbivores are probably in competition (Clutton-Brock & Albon 1992).

Although stocking trends are a very crude instrument with which to explore environmental impacts of sheep grazing, they need to be considered because of the paucity of other information. Figures 1 - 9 are based on data provided from the MAFF/DAFS June Agricultural Census Returns and examine the period 1950 to 1992, although Scottish data were available to us up to 1989. Data have

been examined annually since 1978 and at intervals prior to this. The published data are available only at county level (parish level data are also available from the Public Record Office). The re-organisation of county boundaries in 1974 makes it impossible to present comparable long-term data for many counties; this is a particular problem in England where the boundaries of most upland counties were changed. In the present summaries, counties and regions have been selected where there were no county boundary changes or where these changes were so small as to be inconsequential in influencing the trend in sheep numbers. Two categories of sheep are used in the analyses. *Ewes* refers to the total number of breeding ewes and *sheep* refers to the total number of animals in all classes of sheep and lambs. Temporal and spatial inconsistencies in the way that sheep are recorded within the agricultural statistics precluded the use of other categories.

In England, Wales and Scotland there has been a steady increase in total sheep numbers since the mid 1970s with the steepest rate of increase in England and Wales (Figure 1). Since 1950, however, Scotland has shown relative stability in sheep numbers whereas in Wales and England there has been an approximate doubling of numbers (Figure 1). Since the late 1980s there is some evidence of a levelling off in numbers, mainly in England.

Sheep numbers were examined in four regions of Wales (Figures 2 and 3). A strong increase is evident in all four regions throughout the entire period and it appears to be slightly steeper since the mid 1970s in each region. Very slight levelling of numbers is evident since the late 1980s.

In contrast with Wales, Scotland shows considerable variation between regions (Figures 4 - 6). Two regions of southern Scotland have both experienced increases since the mid 1970s but more markedly in south-west (Figure 4a) than south-east Scotland (Figure 4b). Further north, the trend for Grampian Region (Figure 5a) is similar to that for southern Scotland. In the case of Highland Region and the Western Isles (Figure 5b) there is no evidence of a recent marked increase in sheep. Orkney and Shetland (Figures 6a and 6b) have both witnessed increases in sheep since the mid 1970s though the rate of growth has been steepest in Orkney. A decline in sheep numbers is evident in all the Scottish regions, with the exception of Shetland, between approximately 1960 and 1975. Note that in Scotland there has been considerable reduction of rough grazing (unimproved grassland, heather moor and blanket mire) to forestry and agricultural improvement (Tudor & Mackey 1995) which may have acted to further increase the actual sheep stocking density on unenclosed land. Even where total sheep numbers have remained relatively unchanged, notably in Highland Region and the Western Isles, the effect of these land-use changes may have been to increase stocking densities. It should also be noted that red deer have been increasing in the Highlands since the 1950s (Staines *et al*. 1995) so that even if sheep numbers have been constant the overall pressure from large herbivores has increased.

Trends in three English counties - Shropshire, Derbyshire and Northumberland - each of which has both upland and lowland farming, are shown in Figure 7. The trends are similar, with relative stability, or slow increases, between 1950 and the mid 1970s followed by a rapid rise in numbers. This pattern appears to be typical of much of southern and central England (Figures 8 and 9) indicating that recent increases in sheep are just as much a feature of lowland Britain as they are of the uplands. As with Scotland, several parts of eastern and central England experienced declines between 1960 and the mid 1970s. All the counties/regions of England examined exhibited a levelling or even a decrease in sheep numbers since the late 1980s but in all cases numbers remain far above those present in the mid 1970s.

Regional variation in the current distribution of sheep is shown in Figure 10 for 1969 and 1988. In both years Wales is a region of conspicuously high density, with south-west England, the northern Pennines and southern Scotland also holding major concentrations. The increase in sheep density is clearly evident in many parts of the country over the 20 year period. Figure 11 shows the same pattern in greater detail for the high density sheep areas, defined as those 10 km squares that contained more than 10,000 sheep in 1969. Among the heavily stocked areas, Wales stands out as

having undergone a massive increase in sheep stocking since 1969. There have also been substantial increases in sheep numbers in the northern Pennines, south-east Scotland and north Devon. The data in Figures 10 and 11 are based on sheep stocking densities calculated from the June 1969 and 1988 MAFF/DAFS June Agricultural Census Returns converted to the 10 km square grid by the Edinburgh University Data Library.

2.3 Local Recent Changes in Sheep Numbers in the Uplands

While the broad pattern is one of general increase in sheep in upland districts, for reasons that were discussed earlier the above analyses cannot be taken as proof that sheep have increased on unenclosed hill land. However, several local studies have provided strong evidence that grazing pressure in unenclosed upland areas has recently intensified with consequences for upland vegetation. Anderson & Yalden (1981) showed that increasing sheep were associated with deteriorating heather quality in the Peak District and removal of sheep has resulted in some recovery of the area's vegetation (Anderson & Radford 1994). Turner (1996) has described how high grazing pressure by sheep in parts of the Carneddau has intensified and how the 'best quality and most diverse' vegetation is now found in the least heavily grazed areas. Good *et al.* (1990) provided evidence that sheep were responsible for inhibiting scrub regeneration in north Wales. While there may be few detailed studies, there is a widespread informed opinion that upland areas have experienced increased grazing pressure from sheep in recent decades. This is especially striking in the Welsh uplands and in some of those English uplands close to the Welsh border where many believe that grazing has intensified in recent decades on many unenclosed uplands, with particularly severe impacts on common land.

Local data on stocking trends indicate considerable variation from one area to another. For example, Harding *et al.* (1994) have shown great variation among parishes in the Scottish Highlands in sheep numbers between 1975 and 1986, ranging from >60% decrease to >80% increase. In a study of golden eagles *Aquila chrysaetos* in the Highlands, Watson *et al.* (1987) recorded highly variable trends in numbers of wintering sheep within their 10 study areas between 1965 and 1985. In half the study areas there was a decline but elsewhere numbers either remained fairly stable or initially declined then rose.

Further evidence of the local variability of sheep stocking is given by our analyses of five adjacent parishes that form a part of the Elenydd SSSI in Powys and Dyfed, Wales. The rationale was that these parishes varied in their ratios of unenclosed land to in-bye. Examination of sheep stocking in these parishes may, therefore, give useful insights as to how the distribution of sheep has changed in central Wales. The parish data were collected from the Public Record Office and the trends are shown in Figure 12 for the period back to 1940. There was considerable variation among the parishes. Four of the parishes (a,b,d,e) showed increases over the period but the pattern of change varied substantially with (a) showing an exponential form of increase but (b) apparently reaching a plateau of numbers and decreasing since the mid 1980s. In these parishes numbers increased sharply in the mid 1970s but sheep numbers in parish (e) appear to have been increasing since the 1950s. In contrast to the other four parishes, (c) has remained relatively stable throughout the period. These different patterns of change in stocking did not appear to be linked to the proportion of the parish that was unenclosed. For example, comparing the two parishes with the highest proportion of unenclosed land, (e) (83% unenclosed) showed stability of sheep numbers between 1970 and 1990 while parish (a) (86% unenclosed land) doubled its sheep numbers over the same period. In the case of the latter parish it seems extremely that grazing pressure did not increase substantially on the unenclosed land between 1970 and 1990.

Another approach to determining what has happened on unenclosed land is to examine the HLCA headage payments. Hardy breeds qualify for special payments which can be distinguished from other HLCA payments within the Severely Disadvantaged Area of the Less Favoured Areas. The 'specially qualified flock' component in Scotland and the 'hardy breeds' component of English

HLCA payments broadly relate to sheep which are grazed on the open hill. Figure 13 shows that the specially qualified flock in Scotland has remained relatively constant since the mid 1970s but that sheep qualifying for other HLCA payments have risen. This may suggest that sheep numbers on unenclosed hill land in Scotland have not increased much and that the increases have occurred mainly on enclosed land. However, this does not mean that grazing pressure has not changed on unenclosed land in Scotland because red deer numbers have risen and the amount of rough grazing has been reduced (see above). Figure 14 shows that since the mid 1980s (earlier data were unavailable) there has been a slight increase in the English ‘hardy breeds’ flock suggesting a slight increase in numbers of sheep on open hill land in England. Unfortunately no comparable HLCA data were available for Wales.

2.4 Conclusions

There have been large overall increases in sheep numbers in most regions of Britain, both upland and lowland, since the mid 1970s. This increase appears to have commenced at the same time in all regions. There is, however, considerable variation in the rate of this increase and some regions, notably the Scottish Highlands, have not shown any recent overall increase. In the period 1950 to 1975 there was much regional variation in the trend of sheep numbers; some regions showed stability, others a steady increase but elsewhere there was a drop post 1960. Several regions show a plateau or even a drop in numbers since the late 1980s but in all such cases overall numbers remain far higher than in the mid 1970s. Wales stands out as showing an increase throughout the period since 1950, but this is also evident in Shropshire, Derbyshire and south-west England. It is not the purpose of this report to explore the social and economic factors underlying these changes but it is worth pointing out that the increases in the period 1950 to 1975 may be responses to land improvement (through drainage, reseeding and fertiliser use) especially on enclosed land. The relatively consistent increases post 1975 are more likely to be driven by the subsidy systems (note that the timing of the recent increase exactly matches the introduction of HLCA payments). These broad national and regional trends conceal much variation at the local scale, perhaps especially in the Scottish Highlands where it appears that different areas have experienced strikingly contrasting recent changes in numbers.

There are major problems in using data on stocking rates to draw inferences about changes in grazing pressure. There is a general lack of fine-scale knowledge about how sheep distribution has changed across different habitats. Much of the conservation interest in the uplands focuses on the semi-natural, unenclosed hill land. However, unimproved enclosed grassland can be rich botanically and important for breeding waders and as feeding habitat for many birds nesting on moorland. It is virtually impossible to use stocking data to assess the extent to which the recent increases in sheep have occurred within the unenclosed rather than the enclosed upland environment. However, based on local studies and on analyses of stocking levels within individual parishes, it appears that many unenclosed areas of the uplands have been increasingly heavily grazed since the mid 1970s. This seems to be especially likely in Wales, the Welsh borders, and parts of south-west England, northern England and southern Scotland where increases in sheep numbers have been extremely rapid and the highest densities of sheep now occur. It should be emphasised, however, that even if increases in stocking rates have been strongest on enclosed land this is likely to have implications for those moorland birds which make heavy use of in-bye land adjacent to moorland for feeding.

3. MECHANISMS BY WHICH GRAZING MAY AFFECT UPLAND BIRDS

3.1 Population Changes of Upland Birds in Relation to Grazing

Change in grazing pressure is just one of several factors that have potentially affected upland bird populations over the last 20 years (see section 3.6). It is not, therefore, a straightforward matter to determine the specific role of grazing in the recent population change of any upland bird. Nonetheless, if grazing pressure is a key factor determining the population of any bird species, then one would expect population changes to have been apparent since the mid 1970s, the point at which the recent increase in sheep occurred. Exact coincidence between changes in numbers of sheep and birds would not necessarily be expected for it may take several years for grazing to impact heavily on vegetation and this, coupled with possible site fidelity among breeding birds, could result in a time lag. Unfortunately there has been extremely little long-term, wide-scale systematic monitoring of birds in the uplands, unlike the situation with lowland farmland and woodland (Marchant *et al.* 1990). Here I summarise the more accessible information on the timing and possible causes of population changes in upland birds. The exact mechanisms by which grazing may affect birds are discussed in greater detail in following sections and more detail for individual species is given in chapter 4.

Breeding waders and other birds were surveyed over large areas of moorland by conservation bodies in the 1970s and 1980s. Some of these surveys have been repeated recently but because most of these data are not available in published form they have not been considered here. Similarly, the growing data set on annual site occupancy and performance of raptors in different parts of upland Britain has not been consulted because much of it is unsynthesised.

The longest time-series for upland birds in Britain are those for grouse based on bag records. The red grouse has undergone a long-term decline this century, with especially severe drops in the 1940s and 1970s-80s; reasons have been reviewed by Hudson (1992, 1995). The decline has been attributed mainly to habitat deterioration in which overgrazing has played a part along with reduction in moorland management involving intricate burning. Increase in predator numbers may also have contributed to the decline. Heavy grazing may affect red grouse populations in a complex of ways: the loss of suitable heather habitat, loss of cover for birds and nests, reduction in invertebrate food and by generating higher levels of disease. Black grouse *Tetrao tetrix* have also declined greatly since the early decades of the century. Two major drops in population, around 1910 and 1940, are evident from bag records (Baines & Hudson 1995). As for red grouse there are probably multiple causes including loss of semi-natural habitat to forestry and agriculture, increase in predator numbers and intensified grazing both by deer and sheep.

Shorter runs of annual data are available from two Scottish studies of upland waders. Parr (1992) and Thompson & Thompson (1991) documented change in Scottish populations of golden plover *Pluvialis apricaria* and greenshank *Tringa nebularia* respectively and in each case a collapse commenced at the end of the 1970s. The drop in greenshank was attributed to habitat loss arising from impact of all-terrain vehicles. It was argued that the golden plover had declined as a result of severe overwinter losses, possibly coupled with an inability of the birds to recover due to high rates of nest predation. In neither study was grazing pressure mentioned as a possible causal factor.

Information on population changes for breeding waders is given by Lovegrove *et al.* (1994, 1995) for upland Wales where golden plover, curlew *Numenius arquata* and lapwing *Vanellus vanellus* appear to have decreased. The timing of these population changes is not entirely clear because annual counts are unavailable but golden plover may have been in long-term decline in Wales whereas curlew and lapwing have decreased more recently. For each of these species Lovegrove *et al.* (1995) speculate that increased sheep stocking is a principal reason for the decline (other possible reasons are also listed). In contrast to Wales, golden plovers in the south Pennines appear to have shown little change in some areas but increases have occurred elsewhere since the 1960s (Brown 1993).

Sheep numbers have increased greatly in many parts of the Pennines indicating that simple relationships between grazing pressure and golden plover populations are unlikely to exist. Interestingly, Crick (1992) found that nest failures of golden plovers had not changed since the 1940s for birds nesting on heather moorland and upland bogs, but they had increased during the 1980s for birds nesting on grassland in Wales and northwest England. Crick (1992) suggested that this increasing rate of nest failure on upland grassland was a consequence of the rise in sheep stocking.

There are reasons for thinking that two montane bird species have been affected by increased grazing pressure by sheep on summits to the south of the Highlands (Ratcliffe 1990; Thompson & Brown 1992; Galbraith *et al*. 1993). Both dotterel *Charadrius morinellus* and ptarmigan *Lagopus mutus* were once more widespread in Britain occurring on mountains in southern Scotland, northern England and, in the case of dotterel, in north Wales. Overgrazing by sheep is thought to have changed the vegetation on these summits with deleterious effects on the two bird species. In the Scottish Highlands sheep densities on summits are lower and impacts on montane vegetation are less severe.

An increase of the raven *Corvus corax* population in Snowdonia between the 1950s and 1980s was attributed by Dare (1986) to an increase in sheep carrion. Over the same period, however, the population remained stable within the adjacent Migneint-Hiraethog upland area despite an increase in sheep numbers. The divergence of trends within these two areas was considered to be at least partly a consequence of different patterns of hill farming. Sheep carrion was probably more available within the rugged Snowdonia mountains than within Migneint-Hiraethog where far more of the land was enclosed and dead animals would be more likely to be removed by farmers.

Extremely little is known about trends in moorland passerines. Decline in Scottish twite *Carduelis flavirostris* populations this century were possibly linked to overgrazing and moorland reclamation (Jardine & Reid, in Gibbons *et al*. 1993). However, work in the Pennines (Brown *et al*. 1995) has raised the possibility that grazing could have some beneficial effects for twite by breaking up the heather canopy and raising the availability of *Molinia* seeds, an important food source for the bird. The BTO's Common Birds Census (CBC), which is strongly biased towards the lowlands, shows a sharp drop in meadow pipit *Anthus pratensis* numbers since the early 1980s (Marchant *et al*. 1990). It is unknown if the trend shown by the CBC for meadow pipit is representative of the uplands. Nonetheless, the possibility remains that this could be a response to the more or less ubiquitous rise in sheep stocking. One would predict that severe grazing pressure would reduce habitat quality for meadow pipit (see chapter 4).

In summary, there is limited evidence at present that population changes in upland birds are caused by increased grazing pressure. The strongest evidence, and the clearest understanding of the mechanisms involved, is for red and black grouse though even here there is a need for better data (see below). For several other species there is circumstantial evidence of a link between grazing pressure and population size. The absence of strong evidence for most species does not imply that grazing is ecologically insignificant (see below); rather it reflects a dearth of research focused on the issue and a general lack of information about the population trends of upland birds.

3.2 Overview of Potential Mechanisms

This section outlines the range of processes that are potentially involved in relationships between grazing pressure and bird populations. As described earlier, grazing pressure is not a simple function of overall stocking density. It depends on a combination of factors - vegetation type, land management, stock type, stock management. If the aim was to establish models to predict effects of different levels of grazing pressure on bird populations, then all factors appearing in Figure 15 would have to be considered. Figure 15 indicates the large number of changes other than grazing that need to be considered as possible determinants of bird populations in the uplands. There may

be complex interactions between some of these and grazing pressure - a good example is changes in land-use and land management that affect numbers of predators.

Two classes of mechanisms can be identified, though the division between them is hardly watertight. The first contains those mechanisms that operate, in one way or another, through the modification of vegetation. The second class contains a diverse assemblage of mechanisms that could theoretically affect birds in the absence of vegetation change, either through altering food resources or by directly affecting avian survival or breeding production.

3.2.1 Modification of Vegetation

Changes to the composition and structure of vegetation are pivotal influences of grazing pressure on birds. Vegetation changes are brought about by three processes: consumption of foliage, trampling and deposition of urine and dung. Floristic changes have received the greatest attention but alterations to vegetation structure are potentially at least as significant for bird populations. Grazing can involve direct habitat loss, as in the case of red grouse when overgrazing pushes heather moorland towards grassland. At its most extreme, heavy grazing can lead to bare ground and localised erosion, especially on slopes and peat (Hudson 1984), one of the best documented examples being the Kinder Estate in the Peak District (Anderson & Radford 1994). Alternatively, there may be more subtle changes in habitat quality arising from alteration of food resources or reduction of the plant cover required for concealment of nests, young or adults from predators. Main components of vegetation response to grazing pressure and implications for bird populations are considered further in sections 3.3 to 3.8.

3.2.2 Dung and Drugs

Deposition of dung and urine scorching can influence vegetation composition on moorland but the effect is far greater with cattle than with sheep (Welch 1985). It is possible that amount of dung might directly influence the availability of some invertebrates, especially dung-associated species, as food for birds, though wider effects on the heathland invertebrate fauna are likely to be deleterious (Usher & Gardner 1988). Sheep dung makes a far greater contribution to the species richness of moorland invertebrates than it does to invertebrate biomass (Coulson 1988). Nonetheless, sheep dung creates localised sources of invertebrate food that are exploited by some birds, mainly corvids and starlings *Sturnus vulgaris*.

Attention has been drawn to possible ecological side-effects of some veterinary drugs, notably the avermectins (Wall & Strong 1987). Avermectins are widely used as an anti-parasitic agent on livestock against intestinal parasites and insect pests associated with dung. The concern is that non-target invertebrates may be affected by the drugs and decomposition of dung may be retarded. For example, one detailed study (Madsen *et al*. 1990) found adverse effects of ivermectin on the decomposing fauna of cattle dung, especially Diptera, lasting up to 30 days post-treatment. Most of the ecological work on avermectins has been on cattle and it is not clear what impacts, if any, there may be on the sheep dung fauna though one study at least (Wardhaugh *et al*. 1993) indicates that the drug invermectin can have transient effects on insects feeding on sheep dung. It appears that antihelmintics are not widely used in upland sheep and this, coupled with apparently short-term post-treatment effects, would suggest that implications for upland birds are limited though more information is desirable. The ecological effects of avermectins is a controversial subject for whilst there is considerable evidence from experimental studies that the drugs can have adverse effects on dung fauna it is not always clear how readily these findings can be equated with typical patterns of field usage of the drugs (e.g. Wratten & Forbes 1995).

3.2.3 Carrion

For several birds in the uplands, carrion is a major food source: red kite *Milvus milvus*, buzzard *Buteo buteo*, golden eagle, carrion crow *Corvus corone* and raven. Relationships between each of these species and carrion are further described in chapter 4. Availability of carrion is an important factor determining population size but not breeding success of Scottish golden eagles (Watson *et al.* 1992). The importance of sheep carrion as a determinant of raven population density has been demonstrated in central Wales, north Wales and southern Scotland (Marquiss *et al.* 1978; Newton *et al.* 1982; Dare 1986). Mid Wales carries an exceptional concentration of carrion-feeding birds but ravens are more dependent on the carrion there than are kites or buzzards (Newton *et al.* 1982).

Sheep density is not a good index of carrion abundance. This can be illustrated in a crude way by examining the available information on biomass of sheep carrion in Scotland (Brown & Watson 1964). At that time carrion abundance (in kg/km^2 for sheep and lambs combined) was as follows in descending order: southwest Highlands 472, northern Highlands 227, north-west Highlands 180, eastern Highlands negligible. Exclusion of red deer carrion from the Scottish data makes little difference to the pattern because the overwhelming majority of carrion biomass was contributed by sheep (Brown & Watson 1964) though it must be acknowledged that deer carrion is more abundant today. The more recent transect counts of carrion made by Watson *et al.* (1992) show the same geographical pattern of carrion availability within Scotland. These data indicate huge variation within Scotland in availability of sheep carrion despite *relatively* little broad variation in sheep densities (Figure 10). Indeed, it appears that if anything sheep density is higher in the eastern than western Highlands (Figure 10) though carrion biomass is far lower in eastern Scotland.

Availability of sheep and lamb carrion within a 475 km^2 study area in central Wales was estimated by Newton *et al.* (1982) to be 190 kg/km^2 in the 1970s. This cannot be compared directly with the carrion estimates of Brown & Watson (1964) because the latter appeared to use total biomass whereas Newton *et al.* (1982) based their estimate on utilisable carrion. Welsh mountain ewes on the hill typically weigh 30-35 kg (source: Farmers' Union of Wales) but the weight of lambs on the hill at times of peak mortality are more difficult to estimate. If one assumes average weights of 30 kg for ewes and 8 kg for lambs, Newton *et al.*'s carrion data would indicate a total carrion biomass of 510 kg/km^2. Assuming an average lamb weight of 5 kg reduces this biomass to 375 kg/km^2. Hence, carrion availability in mid Wales in the 1970s was similar to, perhaps greater than, that of the highest Scottish estimates from the 1960s. Any comparisons between these two studies need to be made cautiously, not just because they used different methods, but because the time periods differed. Sheep numbers have declined in the Highlands since the 1960s (Figure 5b) whereas they have considerably increased since the 1970s in Wales (Figures 2 & 3). Hence, assuming that there have been no changes in factors affecting the mortality rate of ewes and lambs, carrion availability will probably have increased in Wales relative to many parts of northern Scotland.

Several factors act to confound any simple relationship between the densities of sheep and carrion. Carrion availability is determined at least as much by husbandry and stock management practices as it is by sheep density. Areas with high sheep densities, but where lambing occurs indoors or close to farms, may actually offer less carrion than areas with much lower sheep densities but where animals are present on the open hill for much longer periods (e.g. Dare 1986). The size, breed and condition of sheep are also relevant. Climate and topography probably play a role too: the western Highlands for instance represents a more severe winter environment for sheep than does central Wales. It is entirely possible, therefore, that in many parts of the uplands recent increases in sheep numbers have not led to an increased supply of carrion.

Carrion provides a food supply for foxes and crows as well as for scavenging birds. This has contributed to an increase in fox populations in some areas, possibly leading to greater predation pressure on ground nesting birds (Watson & Rae 1993).

3.2.4 Predation by Sheep

Predation by sheep on arctic tern *Sterna arctica* chicks and by red deer on manx shearwater *Puffinus puffinus* chicks has been documented by Furness (1988a,b). Such predation may be fairly widespread on islands in northern Scotland (Pennington 1992) and appears to be linked with dietary nutrient deficiencies. Pennington (1992) and Beintema & Muskens (1987) mention that sheep will eat the eggs of waders. I am unaware of such predation being recorded in mainland upland habitats though it may occur (hence its exclusion from Figure 14).

3.2.5 Trampling of Nests and Chicks

If one discounts predation by sheep, trampling is the most direct of impacts. Most of the relevant work has been undertaken in lowland grasslands. Trampling by livestock can result in losses of nests in ground-nesting birds with variation in risk of trampling depending on the bird species, type of stock, density of stock and time of nesting (Beintema & Muskens 1987; Green 1988). Effects of trampling by sheep and cattle on the nest survival of grassland waders were compared by Beintema & Muskens (1988). They found that trampling rates per individual animal were lower for sheep than for cattle. But when equivalent stocking units of cattle and sheep were compared (in which one adult cow = three yearling cattle = five sheep) sheep and cattle were found to inflict similar rates of damage on nests of lapwing, black-tailed godwit *Limosa limosa* and redshank *Tringa totanus*. Nest losses among ground-nesting birds have probably increased in recent years due to trampling. The evidence for this comes from an analysis of nest-record data for lapwings by Shrubb (1990). He found that the percentage of grassland nests lost to trampling in any year was significantly correlated with the overall densities of both sheep and cattle on English and Welsh grassland.

3.2.6 Disease

Rather little is known about disease as a factor in the dynamics of wild bird populations. An exception, however, is louping ill in red grouse which is a major cause of chick mortality (Hudson 1992, 1995). Louping ill is caused by a flavivirus that is transmitted between hosts (mainly grouse and sheep) by the sheep tick *Ixodes ricinus*. Sheep grazing may affect numbers of ticks and incidence of the disease, leading to reduced grouse populations, in two ways. First, abundance of ticks is greater where the vegetation occurs as a thick mat, for instance bracken or *Nardus stricta*. Where grazing pressure is sufficiently high to promote thick mats of less palatable grasses such as *Nardus* a build-up in tick numbers may result. Second, ticks become more abundant where they bite hosts most frequently; hence increasing sheep densities could presumably lead to larger tick populations. The dynamics of the disease and the role played by different hosts is not the same on all moors. In many cases the disease is epidemic and is probably closely linked with the sheep population; under these circumstances the disease can often be controlled by vaccinating and dipping sheep. Elsewhere, however, the disease is endemic, causing constantly high levels of grouse mortality deriving from large tick numbers which are perhaps maintained by mammalian hosts other than sheep.

3.3 Vegetation Change - Alteration of Vegetation Succession and Structure

The most fundamental way in which grazing affects bird populations is through arresting or promoting successional change in vegetation. It may seem trivial to point out that position on the successional gradient is an over-riding determinant of the character of the bird assemblage; one would obviously expect an enormous change in the bird life of moorland that experienced a long-term transition from predominantly short grass sward to scrub. Much finer-scale alteration of vegetation structure can generate major change in habitat quality for many birds, especially for ground-nesting and ground-feeding species. Among species that are extremely sensitive to sward height are most waders, skylark and wheatear which avoid tall, dense vegetation. In the broadest sense, grazing clearly benefits these species but very heavy grazing that creates 'bowling green'

swards is unsuitable, except probably for wheatear. These swards contain little variation in micro-structure, for example few tussocks, which may be important in offering cover for nests and chicks. This leads to two important points concerning preferred vegetation structures: (a) for many moorland species these appear to be created by intermediate or moderate levels of grazing, (b) bird species differ in their structural preferences such that any given level of grazing is unlikely to benefit all moorland species. (See also chapter 4).

Vegetation structure *per se* is only a proximate cue for habitat selection. The functional basis of a preferred vegetation structure is likely to lie with abundance and availability of food resources (section 3.6) and with predation pressure (section 3.7). There are also spatial aspects of vegetation structure that affect habitat suitability and which may be altered by grazing pressure and these are considered in section 3.5.

3.4 Vegetation Change - Loss of Heather

Relationships between grazing pressure, especially from sheep, and the nature of upland vegetation have been researched intensively, generating an extensive literature. This material is not reviewed here because the successional changes associated with different levels of increased or reduced grazing have been summarised elsewhere (Ratcliffe 1959; Miles 1988; Sydes & Miller 1988; Marrs & Welch 1991; Rodwell 1991, 1992; Harding *et al.* 1994; Armstrong & Milne 1995; Thompson *et al.* 1995). The outcome of heavy sheep grazing on dwarf shrub heaths is usually a shift towards grassland composed of unpalatable grasses, especially *Nardus* and *Molinia* on damper soils (Welch 1986). On better drained soils the vegetation may tend towards *Agrostis-Festuca* swards (Miles 1988). In addition to stocking density, the exact pathways and rates of vegetation change depend on several factors:

(1) Breed and condition of sheep. Oates (1993) has described grazing characteristics of different breeds of sheep; in general the older mountain breeds graze less selectively than relatively modern and lowland breeds.

(2) Existing composition of vegetation. Impact on heather, for example, is determined to some extent by the ratio of heather to the more preferred palatable grasses (Armstrong & Milne 1995).

(3) Patchiness of vegetation. For a given ratio of heather to grass, utilization of heather is higher where the grass is fragmented into patches (Clarke *et al.* 1995a,b).

(4) Age and vigour of heather. Young vigorous heather can withstand greater grazing pressure than senescent or slow-growing heather. Thompson *et al.* (1995b) state that in the former case stocking densities as high as 2.2. ewes/ha can be maintained with no reduction of heather cover whereas densities as low as 0.5 ewes/ha are needed in the latter situation.

(5) Management practices including shepherding, seasonal pattern of grazing, supplementary feeding in winter.

(6) There may be regional differences in the response of heather to grazing, possibly due to climate. Heather in uplands in southern and western Britain, for example in Wales, may be susceptible to faster change to grassland than heather in northern and eastern Britain subjected to the same intensity of grazing (J. Miles, J. Milne pers. comm.).

(7) Burning regime. Herbivores are attracted to the young regrowth on recently burned areas. The balance between grazing pressure and the size of area burnt will influence post-fire succession (MacDonald 1990; McFerran *et al.* 1995; Thompson *et al.* 1995b). Burning in

> **areas with moderate or high stocking levels is likely to exacerbate the transition from heather to grass.**

How important is heather moorland to birds and what are the ornithological implications of its loss through heavy grazing? A wide range of bird species make use of heather moorland for nesting, feeding or both activities but rather few are strongly dependent on it. This is illustrated by the assessment of Thompson *et al.* (1995a) who listed 40 species that occur on heather moorland but only one species (red grouse) was confined to the habitat and three others were considered to breed mainly on heather moorland (golden plover, merlin and hen harrier). For a further 16 species, moorland was considered to provide "a major breeding habitat". Stillman (1995) undertook a more quantitative analysis of the habitat distribution of 10 bird species in the eastern Scottish Highlands and the south Pennines. He found that red grouse and merlin in both areas, and meadow pipit in the south Pennines only, were positively associated with cover of heather moorland. Two species - dunlin *Calidris alpina* and skylark *Alauda arvensis* - avoided heather moorland.

Extremely few multi-species studies have been published on the distribution of upland birds in relation to habitat features upon which to base an assessment of the possible effects of a switch from heather to grass. Associations between bird species and broad moorland type (heather or grass) derived from three such studies are summarised in Table 1. It should be recognised that this is a simplistic view and that relationships between birds and moorland habitats are likely to be far more complex (see below). Associations were described for a total of 16 species in these studies and for nine of these species there was evidence of a relationship with either heather or grass moorland or both. Merlin and red grouse showed a strong association with heather as expected from detailed studies of the species (Bibby 1986; Haworth & Fielding 1988; Hudson 1992). Short-eared owl *Asio flammeus*, ring ouzel *Turdus torquatus* and twite were each associated with heather in single studies. The latter two species, however, generated somewhat contradictory results. Ring ouzel selected grassland in one study but heather in another. Twite selected heather moorland and avoided grass in one study but showed the opposite pattern in another. A more detailed study of twite, however, demonstrated a positive link with the distribution of grassland but not with heather (Brown *et al.* 1995). Skylark avoided heather but was associated with grass moorland which is consistent with findings in Wales (Hope Jones 1974; Massey 1978), southern Scotland (Moss *et al.* 1979) and northern Scotland (Stroud *et al.* 1987). Wheatear *Oenanthe oenanthe* also selected grassland in one study. An interesting feature of the results is that no positive associations emerged for waders (analyses were presented for six species: golden plover and curlew in all three studies, dunlin, redshank and snipe *Gallinago gallinago* in two and lapwing in one study). Golden plover avoided grassland and dunlin avoided heather moorland. Topographical variables, notably altitude, were frequently associated with distribution of waders. More subtle vegetation patterns, incorporating vegetation structure, mosaics and dampness, are probably more important determinants of wader distribution than are broad gradients from heather to grass moorland.

Relationships between habitat change (here heather loss) and bird abundance are unlikely to be linear. Site fidelity of individuals is one factor that will tend to introduce a time-lag into population responses to habitat change at the local scale (Wiens *et al.* 1986). Predicting population responses to habitat loss is obviously a scale-dependent exercise. At larger scales metapopulation dynamics and the underlying behavioural-ecological mechanisms determining distribution across patches must be considered (e.g. Bernstein *et al.* 1991) but here the focus is the local scale. Hypothetical responses of species as heather is replaced by grass are illustrated in Figure 16. I suggest that for species depending strongly on heather there may be a critical area of heather below which population density rapidly collapses. Many species, however, may be favoured by mixtures of heather and grass in which case a Gaussian type response is to be expected (Figure 16b).

Large shifts in the composition of bird communities would certainly accompany any transition from heather to grass moorland: some species would lose out but others gain. The above information on habitat associations indicates that a very small proportion of upland bird species depends strongly

on heather moorland. Therefore, one might predict that rather few species would be disadvantaged by heather loss *per se*. This is likely to be true in the case of pure stands of tall heather which appear to be avoided by most upland bird species and generally hold low densities of birds, though it should be noted that nest sites of hen harriers are nearly always in tall heather (Bibby & Etheridge 1993). It is also questionable just how important for upland birds are heather moors with a more varied structure of vegetation such as that created through grouse management. Brown & Bainbridge (1995) could find very little evidence that the British populations of any upland bird species, other than grouse, were strongly associated with, or dependent upon, heather moorland managed for grouse. They pointed out that there is substantial variation in bird populations on grouse moors and that this is probably related to how well these moors are managed: burning creates short swards suitable as wader nesting habitat and predator control may enhance breeding success of many ground-nesting birds. Furthermore, well-managed grouse moors will not be overgrazed by sheep or deer. Brown & Bainbridge (1995) concluded that "Grouse-moor management may well be compatible with a number of wider bird conservation interests but these interests do not appear to depend upon such management; other moorland may be of equal or even higher value". Nonetheless, extreme caution should be used in drawing conclusions about the ornithological significance of heather loss for the following reasons.

First, it must be emphasised that the amount of available information on bird-habitat relationships is extremely limited for the uplands. There may be important regional differences in habitat distribution that are not apparent from the few existing studies. All the above studies were conducted in the breeding season which is certainly the highest priority given that a high proportion of upland birds winter away from the uplands. Nonetheless, work is also needed at other times of year when there may be important bird-habitat associations different to those evident in summer. It has been suggested for example that *Molinia* grasslands, which are generally not noted for their breeding bird communities, may hold larger populations of birds, especially passerines, in winter than other nearby moorland vegetation (Armitage 1933). A second set of reasons for hesitating in drawing firm conclusions about effects of heather loss concerns the nature of habitat requirements of upland birds and the appropriate scale and design of study for detecting these. Severe grazing does far more to the habitat than simply alter its floristics - it fundamentally changes available food resources and the structure of the vegetation, both of which are important factors for birds (see below). The above studies took little account of fine-grain vegetation structure within heather- or grass-dominated moorland. The cover of heather or grass moorland is an extremely crude description of habitat; many species will respond to much more subtle variations of habitat. For example, vegetation height, vegetation density, dampness and spatial patterning in these elements. The presence of heather is an important component in diversifying fine-grained vegetation structure. Furthermore, there are probably non-linearities in relationships between heather cover and bird abundance (Figure 16b) which were not detected in the above studies because they were designed to identify essentially linear relationships. Mixtures of heather and grass (and of other vegetation types) may be highly beneficial to many birds, providing a patchwork of sites suitable for feeding and nesting. Light grazing may sustain such mixed vegetation patterns but severe grazing would obliterate them. This theme is developed further in the next section.

3.5 Vegetation Change - Alteration of Mosaics

The word "mosaic" is frequently used in ecological contexts without clear definition. Perceived patterns of spatial heterogeneity are scale-dependent so it is important to define what is meant by mosaics. Figure 17 illustrates three scales of mosaic that are relevant to birds with different patterns of spatial use. Here I use the word mosaic to refer to fine-scale pattern in vegetation composition roughly equivalent to scales (b) and (c) in Figure 17. Obviously this is a simplistic view because there can be continuous variation in vegetation pattern to which birds may respond.

The habitat requirements of some species may also embrace heterogeneity on more than one scale and the golden plover is a good example. Adults often feed on enclosed pastures adjacent to the

moorland nesting habitat (Ratcliffe 1990, Whittingham 1996). Proximity of these contrasting land-uses - moorland and pasture - is a form of coarse-grained mosaic requirement, though it is not known whether accessibility to enclosed grazed pasture is an obligatory need throughout the British uplands. On a finer scale it seems likely that selection of moorland nesting habitat by golden plover has a mosaic component, for family parties often move to localised rich feeding areas which may not be suitable nesting habitats. (Note, however, that such brood movements in waders may also constitute a predator avoidance strategy (Sonerud 1985)). The whimbrel *Numenius phaeopus* is another example of a moorland bird that appears to benefit from a coarse-grained juxtaposition of habitats (Grant 1992; Grant *et al*. 1992a,b). In Shetland the birds select unimproved heathland as nesting habitat but in the pre-laying period adults feed heavily on ploughed or harrowed reseeded heathland or on older pasture. While many broods remain close to the nesting area on heathland some move onto ploughed or harrowed reseeded heathland.

To some extent, mosaics can be viewed as patches that represent particular stages along various dimensions or gradients. In discussing upland heaths, Usher & Thompson (1993) listed three such gradients: (a) wet to dry, (b) tall to short heather, (c) underlying soil or geology i.e. acid to basic. To these one could add the ratio of heather to grass and the presence of other plant communities such as bilberry or blaeberry *Vaccinium myrtillus*.

How much evidence is there that the presence of vegetation mosaics is an important factor in habitat selection by upland birds? The traditional practice of rotation burning of heather to maintain high quality red grouse habitat is the clearest example of a structural mosaic. The practice is based on knowledge that the birds benefit from a mosaic consisting of different ages of heather in close proximity (Hudson 1988). The young growth that follows fire provides food and the taller heather gives cover. Work on dotterel (Galbraith *et al*. 1993) shows that adults eat tipulids and beetles, whereas chicks eat sawflies. These different diets are derived from different habitats; the transition from moss heath to montane bog ideally meets the requirement of both adults and chicks. Thompson & Brown (1992) predict that dotterel densities should be greatest in montane areas with the highest diversity of habitat. They also state "We expect similar correlations for other birds breeding in montane environments (notably ptarmigan, snow bunting *Plectrophenax nivalis*, golden plover, dunlin and possibly even wheatear)." Another example of habitat juxtaposition influencing distribution is given by the meadow pipit in the northern Pennines (Coulson & Whittaker (1978), summarized in Hudson (1988); Coulson & Butterfield 1985). Timing of first broods matches the emergence of adult tipulids from blanket bog but these insects are unavailable for second broods which are raised on invertebrates from grassland or heathland. Nests of meadow pipits tend to be located at the interface of blanket bog with grassland or heath, thus enabling the birds to exploit the differing seasonal patterns of insect emergence from the different habitats. Usher (1995) states that meadow pipits often nest close to the margin of short and tall heather but does not describe the functional basis of this distribution. Also in the northern Pennines Whittingham (1996) found that golden plovers depended on a mixture of habitats during the breeding season: different habitats were used by feeding adults, by feeding chicks and for nest placement. Finally, flushes are an important element of habitat patchiness for birds because they support concentrations of invertebrates (Hudson 1988; K. Alexander & M. Oates pers. comm.). Grouse, waders and insectivorous passerines are all likely to use flushes as feeding 'hotspots'. So, there is clear evidence that a small number of upland birds depend upon, or benefit from, vegetation mosaics. With further research more cases will almost certainly be described and, indeed, Thompson & Brown (1992) and Usher & Thompson (1993) have speculated on which bird species are likely to be affected by mosaics.

The effect of heavy grazing would be to destroy or reduce the quality of most of the mosaics likely to be beneficial to birds. In areas with existing mosaics, heavy grazing will tend to reduce vegetation height, except in areas dominated by unpalatable species, so structural diversity in the vegetation will tend to diminish. In submontane areas heavy grazing will cause the loss of mosaics of *Calluna* with other species as the *Calluna* becomes replaced by grass. There is evidence in montane habitats

that overgrazing by sheep will lead to replacement of moss heaths by grassland (Thompson & Brown 1992). On the other hand, an increase in grazing pressure on moorland areas that are ungrazed or very lightly grazed may actually create new beneficial mosaics.

The scale of patchiness could well have an influence on the response of a bird population to loss of heather (Figure 15). Where heather fragments into larger patches one might predict that heather-dependent species would show a more delayed response (for a given heather:grass ratio) than in places where the heather is more finely fragmented. On the other hand, relatively fine-scale patchworks of heather and grass may benefit birds that prefer vegetation mixtures. This is of course entirely speculative. An empirical approach is now needed to the whole subject of how birds respond to different vegetation mosaics across gradients induced by management. Usher & Thompson (1993) gave examples of how different bird species might respond to patchwork mosaics created by burning; these ideas need to be tested with field data. Grazing can itself generate mosaics within vegetation (van Wieren 1991) and there is a need to explore how different grazing regimes by sheep might effect spatial pattern in upland vegetation and how this in turn interacts with the grazing process (Clarke *et al.* 1995a,b).

3.6 Vegetation Change - Alteration of Food Resources

Grazing can affect food resources either directly, as in the case of removal of primary production that might otherwise be consumed by birds such as red grouse, or indirectly by changing floristics or vegetation structure in such a way that it alters food availability. Here I consider three types of food resources for birds that can be affected by grazing pressure. Carrion is a fourth food resource affected by grazing pressure (see section 3.2.3).

3.6.1 Fruit

Several plants produce fruit which is eaten by birds in late summer and autumn, the most widespread species being bilberry, cowberry *Vaccinium vitis-idaea* and crowberry *Empetrum nigrum*. Red grouse eat the fruits of bilberry, cowberry and crowberry (Wilcock *et al.* 1984). Most gamebirds will eat the berries of bilberry - grouse, grey partridge *Perdix perdix*, pheasant *Phasianus colchicus* and ptarmigan (Welch *et al.* 1994). Other species that feed on the berries are mistle thrush *Turdus viscivorus*, ring ouzel, woodpigeon *Columba palumbus* and several corvids, even raven. Bilberry is more resistant to sheep grazing than heather (Welch *et al.* 1994), nonetheless grazing in spring and summer could have an impact on the production of fruit and hence food availability for birds. Where sheep are present at high stocking rates they can eat a high proportion of the fruits as is the case with bilberry on the Long Mynd, Shropshire (M. Davies pers. comm.). In such cases availability of fruit for birds is likely to be reduced.

3.6.2 Invertebrates

Grazing is known to have large effects on the diversity, species composition and abundance of invertebrates in lowland grassland (Boyd 1960; Morris 1973; Morris 1978; Gibson *et al.* 1992). Relatively few studies have directly addressed the question of how grazing affects communities of invertebrates in the uplands though recent exceptions are work in Antrim by McFerran *et al.* (1994, 1995) and in Wales by Holmes *et al.* (1993) and Keiller *et al.* (1995). This research indicates that grazing intensity by sheep in the uplands is an important factor influencing the composition of carabid beetle, and in the case of the study by Keiller *et al.* (1995), spider assemblages. In Wales, the biomass of Diptera emerging from moorland swards was found to be greatest in ungrazed areas (Keiller *et al.* 1995). Strong successional changes occur among assemblages of ground beetles and spiders in response to the changes in heather structure effected by burning (Usher & Thompson 1993; Usher 1995). It is reasonable to assume that comparable gradients in habitat structure generated by grazing would be associated with spatial and temporal patterns in invertebrate communities.

Possible relationships between grazing and upland invertebrates are summarized below; this is based partly on discussions of the topic by Coulson (1988) and Usher & Gardner (1988). Many species of invertebrates are closely associated with particular plant communities, often with a single or small number of plant species. Therefore, any shift in floristics as a result of grazing is bound to favour some invertebrate species but disadvantage others. Loss of spatial diversity in plant communities could have deleterious consequences for food availability of several upland birds where food requirements of adults and chicks is different or where seasonal emergence of insects differs between habitats (see section 3.4). Structural changes in vegetation are also important in altering invertebrate communities - for example, spiders tend to live at higher densities in physically complex, taller vegetation which is unlikely to persist under heavy grazing pressure. Keiller *et al.* (1995) concluded that reduction of grazing would probably lead to an increase in diversity and abundance of spiders on Welsh podsolised uplands. The role of dung in creating concentrations of invertebrates which are exploited by some birds was discussed above (section 3.2.2).

Wet flushes provide concentrations of invertebrates (Hudson 1988; K. Alexander & M. Oates pers. comm.) and wet areas generally provide a major source of insects in the spring which is exploited by several bird species (Coulson & Butterfield 1985). The importance to birds of even small wet areas within dry moorland can be out of proportion to the area they cover. Therefore, any impact of severe grazing on wet areas within moorland is potentially serious for insectivorous birds. Possible impacts could include damage by trampling to flushes and other fragile damp plant communities. Surface desiccation, through increased evapo-transpiration, might occur in some habitats if severe grazing substantially reduces the height and cover of vegetation. However, Marrs & Welch (1991) suggested that mire and flush communities could be threatened by reduced grazing which may lead to growth of taller vegetation.

Some birds are selective with respect to invertebrate food. For example, dotterel chicks eat mainly sawflies (Galbraith *et al.* 1993) and black grouse chicks select lepidopteran larvae (Kastdalen & Wegge 1984, cited in Baines 1991). Changes in grazing pressure are very likely to alter the abundance of such preferred foods. Evidence that grazing can reduce insect food supplies of birds comes from work on black grouse and capercaillie *Tetrao urogallus*. Increased grazing pressure from both sheep and red deer is thought to have been an important contributory factor in the decline of black grouse (Baines 1991). Availability of lepidoptera larvae appears to be considerably less in heavily grazed than lightly grazed moorland and this correlates with variations in grouse density and breeding success which are both higher on lightly grazed moors (Baines *et al.* 1995; Baines 1996). Within pine forest, ground vegetation that was ungrazed by red deer appeared to hold on average four times as many lepidoptera larvae as grazed forest (Baines *et al.* 1994). To be absolutely certain of how grazing pressure affects invertebrate food resources on a large scale probably requires a more intensive approach to invertebrate sampling. The potential significance of these findings are such that this issue merits much closer attention.

One consequence of very heavy grazing pressure by sheep in the Welsh uplands is the creation of extremely uniform, short swards within those grassland types preferred by the sheep. These swards become attractive feeding sites for starlings, crows and rooks *Corvus frugilegus*. The attractiveness of these 'lawns' may stem partly from the fact that the birds prefer to feed in areas of short grass, probably because their foraging efficiency is relatively high in short vegetation. However, food availability may be enhanced in heavily grazed areas through the fertilising effect of dung. The input of readily assimilated nutrients in the form of dung is probably an important factor raising the production of soil and turf invertebrates (Keiller *et al.* 1995). It is not known if heavy grazing pressure has improved grassland food resources sufficiently to cause an increase in corvid populations in some upland regions. If this has happened, then grazing may have contributed to greater rates of predation on ground-nesting birds.

3.6.3 Small Mammals

Heavy grazing leading to short swards will tend to reduce small mammal populations leading to food reduction for predators such as short-eared owl and kestrel *Falco tinnunculus*. Relaxation of grazing can result in an increase in voles (Hill *et al*. 1992; Hope *et al*. 1996). It is conceivable that there may be a relationship between vole numbers, as affected by grazing, and predation rates on ground-nesting birds in the British uplands. In Scandinavia grouse numbers are known to be linked to cycling population levels of voles (Angelstam *et al*. 1984; Small *et al*. 1993). It appears that when voles increase, so do their main predators, but when vole numbers decline the predators switch to alternative prey such as grouse. Although there is no evidence to support this 'alternative prey hypothesis' from British grouse populations, it is not impossible that a collapse in vole populations as a result of severe grazing could have a knock-on effect on ground-nesting birds. If any such effect does exist, it would probably be short-lived because one would predict that predator populations would adjust to the reduced availability of prey.

3.7 A Link Between Grazing Pressure and Predation Rates?

I have indicated several hypothetical mechanisms whereby grazing may indirectly affect rates of predation on upland birds by altering food resources (soil invertebrates, carrion, voles) available to generalist predators. Variations in these food resources may affect predator numbers with knock-on effects on ground-nesting birds. Another class of mechanism by which grazing could affect predation rates is through increasing the likelihood of a predator detecting the nest, chicks or adults. This could come about either through (a) loss of cover for direct concealment or (b) through simplification of the sward appearance resulting in poorer camouflage for eggs or birds. This is likely to be one of the most important mechanisms by which grazing affects moorland birds in the most heavily sheep-grazed regions.

The requirement shown by some waders, for example snipe, redshank and dunlin, for nesting in tussocks is probably an anti-predator adaptation. Nests of meadow pipits, skylarks and grouse are also usually concealed in ground vegetation. In extreme cases of heavy grazing, where a very tightly grazed uniform sward is created, the habitat may become completely unsuitable so that these species no longer attempt to nest. Where the density or height of vegetation is reduced less severely, however, birds may continue to nest but perhaps with lower success. Strong evidence that nest cover can be an important factor determining nest survival of ground-nesting birds comes from work on mallard *Anas platyrhynchos* (Hill 1984), partridges (Rands 1988) and sage grouse *Centrocercus urophasianus* (Gregg *et al*. 1994) and from several studies on north American wildfowl. Loss of cover could be significant not only for concealment of clutches but also for concealing chicks of those precocial species that avoid predators by hiding in vegetation. Several ground nesting birds adopt a different strategy to predator avoidance. Rather than concealing nests or young within vegetation, birds such as lapwing and ringed plover *Charadrius hiaticula* rely on the cryptic qualities of their eggs and young. It is possible that this camouflage is less effective against the structurally uniform swards that tend to develop under heavy grazing. Baines (1990) has suggested that this is the reason lapwings suffer higher nest losses on improved than unimproved grasslands.

3.8 Relationship Between Grazing and Other Habitat Changes

Many forces other than grazing act to change upland vegetation and habitats. These are briefly reviewed here with emphasis on any interactions with grazing. Change in upland vegetation can arise through natural events, such as local winter browning and damage from insect attack (MacDonald 1990), but the four anthropogenic processes detailed here each have the potential to cause widespread and long-term change with implications for habitat quality for upland birds. It has been suggested that disturbance by people may constitute a serious problem for birds breeding in upland areas which are heavily utilised for recreational purposes (Yalden & Yalden 1988, 1989,

1990). I have, however, not included disturbance as a general factor affecting upland birds because at present it appears to be essentially a local problem (see for example, discussion in Haworth & Thompson 1990). Nonetheless, it should be noted that high levels of disturbance may be potentially more serious in areas where birds are already vulnerable to predators as a result of overgrazing.

3.8.1 Burning

The important interactions between grazing and burning have been outlined above (section 3.3). Burning is carried out for grouse management and as a means of enhancing the quality of grazing and performance of sheep (Lance 1983). In managing optimally, however, there is a delicate balance to be struck between grazing pressure and the frequency and distribution of burns. Burning moorland, especially in small patches, in areas with high sheep stocks is a recipe for losing heather because the animals will tend to concentrate their feeding on the fresh growth. Stevenson & Thompson (1993) argue that heather has been in decline in several upland regions for 200 to 500 years as a result of a combination of increasing grazing pressure and prolonged burning. There is no evidence of any substantial change in burning management practices since the 1940s, at least in Borders and Grampian (Hester & Sydes 1992).

3.8.2 Drainage and ‘Land Improvement’

Drainage has been widely conducted in the uplands with the intention of raising the stocking capacity of the land and less commonly with the aim of improving grouse habitat. In general, drainage aimed at enhancing grouse habitat is misguided for it can simply serve to remove insect-rich areas that are important feeding sites for grouse and their chicks (Hudson 1988; Coulson *et al.* 1990). Attempts at draining the wettest blanket bog by the use of grips or drainage ditches rarely have any extensive impact on vegetation (Coulson *et al.* 1990; Stewart & Lance 1991).

Extensive improvement of rough grazing land, especially on the moorland fringes, has been of considerable ecological significance. Such improvements typically involved drainage, reseeding and use of inorganic fertilisers and in many areas were probably a necessary precursor to the sharp rise in sheep numbers that occurred from the mid 1970s onwards. Effects on waders breeding in upland-edge fields in the Pennines were examined by Baines (1988, 1989, 1990). He found that densities of breeding snipe, redshank, curlew and lapwing were greatly reduced by grassland improvement and that breeding productivity of lapwings was far lower on improved grassland as a result of relatively high predation. Land improvement probably affects waders mainly by removing the wetter feeding habitats upon which many of these birds depend and also by simplifying the spatial complexity and physical structure of the sward rendering nests and chicks more vulnerable to predation. Baines (1990) suggested that grassland improvement made lapwing eggs more conspicuous to predators because they were less well camouflaged against the uniform background. Escalating densities of sheep within many of these improved grasslands will have further reduced the height and structural diversity of the grassland.

Many moorland birds make use of improved or reseeded moorland for feeding, though they remain dependent on the moorland for nesting. The examples of golden plover and whimbrel were given above (section 3.5). One should be cautious in concluding that moorland improvement may benefit these species because it is not known whether the availability of non-moorland habitat is a determinant of breeding production or density. Furthermore, in these cases the birds do not nest on the improved land so there is likely to be an optimum ratio of moorland to pasture.

3.8.3 Forestry and Predator Control

Expansion of upland forestry has created new breeding habitat for crows and refuges for other predators, especially foxes. Increase in predator populations has probably been given a further boost by the trend of diminishing gamekeepering (Hudson 1992). It is thought the association

between predators and forestry has serious implications for bird populations over much wider areas of upland habitat (e.g. Bibby 1988; Thompson *et al.* 1988). Ground-nesting birds in many upland regions are now probably encountering predators more frequently than was the case perhaps three or four decades ago. Potential effects of forestry extend beyond an effect of predator population size. There is evidence that predation rates on nests placed in open habitats can be higher in proximity to trees (Berg *et al.* 1992a; Burger *et al.* 1994). But these effects do not appear to hold in all habitats because Berg *et al.* (1992b), working on Swedish bogs, and Avery *et al.* (1989), working in Sutherland, could not detect any effect of the forest edge on predation rates when using artificial nests. Avery *et al.* (1989) did, however, find an effect of vegetation type on predation rate which could have been mediated through an exposure and detectability differential. Clearly there is a need for more work on relationships between forestry, grazing pressure and predation. This issue is also relevant to the creation of new native woodland in the uplands (chapter 5).

3.8.4 Acidification and Air Pollution

The history of air pollution and its effects on upland vegetation have been reviewed by Lee *et al.* (1988) who document that emissions of sulphur dioxide have decreased in recent decades but nitrogen deposition has increased four-fold over the last 120 years. Over the past 50 years pure *Racomitrium lanuginosum* heaths have declined on mountains south of the Scottish Highlands coincidentally with a strong trend of increasing nitrogen deposition (Baddeley *et al.* 1994). However, it is not clear how much of this *Racomitrium* decline can be attributed to acidification and how much to overgrazing by sheep (Thompson & Brown 1992). Whatever the exact mechanism, the loss of montane moss-heaths is ornithologically important because dotterel and ptarmigan are closely associated with the habitat (Galbraith *et al.* 1993).

Two studies have provided more general evidence of soil acidification in the British uplands since the 1950s. First, Kuylenstierna & Chadwick (1991) demonstrated substantial acidification of a range of soils in north-west Wales with the largest decreases in pH occurring on those soils that were initially of highest pH. Second, Langan *et al.* (1995) examined soil chemistry at a sample of heather moors in north-east Scotland and concluded that further acidification could lead to reduction of heather productivity and that "potential for change in the species composition of heather moorland and the Scottish landscape in future years is large". It is conceivable, therefore, that increasing inputs of oxides of nitrogen and sulphur could ultimately cause a shift from heather to grass dominated moorlands, much as it has on Dutch heaths and possibly in Breckland heaths (Marrs 1993). Under such circumstances heavy grazing can only exacerbate the vegetation changes. Acidification may have also have an impact on abundance of invertebrates both in vegetation and soil. Invertebrate populations may respond to changing floristics and vegetation structures induced by acidification and, more directly, to changing soil and foliar chemistry.

3.9 Conclusions

There is a web of mechanisms by which change in grazing pressure can potentially affect bird populations but three stand out as critically important: (1) loss of, or creation of, preferred vegetation types, (2) alteration of food supplies and (3) alteration of predation pressure. There is considerable overlap between these three factors - for example, particular vegetation types may be preferred because they provide critical food resources or cover from predators. Given the scale and ubiquity of the recent increases in sheep numbers (chapter 2) it is almost certain that these mechanisms will have brought about reduction in habitat quality for many upland birds.

Land-use changes sometimes cause such an abrupt change in habitat suitability that, for some species, the consequence is almost immediate total loss of habitat. In this case, if they are to survive, individuals have to disperse and seek new areas of suitable habitat. Except in extreme cases, increases in grazing pressure would be expected to have a gradual effect on habitat quality which would manifest itself over several years causing reduction in breeding production or overwinter

survival leading eventually to population collapse. Hence, one would expect a time-lag between increase in grazing pressure and response in a bird population; this would be modified by the longevity and site-fidelity of the species.

Changes in grazing pressure must be viewed as one of a several land-use and other environmental changes occurring in the uplands with possible consequences for birds. On current evidence it is impossible to assess exactly the relative effects of grazing though this has been better achieved for black grouse than any other species (Baines & Hudson 1995). See chapter 6 for discussion of the research that is needed to isolate effects of grazing.

The following chapter takes a species-specific view of the effects of grazing and the likely mechanisms that are relevant to individual species.

4. CHANGES IN GRAZING PRESSURE - A SPECIES PERSPECTIVE

This chapter draws together what is known about interactions between grazing and the breeding ecology of individual bird species. For most species, knowledge is very limited about the exact interactions. Nonetheless, probable responses to changes in grazing pressure can be deduced from an understanding of habitat requirements and feeding ecology which, admittedly, is often rather limited for many upland birds. This is attempted here for upland species, which for the present purposes are defined as those listed by Ratcliffe (1990). I have, however, excluded skuas and gulls which are usually dependent mainly on the sea or non-moorland terrestrial habitats for their food though some of these birds may feed opportunistically on sheep and deer carrion.

As stressed above, grazing pressure is just one of a series of ecological variables that affect the distribution and abundance of birds in the uplands. It is not the intention here to describe the full suite of changes that may impact on each species, nor do I attempt to place grazing into context against these other changes. The purpose is to (a) summarise available evidence of the ecological significance of grazing pressure and (b) to assess the likely mechanisms by which grazing may affect individual species.

The food, habitat needs and nest site requirements of each species in upland Britain have been assessed systematically using the following sources: Cramp & Simmons (1977, 1979, 1982); Cramp (1985, 1988, 1992); Ratcliffe (1990); Cadbury (1992); Cramp & Perrins (1993); Gibbons *et al.* (1993). I have not repeated details of food, habitat and nest site unless this is deemed relevant to potential grazing impacts.

From the following accounts, it is clear that grazing affects different species in different ways. Not only do the mechanisms differ between species but optimum levels of grazing differ from species to species. Any given level of grazing will benefit some but not all species. It does appear, however, that extremely heavy grazing is disadvantageous to the majority of upland birds. The habitats of many upland birds are probably best maintained by light or moderate grazing pressure.

4.1 Red-throated diver *Gavia stellata*

No obvious interaction with grazing.

4.2 Black-throated diver *Gavia arctica*

Harding *et al.* (1994) suggest that if a reduction in grazing leads to widespread regeneration of scrub and woodland this may enhance the fish production of some freshwater systems through input of leaves (and presumably also by invertebrates falling from foliage). On the other hand, this may lead to reduced water transparency with consequences for feeding efficiency. Increased woodland may also enhance water retention, possibly reducing fluctuation in water levels leading to fewer instances of nests being flooded out.

4.3 Greylag goose *Anser anser*

Nest sites are usually in tall vegetation, and in upland areas often on islands, partly perhaps because predation is lower there and partly because islands can support relatively good nest cover in heavily grazed areas. By reducing vegetation height, severe grazing may reduce nest site quality. However, heavy grazing may create suitable feeding habitat in the form of short or medium grass swards. Grassland improvement (to increase stocking capacity) in upland areas may increase foraging habitat.

4.4 Wigeon *Anas penelope*

Nests are positioned on the ground in thick cover such as tall heather, within grass tussocks or beneath scrub; often on islands. Heavy grazing which reduces vegetation height will probably make nest sites less suitable by exposing them to a higher risk of predation.

4.5 Teal *Anas crecca*

Nests are placed on the ground within thick cover of grass, heather or even scrub. For example Fox (1986) found that nests in a Welsh raised mire were always well hidden, being 50-85% obscured by vegetation cover from above. Heavy grazing pressure is likely to lead to increased nest exposure to predators.

4.6 Mallard *Anas platyrhynchos*

Ground nests are typically placed in tall vegetation which offers the best sites in terms of breeding success (Hill 1984). Reduction of vegetation cover by heavy grazing is, therefore, likely to cause increased nest losses.

4.7 Common scoter *Melanitta nigra*

Nests are typically on the ground in deep vegetation so heavy grazing may reduce suitability of nest sites by exposing them to higher risks of predation.

4.8 Red-breasted merganser *Mergus serrator*

Ground-nesting birds are often concealed within thick vegetation so the same arguments hold as for other ground-nesting wildfowl. See also black-throated diver.

4.9 Goosander *Mergus merganser*

No obvious implication but see black-throated diver.

4.10 Red kite *Milvus milvus*

Benefits from sheep carrion which forms a major part of the food in winter in Wales (Davis & Davis 1981). In Wales the species exploits a wide variety of prey (Davis & Davis 1981) and is less dependent on sheep carrion than raven (Newton *et al*. 1982). The Welsh population differs from some other northern European populations in being sedentary and this may be related to a good winter food supply. It is possible that a much reduced supply of carrion might cause the birds to range more widely in winter to locate alternative food supplies. Effects of variation in carrion supply on overwinter survival and breeding success are unknown.

4.11 Hen harrier *Circus cyaneus*

The nest site is located in tall moorland vegetation, often but not exclusively in stands of deep heather. It seems unlikely that availability of such nest sites is a major factor currently limiting the species in the British uplands. Nonetheless, extremely heavy grazing does have the capacity to reduce the suitability of nesting habitat by lowering vegetation height. Where grazing is extremely heavy some relaxation could be beneficial because it may increase the food supply, especially small passerines such as meadow pipit but also small mammals. It is not clear whether the general avoidance of grazed grassland is a consequence of poor food supplies. If this is the case, then reduced grazing pressure may lead to the colonisation of such habitats. It is questionable whether the regeneration of extensive tracts of heather moorland would be entirely beneficial because, whilst

these may provide suitable nest sites, availability of small birds may be less than on heather-grass mixtures. Moderate grazing pressure that generates such vegetation mixtures may suit hen harriers well because they would provide suitable nesting sites and also a diverse range of prey. The latter is an important consideration because the males hunt small birds and mammals, which are fed to the female during incubation, whereas the female will take much larger prey including red grouse. The establishment of open mosaics of scrub and moorland would probably provide excellent food resources. Hen harriers will readily hunt around patches of scrub for songbirds.

4.12 Buzzard *Buteo buteo*

Within grass-dominated areas this species would probably benefit from increased numbers of small mammals following reduced grazing. Whilst carrion is heavily used in many upland areas, the consequences of removing this food supply are uncertain but are likely to depend on availability of other food supplies. The buzzard is such a versatile hunter that in areas with diverse food supplies it may find alternative winter food. For example, in central Wales an exceptionally high density of buzzards is associated with an abundance of both carrion and live prey (Newton *et al.* 1982). Here the impact on buzzard density of reducing carrion may be less than on degraded land in parts of western Scotland where the range of food resources available to buzzards is almost certainly much smaller. The relative contributions of carrion and live prey to density and performance of buzzards is unknown but is worthy of study (Watson *et al.* 1992).

4.13 Golden eagle *Aquila chrysaetos*

Grazing by both sheep and deer has a large effect on food supply for eagles which has been discussed in detail by Harding *et al.* (1994). Throughout the Scottish Highlands, sheep form an important component of the diet of the golden eagle, mainly as carrion; the exception is the eastern Highlands where the diet is predominantly lagomorphs and tetraonids (Watson *et al.* 1993). High grazing pressure tends to reduce live prey (mainly lagomorphs and tetraonids) but increase the amount of carrion. Breeding success is positively correlated with abundance of live prey but eagle density is correlated with availability of carrion (Watson *et al.* 1992). Changes in grazing pressure are therefore likely to affect eagle populations in complex ways that will vary from one region to another. In heavily grazed areas some reduction of grazing pressure would tend to increase densities of the preferred live prey, though this will only happen where heather regeneration occurs. Harding *et al.* (1994) argue that there is likely to be an asymptotic relationship between live prey availability and grazing pressure on heather moorland. This may happen because mountain hares *Lepus timidus* and grouse benefit from the growth of young heather shoots that occurs under moderate grazing. An increase in scrub and woodland regeneration will probably also increase live food resources. In much of the northern and western Highlands the climate is wet, the soils extremely impoverished and heather is scarcer than in the eastern Highlands. Under these circumstances it is by no means certain that live prey would respond strongly to reduced grazing so that improved breeding success could not necessarily be expected.

Against any benefit derived from an increase in live prey must be set the effect of loss of carrion which would be expected to lead to lower eagle densities. Reduction of carrion, either as a result of lowered sheep or deer densities or improved sheep husbandry, will probably lead to lower eagle densities. There is no reason to assume that an increase in live prey would compensate for loss of carrion. The effect on eagle densities would presumably be greatest in those regions where carrion densities were highest, notably the western Highlands. Availability of deer carrion may not be linearly related to deer population density because survival may be density-dependent (Harding *et al.* 1994). Hence, even moderate culling programmes may have a marked effect on eagle food supply.

4.14 Kestrel *Falco tinnunculus*

Heavy grazing in grass-dominated upland areas probably leads generally to reduction in voles which are one of several major foods of upland kestrels. A wide range of prey is exploited by kestrels which do not show the marked population fluctuations that characterise the response of short-eared owls to changes in vole numbers in upland grassland (Village 1987). The effect of reducing grazing is, therefore, uncertain but the regeneration of scrub would probably be broadly beneficial to the kestrel by increasing the amount of potential songbird prey.

4.15 Merlin *Falco columbarius*

Merlins show a generally strong association with heather moorland (Bibby 1986; Haworth & Fielding 1988). In the Pennines the birds prefer to nest on moderate to steep slopes in the headwaters of streams running off moorland plateaux (Haworth & Fielding 1988). The basis of this habitat selection is unknown but it may be partly because the birds appear to prefer tall mature heather as a nest site and it may also be related to food availability in some way. At the broadest level, therefore, overgrazing that results in loss of heather is detrimental to merlins. One might predict that an increased area of heather moorland arising from reduced grazing pressure would lead to increased populations of merlins. Furthermore if sheep grazing was less intense on steep slopes a rather small reduction in stocking might serve to create a disproportionate amount of suitable merlin nesting habitat. Harding *et al*. (1994) considered that this might not in fact happen for two reasons. First, there is evidence (Haworth & Fielding in press, cited by Harding *et al*. 1994) that not all potentially suitable heather habitat is fully occupied by merlins. Second, merlins have started to nest in trees at the edges of mature spruce plantations (Parr 1991; Little & Davison 1992). It is possible that an increasing proportion will use tree nests.

Grazing can also potentially affect merlins through food supply. Where heavy grazing causes a reduction in populations of moorland passerines this would be detrimental. If reduced grazing generates higher densities of passerines on the moorland itself or on the margins this would presumably be beneficial. Open scrub may be an attractive hunting habitat for merlins but closed-canopy scrub would probably not be good hunting habitat even though passerine densities may be relatively high.

4.16 Peregrine *Falco peregrinus*

The only interaction with grazing is that within the inland uplands there are broad spatial relationships between peregrine breeding density and food availability. Historical land-use, including the pattern of grazing and burning, has probably been a factor in determining the broad pattern of food abundance. This applies especially to the low density breeding area in the Highlands that runs through the western Highlands. Interestingly, peregrine populations in the western parts of the northern Highlands have failed to recover fully from the pesticide-induced population crash of the 1950s and 1960s. In the eastern parts of the northern Highlands, where food supplies are richer, the bird has shown a much more complete recovery (Crick & Ratcliffe 1995).

4.17 Red grouse *Lagopus lagopus*

Overgrazing is one of the most important factors implicated in the decline of red grouse (Hudson 1984, 1988, 1992, 1995). The primary mechanism is loss of habitat resulting from conversion of heather to grassland which effectively deprives the bird of food and possibly of cover from predators. It is surprising that the relationship between grazing and habitat quality for red grouse has not been quantified. This may not be simply a matter of the ratio of heather to grass but it is possible that sheep and deer effectively compete with grouse by removing young heather. While severe grazing pressure is detrimental, light or moderate grazing pressure can benefit grouse by stimulating the growth of young heather shoots which are preferred food. Heavy sheep stocking is

also connected with louping ill in grouse which is transmitted between hosts (mainly grouse and sheep) by the sheep ticks (see section 3.2.6).

4.18 Ptarmigan *Lagopus mutus*

Heavy grazing of montane heaths is considered to have been a causal factor in the extinction of ptarmigan in southern Scotland and northern England (Ratcliffe 1990; Thompson & Brown 1992). The mechanism is likely to be a reduction in vegetation diversity, in particular transition from dwarf shrub heaths (bilberry, crowberry, etc.) to grassland, causing loss of food. Reversal of these vegetation changes south of the Highlands may be extremely difficult, even impossible, especially since they have been exacerbated by nitrogen deposition (section 3.8.4). Further north however, the prospects are better for enhancing ptarmigan habitat in areas where local grazing pressure has reduced the cover of dwarf shrubs and the availability of their berries. In such cases reduction of grazing pressure could have considerable benefits. Watson & Rae (1993) state that increased sheep stocking has generated larger fox populations through the provision of carrion possibly causing higher predation on ptarmigan.

4.19 Black grouse *Tetrao tetrix*

Heavy grazing appears to be a major factor in the current demise of the black grouse (Baines 1991, 1994; Baines & Hudson 1995). In Wales and the Pennines, moorland black grouse habitat has been degraded through overgrazing by sheep but within Scottish pine forests red deer have reduced the quality of black grouse habitat in the absence of sheep. Grazing by both deer and sheep has caused loss of habitat on moorland and at the woodland edge through reduction in heather and other dwarf shrubs that provide food and cover from predators. In northern England, where black grouse live on open moorland without trees, in spring and winter the birds avoid heavily grazed grass moorland and depend for food on bogs and heather moorland which is vulnerable to overgrazing (Baines 1994). There is evidence that availability of food (lepidopteran larvae) for chicks is lower in heavily grazed than ungrazed or lightly grazed habitats. This applies in moorland (Baines *et al*. 1995; Baines 1996) and in pine forest (Baines *et al*. 1994). Further work on the relationship between grazing pressure and availability and quality of insect food is highly desirable. Substantial improvements to black grouse habitat could be gained in many areas through substantial reductions in grazing pressure. Scrub regeneration would be considerably beneficial because it would enhance food supplies in many moorland areas. It should be noted that in some areas black grouse use pastures adjacent to woodland for leking but this does not seem to be an essential requirement.

4.20 Oystercatcher *Haematopus ostralegus*

The oystercatcher is not a common breeder on unenclosed moorland but it is present within many upland valleys and commonly breeds on fields on the upland fringes. Baines (1988) found that it was the only wader species that actually increased in response to grassland improvement on the upland margins in the north Pennines. Heavy grazing pressure may benefit this species which, during the breeding season, feeds mainly in short grassy swards. It is continuing to increase in inland areas but at present there is no indication that it is spreading onto sheepwalk.

4.21 Ringed plover *Charadrius hiaticula*

A scarce nester on moorland, though it does breed on coastal heaths in northern and western Scotland. Tall vegetation is avoided so grazing is probably generally beneficial in creating potentially suitable nesting and feeding habitat.

4.22 Dotterel *Charadrius morinellus*

The reduction in dotterel populations on mountains in southern Scotland, northern England and north Wales is probably linked with overgrazing by sheep (Thompson & Brown 1992; Galbraith *et al*. 1993). Nitrogen deposition is also thought to be implicated in the loss of *Racomitrium* heaths (section 3.7.4). The vegetation changes on summits south of the Scottish Highlands have probably been so severe that large-scale habitat restoration may be an unrealistic aim - even with much lower sheep densities there is no certainty that mosaics of dwarf shrub and moss heaths could be reinstated. Nonetheless, where such mosaics do exist they may be enhanced, or at least stabilised, by substantial reduction in grazing pressure.

4.23 Golden plover *Pluvialis apricaria*

Because the species requires short vegetation both for feeding and nesting, some grazing is beneficial; burning also creates short vegetation. The exceptionally high densities of birds breeding on limestone grassland in the Pennines may be partly linked with sheep grazing (Ratcliffe 1976), though it should be said that the area concerned is very small. Sheep show a strong preference for grazing on this grassland which keeps the sward low and possibly enhances numbers of soil and dung-associated invertebrates through intensive dunging. In the north Pennines, acid grassland is an important feeding habitat for chicks and for adults with chicks (Whittingham 1996); it is possible that a level of grazing that created grass patches within a short heather sward maintained by rotational burning could be ideal (A.F. Brown pers. comm.). Crick (1992) has suggested that declines in breeding success on hill grasslands in Wales and northwest England during the 1980s were linked with increasing sheep numbers, though it is not clear what the mechanisms might be. Trampling of nests could be important but it is possible that the clutches of golden plovers are less well camouflaged against the uniform swards that are typical of much heavily grazed grassland. Whilst plovers occur on many heather moors they are by no means dependent on them and the loss of heather moorland with increased grazing pressure has probably not been of great significance to the species. In the Peak District numbers of plovers have not changed despite a large increase in sheep numbers and a decline in heather (Brown 1993). Large-scale development of scrub would be detrimental to golden plovers, unless scrub and woodland was largely confined to the steeper slopes.

4.24 Lapwing *Vanellus vanellus*

Lapwings tend to breed at higher densities on grasslands, often within enclosed fields, at the periphery of upland areas rather than on open moorland. The loss of heather moorland as a result of sheep grazing has probably created a larger area of potential breeding habitat for lapwings within the uplands. A moderate level of grazing is beneficial in maintaining the low vegetation preferred by nesting and feeding lapwings. Where grassland becomes increasingly uniform as a result of grassland improvement it appears that losses to predation intensify, probably because nests are more easily detected by predators (Baines 1990). A similar effect may occur where sustained heavy grazing leads to simplification of grassland structure and appearance. On heavily grazed grassland, eggs may stand out more clearly to predators than against the patchier, less uniform background of lightly grazed swards. There is evidence that trampling of lapwing nests on grassland has increased in recent years with rising livestock numbers (Shrubb 1990). Some reduction of grazing pressure may, therefore, benefit lapwings but, clearly, moderate grazing is desirable. Increase in heather cover would not benefit the lapwing and could even result in density reductions if this occurred on grassland where lapwings were nesting.

4.25 Temminck's stint *Calidris temminckii*

Very rare breeder in upland habitats. Implications of changes in grazing pressure are unknown.

4.26 Purple sandpiper *Calidris maritima*

Very rare breeder on montane summits. Implications of changes in grazing are unknown.

4.27 Dunlin *Calidris alpina*

Any reduction in grazing that caused expansion of heather would not be expected to affect dunlin which are mainly associated with wet areas. In some of the wettest bogs holding high densities of dunlin, grazing probably has only a very minor role in maintaining suitable habitat. However, elsewhere grazing may be important in several respects. The nest is often concealed within a tussock. It is possible, therefore, that by reducing vegetation height, heavy grazing could lower the quality of breeding habitat, perhaps by altering predation rates. Light grazing, however, may create a mosaic of tall and short vegetation which may be ideal for dunlin. Chicks generally feed in areas of low vegetation (Soikkeli 1967) but typically take cover in patches of denser vegetation (personal observation) which would also offer nest sites. The development of scrub would not benefit dunlin.

4.28 Ruff *Philomachus pugnax*

A very rare breeder in upland habitats. Implications of changes in grazing are unknown.

4.29 Snipe *Gallinago gallinago*

Associated with wetter areas within upland habitats (e.g. Calladine *et al*. 1990). Similar comments apply as for dunlin. The bird typically nests within tussocks so heavy grazing that results in lower vegetation could have an adverse affect. The birds will nest within very open scrub but scrub invasion would eventually cause areas to become unsuitable.

4.30 Whimbrel *Numenius phaeopus*

In Shetland whimbrels nest on short heath swards. The birds select relatively tall hummocks and/or short heather as nest sites (Grant 1992). It is possible, therefore, that reduction of sward height by moderate grazing is an important factor in maintaining good quality habitat. Indeed the Shetland population appears to be dependent on common grazing land for nesting habitat. However, if grazing was sufficiently heavy either to reduce heather cover or to damage the hummock structure through trampling this could be disadvantageous. Before laying their clutches, adults feed heavily on established pasture and reseeded heathland that has been ploughed or harrowed (Grant *et al*. 1992a). This appears to be a selection for the habitats that hold the greatest biomass of soil invertebrate prey. It is possible that sustained grazing within the established pasture may have enhanced soil invertebrates.

4.31 Curlew *Numenius arquata*

The nest can be in a tussock but is usually completely exposed. M. Grant (pers comm) found that nesting success of curlews in Northern Ireland was unrelated to height of vegetation surrounding the nest so it seems unlikely that overgrazing was implicated in the low breeding success of the birds in his study area. Chicks use vegetation as cover from predators so heavy grazing could influence losses of young. Evidence of the importance of tall vegetation comes from a study in the southern Pennines by Stillman & Brown (1994) who found that the distribution of curlew was correlated with the cover of tall heather but not with the overall cover of heather moorland. Calladine *et al*. (1990) also reported that curlew used *Juncus* flushes and areas of tall wet vegetation. In many areas, however, the adults and chicks apparently make considerable use of areas of low vegetation, often damp grassland, for feeding. Therefore, a patchwork of short and relatively tall vegetation may be preferred. Baines (1989) found that losses of clutches were higher on improved than unimproved moorland. He did not discuss the reasons but nests may be more visible to predators in

the improved habitat which tends to present a more uniform background than the unimproved habitat (he subsequently suggested that this was the reason why lapwings have lower nest survival on improved grassland (Baines 1990)). Heavy grazing which leads to relatively uniform grassland structure and appearance may have a similar consequence. Curlew will nest within open scrub but avoid areas with dense scrub.

4.32 Redshank *Tringa totanus*

The nest is typically concealed within a tussock which suggests that heavy grazing will be detrimental to the preferred structure of habitat. This appears to be the case on saltmarshes where densities of redshank are lowest on heavily grazed marshes but highest under medium grazing pressure (Cadbury *et al*. 1987). Scrub invasion would have a detrimental effect.

4.33 Greenshank *Tringa nebularia*

The birds select short vegetation for nesting, often in quite dry locations. Therefore, moderate levels of grazing probably have a broadly beneficial effect on habitat structure. Chicks hide in vegetation at the approach of a predator so very heavy grazing may not be beneficial. However, chicks typically feed in wet areas often with small complexes of pools and bogs. Whether such areas contain particular preferred mosaics of vegetation and other habitat features and whether grazing is important in maintaining or harming such mosaics is unknown. Moderate scrub invasion would not necessarily be adverse because the birds will nest within open pinewoods and other places with scattered trees.

4.34 Wood sandpiper *Tringa glareola*

The species breeds in wet swamps and mires, often adjacent to trees and scrub. Grazing is probably not a significant factor in determining vegetation composition and structure in these habitats.

4.35 Common sandpiper *Actitis hypoleucos*

Grazing pressure is likely to affect nest site quality. Nests are typically concealed in dense vegetation which chicks also use as cover from predators.

4.36 Red-necked phalarope *Phalaropus lobatus*

Heavy grazing could potentially affect breeding phalaropes in two ways. First, by removal of emergent vegetation that often forms the main feeding grounds at breeding sites. Second, by exposing nests to greater risks of predation. Nests are usually placed within grazing marsh or swamp adjacent to a waterbody.

4.37 Stock dove *Columba oenas*

No obvious interaction with grazing.

4.38 Cuckoo *Cuculus canorus*

Any interaction with grazing is likely to come about through effects on numbers of its main host, the meadow pipit. A mosaic of open moorland and scrub may enhance the populations of potential hosts.

4.39 Snowy owl *Nyctea scandiaca*

Although Britain lies on the absolute fringe of its range, grazing could affect habitat quality for this species in two ways. First, it is associated with open habitats (mainly maritime heath and montane summits in Britain) so moderate grazing can play a part in maintaining structurally suitable habitat. Second, severe grazing could potentially deplete prey populations for example ptarmigan and mountain hare.

4.40 Short-eared owl *Asio flammeus*

Food availability, mainly voles, is probably reduced by heavy grazing in grass-dominated upland areas (Ratcliffe 1990). The dependence of short-eared owls on voles in upland grasslands is such that they fluctuate markedly in relation to changes in vole numbers (Village 1987). The birds do not show such strong dependence on voles in heather-dominated areas (Roberts & Bowman 1986). Short-eared owls should benefit wherever a reduction in grazing pressure has the effect of causing an increase in voles (Hill *et al.* 1992; Hope *et al.* 1996). Scrub regeneration would probably be broadly beneficial, at least initially, by increasing the amount of potential songbird prey but any advantages are likely to diminish if the scrub becomes too dense.

4.41 Nightjar *Caprimulgus europaeus*

Nightjars were formerly widespread on open moorland, especially on the lower slopes, but the majority of upland nesting sites are now in conifer plantations in the early stages of growth. The decline in the uplands started in the 1950s and it has no obvious explanation for substantial areas of potentially suitable habitat appear to remain. Grazing pressure is an important factor maintaining suitable nest sites i.e. patches devoid of ground vegetation. Despite this, some scrub invasion following diminished grazing would not necessarily be a problem, indeed scattered bushes and trees are a feature of many breeding areas and may even be a requirement. On lowland heathland, for example, favoured sites are typically at the interface of woodland or scrub with heath (Burgess *et al.* 1990).

4.42 Skylark *Alauda arvensis*

In the uplands, the skylark is associated with areas of grass and avoids pure stands of heather (Hope Jones 1974; Massey 1978; Stroud *et al.* 1987; Ratcliffe 1990; Brown & Stillman 1993; Henty manuscript). While the species will tend to be favoured by grazing that causes a transition from heather to grass, very tightly grazed grass swards are avoided because the vegetation is too short for nest concealment and trampling pressure may be high. Hence, moderate or medium grazing pressure that maintains mosaics of heather and grass would probably be beneficial. There is no adequate data on population trends or densities of skylarks in different moorland habitats but one would expect that the extremely heavy grazing pressure currently maintained in south-west England, Wales, the Pennines and Southern Uplands has reduced habitat suitability over large areas of sheepwalk.

4.43 Shore lark *Eremophila alpestris*

Erratic breeder on British montane summits. Implications of changes in grazing are unknown.

4.44 Meadow pipit *Anthus pratensis*

Despite being the most numerous upland bird virtually nothing is known about population trends and rather little about habitat preferences. There have been two notable studies of the bird: one in North Wales (Seel & Walton 1979; Walton 1979), the other in the northern Pennines (Coulson & Whittaker 1978). The bird appears to be ubiquitous in the uplands but this perception may in fact mask considerable variation in density, some of which could be related to grazing pressure. For example, it would be surprising if very heavily grazed sheepwalk held as many pipits as lightly or

moderately grazed moorland. Vegetation that is bitten down short does not offer suitable nest sites - the nest is usually well concealed in a grass tussock or patch of dwarf shrub. There are also finer-scale variations in pipit distribution that are responses to vegetation patterns (Coulson & Whittaker 1978; Usher 1995). It is conceivable that heavy grazing could alter the structure and composition of preferred mosaics. Meadow pipits are unspecialised in their selection of invertebrate prey (Walton 1979) so a general reduction in the biomass of invertebrates as a consequence of heavy grazing could be significant to the species.

4.45 Grey wagtail *Motacilla cinerea*

Regeneration of scrub and trees in response to less grazing in riparian areas would result in increased input of organic matter in the form of leaves and terrestrial invertebrates. This may enhance populations of aquatic invertebrates many of which are taken in emergent form by grey wagtails. On the other hand, moderate grazing at the waterside benefits the species by maintaining short vegetation which is suited to its running and picking foraging behaviour.

4.46 Pied wagtail *Motacilla alba*

There are no obvious interactions with grazing pressure, with the possible exceptions that short swards created by heavy grazing may suit the wagtail's feeding technique and the birds may feed on insects associated with dung.

4.47 Dipper *Cinclus cinclus*

As for grey wagtail, the dipper may benefit indirectly from growth of trees and scrub at the margin of rivers. The input of leaves and invertebrates may increase abundance of aquatic invertebrates.

4.48 Wren *Troglodytes troglodytes*

Rather little is known about the ecology of wrens in the uplands. The bird nests in a variety of habitats: gullies and streamsides, cliff faces, scree slopes and heather moorland. While many upland nests are situated in rocky crevices the bird probably also nests among patches of scrub and in tall heather. Heather and bracken are certainly used extensively for feeding so heavy grazing that reduces vegetation height (though this is unlikely in the case of bracken) would have an adverse effect on upland wrens. Conversely, light grazing that allowed the development of open scrub could create good conditions for wrens.

4.49 Whinchat *Saxicola rubetra*

Whinchats are associated with areas of tussocky, tall vegetation, sometimes with low scattered bushes. They avoid dense scrub. Light grazing regimes are, therefore, broadly favourable to the species. Heavy grazing which severely reduced vegetation height, or complete absence of grazing in the absence of vegetation cutting would be detrimental. In some upland areas the bird is strongly associated with bracken (Brown & Stillman 1993; Stillman & Brown 1994; Allen 1995; Henty manuscript) but it is by no means confined to bracken for it frequently nests within rank grass and to a lesser extent in heather (Fuller & Glue 1977).

4.50 Stonechat *Saxicola torquata*

As for whinchat, light grazing is generally beneficial in maintaining the open habitat structures, dominated by a rank field layer, that are preferred by the stonechat. An interspersion of tall and short patches of vegetation may be the most preferred structure. The bird is more strongly associated with heather than is the whinchat (Phillips 1970; Fuller & Glue 1977). Low scrub (gorse is widely used) is often present in territories but is not essential because many moorland territories

are centred on patches of tall rank heather. Clearly, heavy grazing is not compatible with maintaining good stonechat habitat. The stonechat in general is more closely associated with persistent woody shrubs than the whinchat which makes more use of seasonal green growth (long grass, bracken). The stonechat is, therefore, potentially more vulnerable than the whinchat to habitat change that derives from heavy autumn, winter or early spring grazing.

4.51 Wheatear *Oenanthe oenanthe*

Heavy grazing appears to be entirely advantageous to the wheatear which prefers extremely short vegetation and bare areas for feeding. It is common on many tracts of sheepwalk, other areas with tightly grazed turf and the sparsely vegetated summits of mountains. The species does not appear to be dependent on tall vegetation in any way. Males select territories with short vegetation which is the habitat supporting the highest densities of available prey (Tye 1992). Territory size is smaller and male arrival date earlier on territories with relatively short vegetation and small territories tend to have larger proportions of short vegetation (Tye 1992). Hence, territory quality is closely linked with short vegetation which appears to be used as a cue for identifying places with high prey density. A similar conclusion was reached by Brooke (1979) who found that territories where the earliest breeding took place tended to contain relatively large areas of short vegetation on level ground that suited the wheatear's feeding technique.

4.52 Ring ouzel *Turdus torquatus*

It is rather difficult to characterise the habitat of the ring ouzel. The bird is widely distributed in sheepwalk, heather moorland, craggy broken terrain and montane areas. Highest densities probably occur on moorland with considerable amounts of heather and varied topography; within such areas it nests on steep slopes, in rocky stream valleys, craggy outcrops and even on level ground where there is deep heather or tussocky grass. The great majority of British nests are either placed in crevices/ledges or close to the ground in heather, bracken or bilberry (Flegg & Glue 1975). In one detailed study, nests were mainly concealed beneath heather (Poxton 1986). Severe grazing would, therefore, presumably have adverse consequences in terms of nest site quality. Another potentially detrimental effect of grazing is the reduction of moorland fruit which is an important food in late summer.

Conversely, grazing can have positive effects through the creation of short grass which can be used as feeding habitat when it exists in proximity to nesting habitat (Poxton 1986; Leo Smith pers. comm.). Birds from different territories may use the same patches of short grass where they forage for soil invertebrates, especially earthworms. Ratcliffe (1990) points out, however, that ring ouzels breed in places with infertile soils where earthworms are absent so they appear to be capable of exploiting different types of invertebrate prey in different upland regions.

An association with steep slopes has been recorded in two studies (Poxton 1986; Stillman & Brown 1994). In heavily grazed areas the best nesting habitat will often be found on the steeper slopes because these tend to be grazed less by sheep than level areas. Hence, moderate to heavy grazing pressure in topographically diverse moorland may create a good mixture of nesting and feeding habitat.

4.53 Chough *Pyrrhocorax pyrrhocorax*

There is a strong link between grazing and habitat suitability for chough. The bird is specialised for feeding on ground-dwelling and near-surface invertebrates in very short vegetation. Preferred feeding sites are short turf or heath that is kept low through grazing by rabbits, sheep or cattle, possibly combined with effects of wind exposure. Proximity of such feeding habitat to suitable nest sites appears to be important in determining distribution. Heavy grazing by sheep may be

especially beneficial because this generally creates very tight swards. Dunging may be an important factor in enhancing abundance of invertebrate prey.

4.54 Jackdaw *Corvus monedula*

Grazing creates habitat structures and food resources which are used by jackdaws in the uplands. Short grassy swards derived from heavy sheep grazing are strongly favoured by jackdaws which, often in mixed flocks with rooks, feed on soil and surface invertebrates. The birds exploit the invertebrate fauna of dung.

4.55 Carrion & hooded crow *Corvus corone*

Crows are highly adaptable birds using a variety of nest sites and food resources; this adaptability allows them to survive under a range of grazing pressures. The creation of scrub and trees through relaxed grazing pressure can provide more nest sites and observation posts for feeding. Where reduced grazing pressure leads to higher densities of grouse and passerines, crows will have more opportunities to feed on the eggs and young of these birds. On the other hand, heavy grazing pressures may be associated with higher availability of carrion and the opportunity to feed on the invertebrates of short grassy swards in the same manner as jackdaws and rooks.

4.56 Raven *Corvus corax*

The overriding influence of grazing systems on ravens is through the provision of carrion. Throughout much of the uplands, sheep carrion is the main food of the bird (Ratcliffe 1962; Newton *et al.* 1982). In Wales, ravens are strongly dependent on carrion; their annual clutch size is positively correlated with carrion availability and their time of breeding corresponds closely with the seasonal peak of carrion abundance (Newton *et al.* 1982). Wales stands out as the largest area of high raven density in Britain. Almost certainly, the supply of carrion plays a major part in this distribution pattern. Wales has long been an area of high sheep density within the uplands and among the high density sheep areas it stands out as having experienced a large increase in stocking since the late 1960s (Figure 11). The raven, therefore, is most abundant as a breeding bird in those areas of Britain where the change in sheep numbers has been the greatest over the last 20 years.

Interestingly, Gibbons *et al.* (1994) found that the distribution of managed grouse moors better fitted the upland distribution of ravens (a negative relationship) than did geographical variation in sheep density. It is widely considered that persecution limits raven distribution -there is no doubt that the species is very scarce in those areas where the interest in grouse management is strongest. Though highly suggestive, the result of Gibbons *et al.* (1994) cannot in itself be taken as direct evidence of a persecution effect. A negative association with grouse moor management could possibly have arisen for other reasons connected with the occurrence of grouse moors, for example availability of food or nest sites. Indeed, carrion availability is very low in eastern Scotland which is a region with a heavy concentration of managed grouse moors. Sheep density is not a good index of carrion (see section 3.2.3) and this is probably the reason why it did not emerge as a good predictor of raven distribution in the models of Gibbons *et al.* (1994). In reality the distribution of the raven is probably determined by a combination of persecution and food availability, especially carrion. The exceptionally high densities in Wales are probably a consequence of an abundant supply of carrion coupled with low levels of persecution. The low densities or absence of ravens from the eastern Highlands and parts of the Pennines probably reflect higher levels of persecution and a poorer carrion supply.

4.57 Twite *Carduelis flavirostris*

Whilst it is possible that overgrazing is one of the factors implicated in the long-term decline and range contraction of the twite in Britain, exact interactions between the species and grazing pressure remain unclear. The potential significance of grazing was recognised by Brown *et al*. (1995), on the one hand by reducing nesting cover and on the other in promoting *Molinia*. The spread of *Molinia* that has accompanied overgrazing by sheep in some areas may have been beneficial because burned *Molinia* provides an important supply of seeds in spring (Orford 1973). Increased grazing pressure and associated land improvements in moorland-edge pastures has been significant in reducing suitable food for twite - thistles, sorrel, etc. are now rare in such pastures.

4.58 Lapland bunting *Calcarius lapponicus*

Erratic breeder on British montane summits. Implications of changes in grazing are unknown.

4.59 Snow bunting *Plectrophenax nivalis*

There are no established links between the ecology of snow bunting and grazing pressure. Thompson & Brown (1992) point out that the species may depend on certain mosaics and vegetation patterns on montane summits. If this is the case, they would be potentially vulnerable to heavy grazing that modified such mosaics.

5. CONSEQUENCES FOR UPLAND BIRDS OF REDUCING GRAZING PRESSURE

5.1 Responses of Birds to Possible Vegetation Changes

Relaxation of sheep grazing will not necessarily trigger a sequence of vegetation changes that are a reversal of those occurring with intensified grazing. Restoration of heather can occur where it has disappeared through grazing (e.g. Rawes 1983; Anderson & Radford 1994) but exclosure experiments indicate that vegetation responses are highly variable for several reasons (Marrs & Welch 1991; Hill *et al*. 1992; Hope *et al*. 1996). These include soil type, composition of initial vegetation, proximity of seed sources, presence of other herbivores, especially deer, which may increase in the absence of sheep, and whether the area is burned. Exclosure experiments are extremely useful in illustrating the profound effects of grazing on the floristics and structure of vegetation but they have several drawbacks for purposes of predicting wider effects of land-use change. First, most involve exclusion of sheep (but often not of lagomorphs or deer) so they usually reveal vegetation responses to removal rather than reduction of sheep grazing. Second, exclosures are usually conducted on a small physical scale which is not ideal for developing an understanding of how vegetation might change if grazing were reduced or excluded over much larger areas within which rates of colonisation and changes in vegetation pattern may be spatially variable. Colonisation of scrub, for example, may be more rapid within large areas simply because there is a greater probability of initial establishment - a chance effect.

Several tentative conclusions can be drawn about effects of reduced grazing from work conducted to date. These are discussed here with reference to possible ornithological implications based on the above mechanisms. The ecological consequences of reducing grazing pressure and completely removing livestock may be very different; here I am concerned mainly with the consequences of complete removal, or very major reduction, of livestock.

(1) *Pattern of* **Calluna** *recovery.* **When heather has been lost from the vegetation its recovery is unpredictable (Marrs & Welch 1991) though this may depend on presence of viable seed and proximity of mature stands (Harding *et al*. 1994). Responses of birds to the development of heather or heather/grass mixtures will depend on the requirements of individual species (section 3.3). The establishment of extensive stands of pure heather is unlikely to result in the richest moorland bird communities. Mosaics of heather with other vegetation are more likely to offer conditions suitable for a wide range of moorland birds. In the absence of heather some areas may develop into tall grassland (Marrs & Welch 1991). Extensive areas of tall grass will not provide suitable habitat for most moorland bird species. A high proportion of moorland bird species require at least some areas of short vegetation for foraging (see chapter 4).**

(2) *Plant diversity and mosaics*. **Effects are likely to depend on the initial grazing pressure and the scale of reduction in grazing pressure. Cessation of grazing may cause reduction of plant diversity and increasing dominance of certain plants may occur with reduction in spatial heterogeneity (Rawes 1981; Marrs & Welch 1991). Loss of plant species in itself may not be important to most birds, unless associated with large reduction in invertebrate biomass. Loss of fine-scale pattern in vegetation is potentially highly significant to birds which may use different components of the vegetation mosaics for different purposes or at different times of the breeding season (section 3.4). On the other hand, a shift from sustained heavy grazing to moderate grazing pressure may increase diversity and spatial heterogeneity.**

(3) *Mire and flush communities*. **Tall vegetation may replace the plant communities of wet habitats (Marrs & Welch 1991). Such a process could lead to loss of important feeding sites for several birds (sections 3.4 & 3.5.2). The impacts on the concentrations of invertebrates associated with these habitats would probably be negative. Many ground-feeding bird**

species require short vegetation for efficient foraging which would be impaired by encroachment of tall vegetation.

(4) *Lichens*. Increase in lichens may occur (Marrs & Welch 1991) but there are no obvious effects for birds, unless the development of lichen carpets provides feeding sites for birds such as golden plover.

(5) *Invertebrates*. Reduction of grazing pressure in areas where it is currently high will have considerable effects on the community composition, abundance and biomass of invertebrates. Abundance and probably biomass of spiders and Diptera may increase (Keiller *et al*. 1995) which could benefit ground-nesting birds such as pipits, skylark and waders. Insect food supplies for black grouse would also be enhanced in many overgrazed moorland areas by reducing grazing pressure (Baines 1991). On the other hand two groups of invertebrates would be expected to decrease: (1) the decomposing and scavenging fauna associated with dung and (2) soil invertebrates (Keiller *et al*. 1995). The birds that exploit the latter two groups of invertebrates are mainly starlings and corvids. Hence, changes in invertebrate populations in response to reduced grazing should be broadly beneficial to many moorland birds. There could also be benefits to woodland and scrub bird species. An obvious example is capercaillie whose insect food supplies have been widely and seriously depleted by severe deer grazing (Baines *et al*. 1994). Many passerines feed in the field layer, both within the forest and at the forest edge. Atlegrim (1989), for example, reported that birds, including pied flycatcher *Ficedula hypoleucos* and great tit *Parus major*, were responsible for removing more than 60% of the insect larvae in the blaeberry field layer within Swedish forests. Reduction of grazing could have widespread benefits for bird communities within upland landscapes simply by enriching the food resource for insectivorous birds.

(6) *Small mammals*. An increase in voles is likely where taller vegetation develops, especially grass (Hill *et al*. 1992; Hope *et al*. 1996). This will benefit the guild of predators that feed on voles: barn owl *Tyto alba*, tawny owl *Strix aluco*, long-eared owl *Asio otus*, short-eared owl and kestrel (Village 1981, 1987, 1990). Short-eared owl in particular may increase in numbers in response to relaxation of grazing in grass-dominated areas. Working in southern Scotland, Village (1987) found that short-eared owls were far more dependent on voles than were kestrels, the owls showing greater fluctuation in numbers and more spatial variation in density according to vole availability. In this study both short-eared owls and voles were far less numerous on grazed sheepwalk than in young conifer forest. In heather-dominated moorland areas it is less clear what implications relaxed grazing may have for short-eared owls. In these habitats *Microtus* voles are less abundant, small mammal populations are generally more stable, and short-eared owls are far less dependent on voles (Roberts & Bowman 1986).

(7) *Carrion*. In most upland areas a reduction in sheep stocking would probably lead to less carrion which is a food supply for golden eagle, red kite, buzzard, raven and crow. The dependence on carrion varies between species and between regions. Implications of reduced carrion are discussed for each of these species in chapter 4. The main point to be made here is that reduction of carrion may lead indirectly to greater rates of predation on ground-nesting birds. Carrion is a significant food for corvids and foxes in many regions, so it is possible that a reduction in this food supply may cause these predators to switch to other food types such as the eggs and young of birds. One factor weighing against this idea is that, at least in Wales, sheep carrion is mainly available in late winter and early spring at a time before most ground-nesting birds have laid eggs (Davis & Davis 1981). Any such enhanced impacts on ground-nesting birds would presumably be temporary until the predator populations adjusted to the new food resource level.

(8) ***Scrub and woodland.*** **Increase in scrub and woodland as a result of natural regeneration should follow from reduction in sheep grazing but this will only occur where deer numbers are also controlled (Hester 1995; Hester & Miller 1995; Staines *et al.* 1995). Ornithologically this is one of the most significant consequences of reduced grazing and its implications are discussed below. There is also another relationship between reduced grazing and woodland cover. Falling sheep stocks may create pressure for a more general change in upland land use from rough grazing to forestry. The consequences for moorland birds would be localised, or even large scale, loss of habitat and possibly further increases in numbers of predators.**

5.2 Scrub and Woodland Development in the Uplands

Scrub invasion onto moorland is perceived as a conservation opportunity by some (e.g. Usher & Thompson 1993) but others will see a conflict with conservation of open moorland habitats, especially heather. To some extent, divergence of opinion has a regional basis. In regions with little heather moorland, or where heather has greatly declined, a high priority will tend to be placed on traditional moorland management to maintain and enhance heather. Even in such regions, local patches of scrub could be allowed to develop without compromising the principal goal of management for heather moorland. In areas of grass-dominated upland where the prospects for regeneration of extensive heather are less clear there would appear to be strong arguments for allowing extensive cover of scrub to become established in some areas following reduction of grazing. Some of these areas might be managed as scrub/moorland mosaics, others as more or less pure scrub, others still could be left as natural woodland with a clear policy of non-intervention. The types of scrub and woodland that might develop would vary according to region, soil type and management. Birch *Betula* spp. scrub is more likely to become widely established in Scotland than in Wales and vice versa for hawthorn *Crataegus monogyna*.

With regard to upland birds several questions concerning scrub invasion are pertinent. What are the implications for birds that currently inhabit open moorland? Which species would increase in numbers or colonise upland as a consequence of scrub establishment? How would birds respond to different types of mosaics of scrub and moorland vegetation? At the outset it must be acknowledged that there is a general paucity of information on bird communities in scrub. I am unaware of any quantitative work on bird communities in upland scrub though a limited knowledge exists for lowland scrub (Fuller 1995). Detailed answers cannot, therefore, be given to the above questions but some general observations can be made.

It is obvious that a successional shift from moorland vegetation to woodland will cause species that depend on dwarf shrub heaths and grassland to be replaced by woodland species. The interesting questions concern the speed and pattern of change in community composition in relation to (a) successional stage of woodland development and (b) the grain or scale of patchiness of the scrub. There will be differences between moorland bird species in their tolerance of scrub. Among waders for example, curlew and snipe will nest within scattered scrub but golden plover and dunlin appear not to do so. Meadow pipit will tolerate more scrub within its territories than will skylark (Fuller 1995). A few species such as black grouse, grasshopper warbler *Locustella naevia*, whitethroat *Sylvia communis* and whinchat *Saxicola rubetra* will benefit from a certain amount of scrub colonisation but will disappear once the canopy closes. Woodcock *Scolopax rusticola* would also increase in response to upland scrub development but whether it would gain most from extensive areas of closed canopy or from a mosaic of scrub and open areas is uncertain.

Patterns of change in diversity of bird communities with scrub development will probably vary from one region to another according to variations in the species pool for moorland and woodland habitats. Hypothetical patterns of change in diversity are explored in Figure 18 at the scale of the study site (alpha diversity). In northern Scotland the moorland community is relatively rich but the scrub community relatively species poor (it is strongly dominated by two species - willow warbler

Phylloscopus trochilus and chaffinch *Fringilla coelebs*). In Wales, the opposite is likely to be the case - here the moorland community is relatively impoverished and the scrub community relatively rich. In the former case the greatest richness of birds may occur in early stages of scrub growth when many moorland species remain and scrub species are colonising. In the latter case, however, there may be a curvilinear increase in avian richness. The pattern of patchiness will probably modify these relationships - one might predict that where scrub colonised as discrete, relatively large patches (i.e. a coarse-grained mosaic of moorland and scrub) moorland species would persist longer than in a fine-grained mosaic of moorland and scrub.

Models of successional dynamics in bird communities should ideally take changing predation rate into account as well as the structural suitability of habitat. With increasing amounts of scrub it is probable that populations of some predators will increase. The bushes will also give vantage posts for predators. These two factors may act to reduce breeding success of some moorland species where they are nesting within or near to scrub mosaics (see section 3.7). On the other hand, some of the moorland birds of prey such as short-eared owl, merlin and hen harrier, may actually benefit from a new food source provided by passerines breeding in the scrub, which might even reduce predation pressure on moorland birds.

One point that needs to be made in the context of scrub and woodland regeneration concerns the use of fences, especially deer fences. For capercaillie and black grouse, fences are a serious collision hazard (Catt *et al*. 1994). Where fences are used to promote regeneration, this disadvantage could even offset the benefits gained from any improvement in habitat quality.

It would be especially interesting to explore whether moorland-scrub mosaics can be created which retain a high proportion of moorland bird species as well as a proportion of the potential scrub colonists. It is most unlikely that a single type of mosaic could support the full range of moorland and woodland species occurring within any region. Studies of turnover in bird communities across similar successional gradients such as coppice and downland scrub show that no successional stage can provide habitats for all species found across the gradient (Fuller 1995). In all likelihood a conservation strategy that sought to maintain substantial areas at different successional stages would offer the widest range of habitats and maintain the highest species richness of birds in the upland environment. Such a strategy is based on enhancing and maintaining beta diversity and could be compared with suggestions for strategic conservation in lowland woods advocated by Fuller & Warren (1995). The most difficult part of this approach is that it requires major questions to be addressed about the management goals for specific areas of land. Furthermore, information is needed on minimum area and minimum population sizes in relation to population persistence. It would be essential that features of high conservation interest were recognised and maintained; for example it would be self-defeating if grazing were totally removed from moorland areas carrying high densities of breeding waders, or from stream valleys with rich mixtures of vegetation currently maintained by low grazing pressure.

5.3 How Much Grazing?

Large herbivores have played a major part in the creation of the vegetation types now present in the British uplands and their continued presence is vital if a wide range of upland habitats and wildlife is to be maintained. The open nature of moorland can be maintained to some extent by burning and, more locally, by cutting. Burning is not, however, a general solution to maintaining open upland habitats. Areas such as exposed summits, steep slopes and wet blanket bogs should not be burned (Thompson *et al*. 1995b). Low intensity grazing is essential to maintain some of the vegetation mosaics that occur within the uplands, while certain vegetation types, for example bilberry, benefit from moderate grazing (Welch *et al*. 1994).

As stressed earlier it is dangerous to generalise about stocking densities; these depend on a range of site-specific factors including the condition of the heather, soil type and altitude. The broad

guidelines for sheep stocking suggested by Thompson *et al*. (1995b) allow for these types of factors and they recommend a range of sheep densities from 0.5 to 2.0 ewes per hectare depending on site conditions. Additional variation in stocking regime is provided by the proportion of sheep wintered off the moor. In many cases light summer grazing is probably an appropriate strategy (Brown & Bainbridge 1995).

A further consideration in reaching preferred sheep stocking densities is that of the objectives for the land in question. The recommendations of Thompson *et al*. (1995b) were aimed at enhancing moorland vegetation. Within some areas it would be entirely appropriate to shift the succession further towards scrub and woodland, especially where the present conservation interest of the open moorland was rather low. It should be possible to create and maintain mosaics of moorland and scrub through manipulation of grazing regimes. To achieve this may require initial cessation of grazing to allow substantial scrub regeneration, at which point herbivores could be reintroduced at low density and their numbers subsequently adjusted to maintain the desired balance of moorland and scrub. Use of large herbivores as a management tool in this way has been pioneered in The Netherlands (van Wieren 1991) but does not appear to have been attempted in Britain. The uplands offer immense potential for such innovative conservation management. This type of strategy depends on the ability to control grazing pressure by both sheep and deer, for removal of sheep may merely lead to increased grazing by deer (Clutton-Brock & Albon 1992; Hope *et al*. 1996). The threshold density at which red deer inhibit tree regeneration is affected by many factors; nonetheless it would appear that in many areas, regeneration will occur on open land where winter densities are no more than approximately one deer per 15 hectares (Staines *et al*. 1995).

6. CONCLUSIONS AND FUTURE RESEARCH

6.1 Grazing in Context

The number of potential mechanisms by which grazing can affect birds is large but there have been few convincing demonstrations that these are definitely linked with recent changes in the status of bird populations in the uplands. This reflects a lack of relevant research and of basic monitoring; it does not imply that increased grazing has been of little significance to upland bird populations. Grazing pressure has undoubtedly been a fundamental influence on upland bird communities both historically and in recent times. Changes in vegetation, leading to increased predation, habitat loss and food reduction are likely to be central mechanisms in effects on birds. With information currently available it is probably impossible to isolate these mechanisms from other non-grazing factors. Overgrazing should, therefore be regarded as one of several inter-related, long-term trends combining with adverse consequences for some of the characteristic upland species. High grazing pressure is likely to compound effects of increasing predators, poor burning and acidification. Deleterious impacts of these trends are likely to be less severe under light grazing pressure.

Recent declines of upland birds appear to be especially severe on Welsh moorland. The circumstantial evidence is reasonably strong that overgrazing is implicated. Upland Wales happens to be the most heavily sheep-stocked area of Britain (Figures 10 & 11) and the rate of increase in sheep there has been steep in recent decades (Figures 2 & 3). Unlike other parts of Britain, Welsh sheep numbers have been increasing since the 1950s. The Welsh uplands have a much longer history of *intensive and controlled* grazing than most upland areas but they also lie close to some of the most industrial parts of Britain. It is possible that a long history of grazing and burning, coupled with air pollution over the last 150 years, has seriously reduced the productivity of the system. Collapse in bird populations may be a response to the recent intensification of overgrazing (coupled possibly with increased predation rates) superimposed on this long-term reduction in carrying capacity. One is generally hampered by lack of quantitative long-term information on upland bird populations. Nonetheless, it is interesting that there is little evidence, with the exception of red and black grouse, of large recent population declines of moorland birds in the other areas of upland Britain that have experienced large increases in sheep numbers. There is, however, no doubt that bird populations, especially breeding waders, have collapsed on much farmland on the margins of the unenclosed uplands and that increase in grazing pressure and associated land improvement is implicated (section 3.8.2).

6.2 Research Requirements

This review has established that exceedingly little is known about the ecological relationships between grazing and upland bird populations. In several parts of this review I have been forced to speculate about general mechanisms and specific effects on species. This is an unsatisfactory situation given the scale of the increases in sheep numbers since the 1970s (chapter 2) and the potential significance of the intensification in grazing pressure that must have occurred in many parts of the uplands (chapter 3). There is a clear need for specific research into the implications for bird populations of heavy grazing by sheep and also of the implications of reduced grazing. First, however, it is essential that some means of tracking upland bird populations is developed.

6.2.1 Monitoring

Quantitative information on large-scale population trends of birds in the uplands is almost non-existent with the exception of grouse and possibly raptors. Sound information on population trends is a pre-requisite for assessing possible effects of land-use change. A monitoring system is urgently needed. There is probably considerable regional variation in population trends of upland birds (contrast, for example, the golden plover populations of Wales and the Pennines). Any monitoring

scheme therefore needs to address this regionality. The BTO/JNCC/RSPB Breeding Bird Survey should provide a basis for the required monitoring effort in the uplands.

6.2.2 Habitat Requirements and Habitat Use

A better understanding of habitat requirements will help to predict effects of increased or reduced grazing pressure. This needs to be pursued on three different scales.

(1) Assess how broad patterns of distribution of birds within the uplands, and spatial changes in community composition and species richness, are influenced by land cover. This work can be pursued through analyses of coarse-grained data sets such as the BTO breeding bird atlases coupled with environmental data. Though perhaps not specifically relevant to the issue of overgrazing, this type of analysis can provide useful contextual background to the discussion of grazing issues.

(2) More quantitative studies are needed of the distribution of upland birds across different habitats within clearly defined upland regions. It is unwise to base assumptions about habitat associations on studies conducted within one or a small number of regions for, almost certainly, there are major regional differences in habitat occupancy. Such work should seek to take account of non-linear relationships of birds and habitat across environmental gradients such as the heather to grass transition associated with grazing pressure (Figure 16). Habitat definitions employed in most previous studies have not been sufficiently detailed for this purpose. Studies of breeding productivity across such gradients are also needed.

(3) Territory scale work to establish how birds respond to habitat fragmentation and whether birds depend on vegetation pattern. Are vegetation mosaics really important for foraging - and within what sized area must such mosaics be present? (This demands information on food requirements and ranging behaviour of adults and chicks.) Species for which such studies would be highly desirable include curlew, golden plover, ring ouzel, meadow pipit and skylark. This work needs to be carried out in different parts of the upland range of the target species to assess whether the requirements of species and their patterns of habitat use differ in environments that offer different suites of habitats.

6.2.3 Further Knowledge about Effects of Grazing on Vegetation

Much is known about effects of grazing by sheep and deer on vegetation. Nonetheless, there may be scope for improving knowledge of how different grazing regimes affect the preferred vegetation structures and patterns of selected bird species. Also, how do mosaics that are sustained by light grazing compare with those that derive from burning in terms of the bird requirements? Interactions between grazing and other environmental factors, such as acid deposition, need to be taken into account.

6.2.4 Predation

Work is needed on predation rates on ground-nesting birds in upland habitats in relation to habitat structure. This should involve studies of selected species nesting in different vegetation types (pipits and skylarks would be ideal). Artificial nests could also be employed but work should not rely entirely on dummy nests. More work is needed to establish whether predation is affected by proximity of forest edges. Though Avery *et al.* (1989) could find no evidence of such an effect in northern Scotland the situation could be different elsewhere. This may have an interaction with grazing pressure in that heavy grazing in areas where the amount of moorland to forest edge is high, may have a disproportionate effect on breeding success compared with areas where there is less forestry.

6.2.5 Experiments and Case Studies

There may be some opportunities for making spatial comparisons of bird populations on areas within the same geographical areas that have different grazing pressures. For example, such a situation exists in Shropshire where the Long Mynd is extremely heavily grazed by sheep but the nearby Stiperstones National Nature Reserve has very light grazing. The problem with this approach is that differences in grazing pressure are often confounded with other factors e.g. burning regimes and topography. Furthermore, in many regions grazing is now so intense that it can be difficult to locate lightly grazed moorland.

There is a very strong argument that large-scale experiments should be undertaken to assess what happens to bird populations when grazing pressure is manipulated. Treatments would include stocking level and predator control so that low and high stocking could be compared with and without high predator pressure. Burning would need to be controlled as part of the experimental design. Treatments on individual plots could be changed after a period of years. This work must be on a sufficiently large scale to obtain reasonable samples of birds and must use replicates. Individual treatment plots will need to cover several square kilometres. The manipulation may involve shepherding to achieve particular vegetation structures as well as controlling stock density. Such an experiment could permit the effects of grazing pressure on territory numbers and breeding success to be determined for several bird species.

6.2.6 Scrub and Woodland

Increased colonisation of moorland by scrub and woodland is to be expected if there is large scale relaxation of grazing pressure through deer control and reduced sheep stocking. There is a need to establish (a) how much scrub invasion different open moorland birds can tolerate, (b) whether mosaics of scrub and moorland have the potential to support diverse assemblages of species and (c) whether desired mosaics could be maintained by light or intermittent grazing regimes (see chapter 5).

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Table 1 Associations of upland birds with heather moorland and grassland as shown by three quantitative multi-species studies of upland bird distribution (Haworth & Thompson[1]; Brown & Stillman[2]; Stillman & Brown[3]. + indicates significant positive association with habitat type and - indicates avoidance.

Species **(no. of studies)**	**Heather moorland**	**Grassland**
Merlin (2) ***Falco columbarius***	+[1,3]	
Red Grouse (2) ***Lagopus lagopus***	+[2,3]	-[3]
Golden Plover (3) ***Pluvialis apricaria***		-[2,3]
Dunlin (2) ***Calidris alpina***	-[1,3]	-[3]
Short-eared Owl (2) ***Asio flammeus***	+[3]	
Skylark (1) ***Alauda arvensis***	-[2]	+[2]
Ring Ouzel (2) ***Turdus torquatus***	+[1]	+[3]
Wheatear (2) ***Oenanthe oenanthe***		+[3]
Twite (2) ***Carduelis flavirostris***	+[1] -[3]	+[3] -[1]

[1] **Haworth & Thompson (1990). South Pennines on Yorkshire/Lancashire border. Associations determined by discriminant function analysis. Cases are indicated where either *Calluna, Molinia* or *Nardus* featured among the five most significant habitat variables. Eight species studied: golden plover, dunlin, redshank, curlew, ring ouzel, twite, short-eared owl and merlin.**

[2] **Brown & Stillman (1993). Eastern Highlands of Scotland. Associations determined by correlation. Associations of P<0.01 are shown here. Variable definition: heather moorland = heath, grassland = grass. Eight species studied: red grouse, golden plover, snipe, curlew, skylark, meadow pipit, wheatear, whinchat.**

[3] **Stillman & Brown (1994). South Pennines, Yorkshire. Associations determined by correlation. Associations of P<0.005 are shown here. Variable definition: heather moor and grass moor are the variables used here. 14 species studied: curlew, dunlin, golden plover, lapwing, merlin, peregrine, red grouse, redshank, ring ouzel, short-eared owl, snipe, twite, wheatear, whinchat.**

Figure 1. Trends in total numbers of sheep in England, Wales and Scotland since 1950. Source: June agricultural census.

Figure 2. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in two regions of southern Wales since 1950.

Source: June agricultural census.

Figure 3. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in two regions of northern Wales since 1950. Source: June agricultural census.

Figure 4. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in two regions of southern Scotland since 1950.

Source: June agricultural census.

Figure 5. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in (a) Grampian Region and (b) the Highlands and Western Isles of Scotland since 1950. Source: June agricultural census

Figure 6. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in (a) Orkney and (b) Shetland since 1950.

Source: June agricultural census

Figure 7. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in three English counties since 1950. Source: June agricultural census.

Figure 8. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in three regions of southern England since 1950. Source: June agricultural census.

Figure 9. Trends in numbers of breeding ewes (triangles) and all sheep (squares) in three regions of central and eastern England since 1950. Source: June agricultural census.

(a) 1969

Figure 10. Geographical variation in density of total sheep in (a) 1969 and (b) 1988. Numbers of sheep within 10-km squares of the national grid are shown with increasing dot size representing the following classes of sheep numbers: 0.1-400.0, 400.1-2000.0, 2000.1-4000.0, 4000.1-10000.0, 10000.1-20000.0 and >20000. Source: June agricultural census/Edinburgh University.

(b) 1988

Figure 10. Continued

(a) 1969

Figure 11. Geographical variation in density of total sheep in (a) 1969 and (b) 1988 within high density sheep areas defined as the two highest classes of density in Figure 10. Numbers of sheep within 10-km squares of the national grid are shown with increasing dot size representing the following classes of sheep numbers: 10,000.0-19,999.9, 20,000.0-29,999.9, 30,000.0-39,999.9, 40,000.0-49,999.9, 50,000.0-59,999.9, >60,000. Source: June agricultural census/Edinburgh University.

(b) 1988

Figure 11. Continued

Figure 12. Trends in sheep numbers within 5 parishes in mid Wales. Note that sheep numbers were not available separately for parishes (d) and (e) in all years but were combined in some years. Therefore (f) shows an amalgamated total for parishes (d) and (e). Source: June agricultural census/Public Record Office.

Figure 13. Scottish HLCA headage payments within the Severely Disadvantaged Area 1976-1993. Numbers of sheep in the Specially Qualified Flock (these tend to be hill sheep) are shown separately from the total sheep for which payments were made.

Figure 14. English HLCA headage payments within the Severely Disadvantaged Area 1985-1994.

Payments for hardy breeds (all sheep) are shown separately from the total where any payments were made.

Figure 15. Factors potentially involved in relationships between grazing pressure and the survival and breeding production of birds. Note that heavy grazing pressure may also have an effect on habitat loss which is not included in the diagram. For example, a species may require a minimum coverage of heather of 50% to continue occupying an area of moorland. Habitat loss occurs when the cover of heather is pushed below this threshold resulting in the emigration or death of individuals in the population of that area.

Figure 16. Hypothetical changes in abundance of bird species with transitions from heather to grassland as a consequence of heavy grazing. Thick lines indicate responses where heather persists in large patches (coarse-grained mosaic) and thin lines where heather fragments into small patches (fine-grained mosaics).

Figure 17. Three scales of spatial mosaic likely to be relevant to birds: (a) some raptors hunt over large tracts of country, perhaps exploiting different blocks of broad vegetation and land-forms at different times of year and for different types of prey; (b) many birds, for instance waders and ring ouzel, forage at some distance from the nest (perhaps up to 1km) and, in the case of nidifugous species, have the capacity to move their recently fledged young to exploit localised food sources such as flushes; (c) species such as meadow pipit and wheatear tend to forage close to the nest and the availibility of both feeding and nesting habitat within relatively small areas is important.

Figure 18. Hypothetical relationship between scrub succession and species richness of breeding bird community in (a) an area where moorland bird communities are relatively species-rich but scrub communities are species-poor and (b) an area where moorland bird communities are relatively species poor but scrub communities are species-rich. Situation (a) is more typical of northern Scotland and situation (b) more typical of Wales and south-west England. Thick lines indicate responses where open moorland persists in large patches (coarse-grained mosaic) and thin lines where moorland fragments into small patches (fine-grained mosaics).