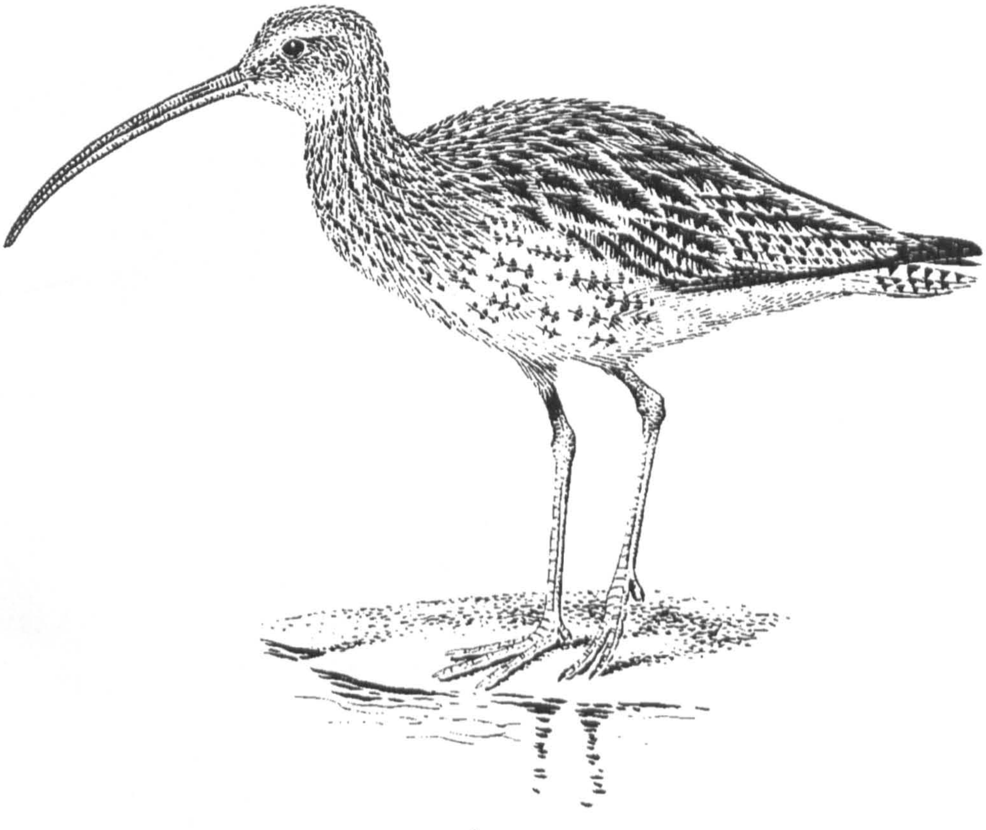
THE BREEDING ECOLOGY OF CURLEW *NUMENIUS ARQUATA* ON NORTH PENNINE MOORLAND

Glen Robson



A thesis submitted in partial fulfilment of the requirements of the
University of Sunderland for the degree of Doctor of Philosophy.

March 1998

CONTENTS

ABSTRACT

This thesis set out to quantify habitat selection by breeding Curlew on Heather *Calluna vulgaris* moorland. The main study sites were managed primarily for Red Grouse *Lagopus lagopus*, which produced a mosaic of different habitat types. Habitat selection during the three life-stages (egg, chick and adult) were investigated.

Curlew demonstrated a strong preference for nesting in recently burnt patches of Heather, where no re-growth of vegetation had occurred. Nest survival rates were not found to differ between habitats. The main cause of egg reproductive failure was predation by Stoats *Mustela erminea.* Nest predation rates varied significantly between years with the number of nests predated rising from 18% in 1994 to 65% in 1996.

Chick habitat selection was investigated using radio-telemetry. Chicks that had Soft Rush *Juncus effusus* flushes within their home range selected that habitat. Those chicks that were not in the vicinity of Soft Rush flushes utilised other habitats within their home range, showing no significant preferences. Chick predation, largely by Stoats, was high with an average of 0.17 fledglings per pair being produced.

Adult foraging behaviour was investigated using radio-telemetry. The vast majority of foraging activity took place in enclosed fields adjacent to moorland. The fields that were selected by foraging Curlew were characterised as being large (probably as an anti-predator response) and close to the breeding moor (energetically the most efficient since flight distance was minimised). Foraging Curlew used pastures, hay meadows and rough grazing fields.

These results were used to produce an integrated management plan for application by upland land-managers, designed to benefit breeding Curlew.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my supervisor, Dr Steve Percival, who has been instrumental in all aspects of the project. Steve was kind enough to contact me when he obtained the initial contract to carry out research on Curlew and has since made himself available to discuss the project and assist with fieldwork whenever needed. Steve was also kind enough to contribute financially to the project from his personal research budget from Sunderland University. Steve's comments on the draft of this thesis were also greatly appreciated. Seriousness over, Steve "the bureaucrats will never take me alive" Percival is a top bloke whose prowess around the beer table has never ceased to amaze me. Having a down to earth, approachable supervisor, who can take advice as well as give it, was a great bonus. Cheers Steve!

This project was funded almost entirely by English Nature and I would like to take this opportunity to thank them. In particular I would like to thank my external supervisor, Dr Andy Brown, who got the project rolling and who has assisted with field work every year. Andy has also kindly made himself available to discuss the project at any time (so long as he was in the country of course!). Having done a fair-bit of field work together, I've watched Andy progress from an unfit smoker to, ...er well..., an unfit non-smoker. Only kidding though, Andy's a great bloke and I greatly appreciated his help, even if his Geordie accent was one of the worst I've ever heard (though he was coming along well with "why eye man!" – not the proper spellings of course, but easier for Southerners to read). Anyway, I digress. Andy's comments on the draft of this thesis were also greatly appreciated.

The project could not have been carried out without the permission of Lord Barnard and Raby Estates who kindly allowed the research to be carried out on their land. Many thanks also go to the farmers of the moorland and farmland study areas – Nevil Bainbridge, John Bell, Jesse Carrick, Ken Hutchinson, Donald Hughs, Fred Raine and David Scowen who also agreed to allow the research to be carried out on their holdings.

Lindsay Waddell, the head gamekeeper of Monk's Moor and Langdon Common also deserves many thanks as he agreed to allow me to work on these sites. Lindsay has always shown a keen interest in the study and has been extremely helpful with many aspects (he also rescued me when my vehicle broke-down, for which I will be eternally grateful). Thanks also to Lee Wearmouth, the gamekeeper from Monk's Moor, and to David Clark and Michael Gibbs who kindly allowed me to work on Langlydale Common.

As well as assisting with field work on a number of occasions, Amanda Dodd had the unenviable task of proof reading each chapter of this thesis before they were sent to my supervisors so they owe her almost as many thanks as I do! I would also like to take this opportunity to thank Amanda for her patience and support while I carried out this research. It wasn't easy for a new couple to spend the bulk of two field seasons apart, but I must have been doing something right as she's soon to forsake the surname Dodd and replace it with mine. That's mine as in Robson, not mine as in Amanda Mine!

Andrew Bradley, my best mate whom I first met at school in 1982, deserves a round of applause for his assistance with fieldwork and for helping me keep things in perspective. Every time my patience was waning while I was writing up, Andrew was there for me to moan to. Andrew often took me aside (generally for several beers) and told me how fortunate I was to be doing a job I enjoyed (as opposed to himself who hated his job). He was right of course. Andrew also loaned me his laser printer so that I could print this thesis. Cheers Andrew.

Thanks also to another member of the Friday night lad's night out society – Mr Jim Windram, for proof reading the final version of this thesis and for his trouble-shooting when I had PC problems (that is, when Andrew could not solve the problem).

I must also take this opportunity to thank my brother, Bill Robson, for providing financial assistance so that I could buy a colour printer. All of the colour figures within this thesis (unless of course you've just photocopied my life's-work) were printed on that printer. In return for his financial assistance - if any one reading this requires double-glazing, Bill's the man for the job- excellent work at competitive prices. You can track me down via the address on the front cover and I'll let Bill know you want a quote (no charge of course).

Many thanks also to Dr. Mark Whittingham for his advice on the project and for his assistance with fieldwork. I am also very grateful to Mark and Dr Dave Parish for some amazing curries followed by several beers in the Golden Lion (living in a flat behind a pub with other starving and dehydrated field workers certainly had its advantages).

Dr. Murray Grant was also kind enough to provide advice on the project and to allow me to use one of his adult Curlew traps. I would also like to thank all those other people who assisted with fieldwork or provided additional information: Dr Åke Berg, Sarah Callahan, Alan Davis, Dr Simon "no they do not hang monkeys in Hartlepool" Hodge, Zoe Humphries, Robbie McDonald, Neil Peart, Tracey Percival, Gary Tudor and Dr Nina Wilson.

Obviously this paragraph was written post-viva as I would like to thank Dr Paul Eady and Dr. Rob Fuller who were my examiners. Surprising as it sounds the whole experience of being grilled for three hours was a valuable and interesting affair. Both examiners provided valuable comments regarding this thesis and provided plenty of ideas and tips for when I begin churning papers out.

Finally I would like to take this opportunity to thank my parents who encouraged me throughout and who provided much needed financial assistance in the form of exceptionally cheap board and lodgings!

CHAPTER 1.

INTRODUCTION

Aims of chapter

The general aims of this chapter are to provide the background for the thesis, describing the ecology of Curlew and the habitats they utilise, and to introduce the specific aims and objectives of the thesis.

The specific aims of the chapter are to provide information on Curlew population sizes nationally and locally, in both winter and the breeding season. Information on upland habitats in which Curlew breed is presented, with particular reference made to those moorlands managed primarily for Red Grouse. Factors potentially governing the selection of particular habitats and potential threats to them are also addressed.

Why study Curlew?

Curlew are a Red Data Bird species (Batten *et. al.* 1990), satisfying criteria number 1 of the selection process for inclusion. This criteria states that British populations should be of international significance and should hold greater than 20% of the north-west European wintering or breeding population. Internationally important numbers of Curlew breed in Britain, some 28% of the European total (35,000 pairs). Internationally important numbers of Curlew also winter in Britain, with estimates ranging from 91,000 (Batten *et. al.* 1990) to 200,000 birds (Lack 1986). The species is also listed on Annex II/2 of EU Directive 79/409 on the Conservation of Wild Birds and Appendix III of the Berne Convention (convention on the Conservation of European Wildlife and Natural Habitats) (see FitzGerald & Carter 1996 for explanation of EC birds directive and Berne convention). Britain, therefore, has a clear international obligation to conserve this species and its habitat.

Despite the acknowledged conservation importance of Curlew populations, no detailed studies of the breeding ecology of this species in Britain have been published. A number of studies have been carried out in other countries (see, for example Berg, 1992a and 1992b, Boschert and Rupp, 1993) but these are concerned with Curlew breeding on farmland rather than moorland. A number of publications are expected in the near future from studies carried out in Orkney and Ireland (M. Grant pers. comm.), but again, these were not carried out on "typical" upland moors (the Orkney study was carried out on semi-natural habitats fragmented by improved grasslands for example).

In Britain, vast areas of uplands are managed primarily for sheep and grouse, but little is known about the effects of many of the management practices on upland birds. There are no published studies of Curlew habitat preference in such upland areas in Britain. Therefore, if management recommendations for the conservation of Curlew are to be formulated, detailed studies of their habitat requirements are paramount.

The remainder of this chapter describes general background on Curlew and provides an indication of the character and management practices of Britain's uplands.

General description of Curlew

Curlew are the largest wader in the western Paleartic, weighing between 700-1000g and standing to a height of 50-60cm (Cramp *et. al.* 1983). The most characteristic feature of these otherwise drab brownish waders is their long decurved bill (10-15cm). Curlew can also be readily identified at a distance by their characteristic undulating display flight, bubbling song and distinctive onomatopoeic call.

Curlew are generally viewed as being an upland breeding species, despite the recent colonisation of some lowland areas (Ferns 1992, Gibbons *et al* 1993) and can be found in most upland areas of Heather dominated and grass dominated moor in Britain. Curlew will nest in a variety of habitats ranging from agricultural rough grazing pastures and hay meadows to Heather, Bracken *Pteridium aquilinum* and grass-dominated moorlands (see chapter 4 for a more detailed account of nesting habitats).

Curlew are a ground nesting species that probably start to breed at two years old (Glutz von Blotzheim 1977). The nest scrape consists of a shallow depression, either directly on the ground or slightly raised within a tussock of vegetation. The clutch size is generally 4 eggs but ranges between 2 and 5, with eggs being laid at intervals of 1 to 2 days (Cramp *et al* 1993).

Incubation begins on laying the final egg and lasts for approximately 29 days, during which time both adults generally share incubation (Cramp *et al* 1993). If a clutch is lost (due to predation for example) a replacement can be laid within 4 to 15 days (Glutz *et al* 1977). Since incubation begins at the laying of the final egg, hatching occurs synchronously and once dry the precocial and nidifugous chicks leave the nest to feed themselves (Cramp *et al* 1993). However, parental duties continue throughout the pre-fledging period with adults alarm calling when danger approaches and in the case of very young chicks, brooding (Cramp *et al* 1993).

Chicks generally fledge at between 32-38 days old and become largely independent soon after (Cramp *et al* 1993). At this time juvenile Curlew and their parents leave their upland breeding grounds to winter in traditional feeding grounds, most commonly in coastal and estuarine areas (see national winter distribution for further details).

Curlew population distribution

- **National breeding distribution**

Most abundant in Britain's uplands, Curlew commonly breed at altitudes up to about 550m with a few up to 760m (Sharrock 1976) and are most common in the North Pennines, Southern uplands and Eastern Highlands of Scotland, Caithness, Orkney and Shetland (Gibbons *et al* 1993).

During the breeding season Curlew feed in a variety of habitats including open moorland and agricultural fields. The bulk of their varied diet consists of invertebrates, such as earthworms *Allobophora*, the adults and larvae of Carabid and Staphylinid beetles, craneflies (Tipulidae) and Lepidopterans (Cramp *et. al.* 1983). Vertebrates such as lizards and frogs (Cramp *et. al.* 1983) and tadpoles (pers. obs.) are also taken occasionally.

- **National Winter distribution**

Soon after fledging in June or July, juvenile curlew and their parents migrate to their wintering grounds. These are generally coastal areas, where large expanses of sand and mud are exposed at low tide, such as estuaries (Prater 1981). Some Curlew however, have traditional wintering grounds inland in areas such as permanent pastures and industrial settling beds (Lack 1986).

It is in their estuarine feeding grounds where the long-decurved bill of Curlew comes into its own, allowing them to probe deeply for worms (e.g. Lugworms *Arenicola*) and molluscs (eg Mytilus) (Lack 1986). Their varied diet also contains crustaceans (e.g. crabs *Carcinus*) and Amphipods (e.g. *Gammarus*) as well as small fish (e.g. *Pomatoschistus microps*) (Cramp *et. al.* 1983).

National breeding Curlew population

The breeding density of Curlew can be highly variable, largely due to the range of habitats that are utilised for nesting. Grant (in Gibbons *et. al.* 1993), for example, describes wetland and moorland fragments below 100m in Orkney holding 55 pairs km^{-2}, though this appears atypical with extensive areas of moorland above 100m holding an average of 12 pairs km^{-2}. Baines (1988) found densities of 10 pairs km^{-2} on marginal farmland in the Northern Pennines.

Large variations in breeding densities have also been recorded between different areas of similar habitat. For example, on two Heather moorlands managed for Red Grouse in Teesdale the breeding densities were 5.5 pairs km^{-2} and 8.9 pairs km^{-2} (pers obs.). Consequently this highly variable breeding density leads to problems in estimating the national population size. The number of breeding pairs in Britain had been estimated as being between 33,000-38,000 (Reed 1985b), but a more recent estimate of over 75,000 pairs has been put forward (Grant, 1997). However, this recent estimate does not indicate an increase in the population size, but rather is a result of an improvement in the source data upon which the estimate was based. The most recent estimate was based upon much more extensive surveys than the estimate from the 1980's (Newbery & Crockford, 1998).

At present, no clear trends in the population size of Curlew in Britain are apparent, but an overall increase has been suggested by Marchant *et al* (1990) due to an expansion of the breeding range. However, Ratcliffe (1990) has suggested that Curlew numbers have declined steadily, particularly as a result of habitat loss and the RSPB (Newbery & Crockford, 1998) has suggested that population numbers may be declining due to problems on breeding grounds in a number of areas (e.g. Northern Ireland and North Staffordshire Moors). There are currently no quantified data on regional differences in Curlew numbers (Marchant *et al* 1990).

Elsewhere in Europe, the population trends have been variable. There has been an expansion in the range of Curlew in Northern Europe (Marchant *et al* 1990) and an increase in numbers in some countries such as France, but numbers have declined in some countries such as the Netherlands (Cramp *et al* 1983).

Population size in County Durham

Curlew are abundant in County Durham (Gibbons *et al* 1993). However, since the breeding density of Curlew is highly variable, largely due to the range of habitats that are utilised for nesting, this leads to problems in estimating the population size in the county with any accuracy. However, using vegetation, soil and altitude maps from Graham (1988) and average breeding densities found in the county from this study, an estimate of the population size was calculated.

To estimate the population size in County Durham, a mean Curlew density on Heather moorland was calculated using data from this thesis. The density of Curlew on grass-dominated moorland was also taken from this thesis. Using maps of Curlew distribution in County Durham (Westerberg *et al* in prep.) and the vegetation maps in Graham (1988), the number of tetrads which had Curlew and contained Heather moorland and grass moorland were calculated. These figures were multiplied by Curlew density on Heather moor and grass moor respectively. Those tetrads which had Curlew but were not moorland were also included (such as lowland areas), using the lower Curlew density value (as these other habitats were not considered to be optimum). Using the figures obtained by this method a rough estimate of between 2600-6100 breeding pairs was obtained for County Durham (Robson in Westerberg *et al* in prep.).

Maintenance of population

Curlew are relatively long-lived, the oldest recorded ringed bird being over 31 years old (Rydzeski 1978 in Cramp *et al* 1993). In addition, a number of studies have demonstrated adult Curlew mortality to be relatively low, ranging from 11.5% (Kipp 1982) to 17.9% (Berg 1994) (though Bainbridge and Minton (1978) estimated first year mortality after fledging to be higher at 53%).

Therefore, in theory, since adult mortality rates are relatively low, relatively few adult Curlew need "replacing" in order to stabilise the size of the population. This results in the requirement of a relatively low level of annual productivity to maintain the population. This is perhaps just as well since a number of studies have reported low Curlew productivity caused by heavy nest and chick losses (Boschert and Rupp 1993, Berg 1994 and M. Grant pers. comm. for example). Curlew are not in isolation as a species where low productivity's have been recorded. For example, Whittingham (1996) found that Golden Plover productivity was relatively low on study sites in the North Pennines and Redmond & Jenni (1986) found that productivity was relatively low in a population of Long-billed Curlew in Western Idaho, USA (though probably high enough to maintain the population). However, low productivity is not always the case and a review of the variable hatching success in shorebirds, for example, both between different species and between the same species in different years can be seen in Evans and Pienkowski (1984).

The present Curlew population trend in Britain and Europe is uncertain (Marchant *et al* 1990), but numbers appear to be declining in some areas of Britain (see section above on national breeding population) and Europe where habitat change is often the most suggested cause (Gibbons *et al* 1993, Ratcliffe 1990 and Braaksma 1960). Predation of eggs and chicks has also been highlighted as a possible cause of Curlew population declines in a number of regions and countries. For example, increased predation rates on eggs and chicks have been identified as a possible cause in the decline of the breeding population of Curlew in Northern Ireland (Grant 1997) and in the Netherlands, foxes *Vulpes vulpes* were identified as the major factor in the decline of a Curlew population breeding in dune habitat (Mulder & Swann 1988).

Curlew population sizes in some areas have also been adversely affected by severe weather on their over-wintering grounds. For example, reductions in numbers were recorded following the severe winter of 1962/63 (Dobinson and Richards 1964). Loss of feeding habitat due to sea level rise and from developments (e.g. tidal barrages) have also been identified by the RSPB as causing threats to wintering Curlew populations (Newbery and Crockford 1998).

Curlew could therefore be at risk from a wide variety of factors which could cause a reduction in their population size. For example, in some areas habitat change may cause of reduction in breeding densities (see Baines 1988 for example), in others predation may be the main cause of a decline in population size (M. Grant pers. comm.), while elsewhere over-winter mortality caused by feeding habitat loss may be the main cause (e.g. Newbery and Crockford 1998). The overall impact of each of the factors mentioned on the maintenance of Curlew populations is difficult to address in general terms because different populations in different regions and countries are affected by different factors.

However, since a number of the factors affecting Curlew populations can be readily controlled such as maintaining suitable feeding and breeding habitat for example, positive management action based upon sound research from a variety of studies should be taken wherever possible. The question raised from the example above however, is what constitutes suitable breeding and feeding habitat for Curlew in Britain's upland areas? These are the main areas that this thesis aims to address so that positive management for breeding Curlew can be carried out in Britain's uplands in the future.

Upland breeding habitat

It is impossible to give a strict definition of what constitutes a British upland and even a broad definition can prove difficult to produce. This is largely due to the difficulty in defining the characteristics of uplands, which are often wide ranging. Probably the most widely used criteria for defining uplands is by altitude along with those plant species which are considered characteristic of those habitats. However, defining uplands by these criteria are not clear-cut. This can be demonstrated by considering the moorlands of Shetland which contain characteristic upland plants, but are at sea level. At sea level in Cornwall, however the vegetation is considered to be characteristic of lowlands (Bunce 1987). Clearly, latitude can also be of great importance.

Climatic and soil conditions can also be important indicative features of uplands. The climate in upland areas is generally harsh with high rainfall and low evapotranspiration. Since the majority of upland rocks are acidic (Fuller 1982), this, coupled with nutrient-leaching rain generally leads to the production of infertile soils.

Because there is no strict definition of uplands available, there have been a variety of general definitions produced by various authors. Fuller (1982) wrote

"The term uplands is widely accepted to distinguish the rough grazings, bogs, moors, and mountains that dominate so much of northern and western Britain........mostly confined to the higher ground above 300m".

Though this is by no means a universal definition, it does indicate the general nature of British uplands and it is suitable for the purpose of this thesis.

Upland vegetation

The vegetation types found in uplands are diverse and a number of different classifications have been described (see for example Hill & Evans 1978, and NCC 1986). The Institute of Terrestrial Ecology (ITE 1982) identified four main upland vegetation groups in England and Wales. Though not the most definitive method of vegetation classification, (see Chapter 2), all four major ITE groups are present within the study area and provide a good general introduction to upland vegetation types. Those groups are:

- **Improved pastures**

These are productive farmland pastures characterised by the presence of introduced species of agricultural value such as Rye-grass *Lolium perenne*, Cocks-foot *Dactylis glomerata* and White Clover *Trifolium repens*, together with various herbs. Depending on variables such as soil conditions and management (e.g. fertiliser application), other species such as Bracken, Rushes *Juncus* and Thistles *Cirsium* may also be present.

- **Rough pastures**

These are subject to less intensive management than improved pastures, contain less introduced species and more native species and are often found on fairly acidic, low-fertility soils. Rough pastures are dominated by species such as Bent grasses *Agrostis*, Sheep's Fescue *Festuca ovina* and Rushes.

- **Grassy heaths**

The species which dominate this vegetation group are coarse native grasses such as Mat-Grass *Nardus stricta*, Wavy-hair grass *Deschampsia flexuosa*, and Purple-moor Grass *Molinia caerulea*. Other species such as rushes and Bracken may be present and Heath Bedstraw *Galium saxatile* is also common. Often there is also a shrub presence (though sub-dominant), most commonly Bilberry *Vaccinium myrtillus*.

- **Shrubby heaths**

The predominant species in this vegetation group are dwarf shrubs such as Heather, Bilberry, Bell Heather *Erica cinerea*, Cross-leaved heath *E. Tetralix* and Crowberry *Empetrum nigrum*. Various grasses, sedges, rushes and Gorse *Ulex* may also be present.

Though each of the four ITE classes were present within the study area, the main bulk of this project concentrated on habitats which fell into the shrubby heaths category of the ITE classification. It was those shrubby heaths which were managed primarily for Red Grouse ("grouse moorlands") which were the main focus of this thesis.

General description of moorland managed for Grouse

Red Grouse are game birds of high economic value, with income often exceeding that which can be gained from sheep-farming or forestry (Miller 1980). The main food source of Red Grouse is Heather, which they also use for cover and as a nest site. The general aims of managing moorland for Red Grouse are to produce areas which will provide suitable habitats for feeding, nesting and shelter.

The main management practice used to produce these conditions is burning patches of the moorland to produce a mosaic of Heather stands of different ages, heights and densities. The length of rotation of the burning regime is generally 10-15 years (Coulson *et. al.* 1992). More specifically, it is recommended that burning should be carried out once the Heather reaches 30cm in height (Muirburn working party 1977, Philips *et al* 1995), though this can vary in time depending on topography and altitude (Coulson *et. al.* 1992) for example.

The regeneration of Heather in the burnt patches produces young shoots, which contain more nutrients than older-growth Heather (Miller 1979). The growth of these shoots is also more prolific in younger Heather than in the older stands (Coulson *et. al.* 1992). While these areas of young Heather produce good feeding areas, it is the older, dense stands of Heather which are required to provide shelter (Miller 1980, Philips *et al* 1995). Taller stands also conceal nesting grouse (Philips *et al* 1995), though nests can also be found in new burns with no new Heather growth (pers.obs.).

An actively managed grouse moor thus provides a mosaic of different habitats that are specifically aimed at maximising grouse production. One of the major aims of this project was to investigate the effects of this management regime on breeding Curlew. Other associated management practices such as game-keeping and blocking drainage ditches to produce wet flushes will also be considered within this thesis.

Habitat selection by Curlew

From the descriptions of upland vegetation above, it is clear that there are wide ranges of habitat types available for selection by Curlew as nest and feeding sites. Since this thesis is largely concerned with habitat selection it is important to address some of the factors which may influence the selection of particular habitats by Curlew.

From the perspective of breeding, there is evidence that adult Curlew are philopatric to the same territory and this has been correlated to reproductive success (Berg 1994), i.e. territories in which chicks were successfully hatched are often utilised the following year. This is also evidence of this philopatric behaviour with species such as Golden Plover *Pluvialis apricaria* (Whittingham 1996) and Lapwing *Vanellus vanellus* (D. Parish pers. comm.).

A returning Curlew may therefore establish the same territory as in previous years. However, how does a first time breeder select its territory? It could be that it has returned to the site in which it was raised and attempts to obtain a territory in the same area. However, since Curlew are indeed territorial, an earlier arriving or more competitive bird (possibly a parent) may deter the first year breeder from establishing a territory in that area. This bird may then be forced into an unoccupied territory - unoccupied possibly because it is sub-optimum in quality. In this situation the distribution of individuals is described as despotic (Fretwell and Lucas 1970) and is a result of either earlier settlers occupying the best habitats first or the most competitive individuals obtaining the best habitats (interference model (Sutherland and Parker 1985)). Evidence of despotic distributions have been found in a number of species (e.g. aphids on a leaf (Whitham 1980) and Oystercatchers *Haematopus ostralegus* (Goss Custard *et al* 1982)) a review of which can be seen in Parker and Sutherland 1986).

However, such theories describe the overall distribution of individuals in a population, but in this case do not answer key questions about which criteria Curlew use to choose a specific nest site within a territory. Any given territory may consist of a number of different habitat types, depending on its size and location. For example, in some areas of moorland, several habitat types (e.g. different aged burns, flushes and mature Heather) occur as relatively small patches within a relatively small area. Therefore, once a territory has been established, perhaps on the basis of previous reproductive success, the actual nest habitat within that territory must then be selected from those available. However, the selection of a nest site may not be a question of habitat type alone. For example, do Curlew select nest sites on the basis of greatest concealment for their eggs, or do they prefer to nest in areas where visibility of the surrounding land is greatest? These and other aspects of nest habitat selection will be discussed in greater detail in chapter 4.

In addition to nest habitat preferences, feeding habitat preferences are also important. Why do Curlew choose to feed in particular areas? Is greatest food abundance the key to selecting a feeding habitat or is visibility of the surrounding area to allow approaching predators to be observed the highest priority or is there a trade-off between the two? Again, these and other aspects of feeding habitat preferences will be discussed in detail in chapter 6.

It is these questions of habitat selection on a small-scale (rather than broad-scale population distributions outlined above) and the possible mechanisms governing them which were the main focus of the investigation habitat preferences in this thesis.

These aspects of habitat selection for breeding and feeding by Curlew are discussed in more detail in the appropriate chapters. Theories for why particular habitats are chosen by nesting Curlew can be found in Chapter 4 and feeding habitat selection by Curlew chicks and adults will be discussed in chapters 5 and 6 respectively.

Potential threats to Curlew populations

Though there are conflicting reports regarding overall trends in population sizes, declines in Curlew numbers have been reported in many countries in recent decades. In areas where declines have occurred, habitat change is often responsible (Cramp *et al,* 1983). Nationally, upland afforestation is a potential threat to Curlew along with agricultural changes, in particular overgrazing of breeding habitat by sheep, land drainage and re-seeding. More recently, the construction of wind-farms in upland areas has been construed as a potential threat to Curlew.

- **Threats from afforestation**

In the past some upland areas were free from the threat of afforestation due to their physical attributes (e.g. slope, water table level). However, advances in modern technology have allowed even the most unlikely places to be forested. This, for example, has been the case in the much publicised 'flow country' of Caithness and Sutherland in Scotland. Here, vast expanses of blanket bog exist and with the advancements in ploughing, drainage techniques, fertilisers and with the use of exotic tree species, much of this internationally important habitat has been forested (NCC 1986).

The vast majority of upland afforestation is by conifer plantations, normally monocultures of exotic species such as Sitka Spruce *Picea sitchensis*, Lodge-pole Pine *Pinus contorta* and European Larch *Larix decidua*. The majority of these plantations cover large areas of land and the term 'blanket' afforestation is often used to describe the vast continuous plantations. It is clear that afforestation will have detrimental effects on resident upland communities. The most obvious effect is the direct loss of upland flora within the plantation and the fauna which depends on the open country and its vegetation.

It is generally accepted that the change from a moorland bird community to a woodland community is a gradual one (Fuller 1982), but many waders are affected immediately and disappear (Fuller 1982, NCC 1986, Ratcliffe 1986). This is certainly true of Curlew and other species such as Golden Plover, Dunlin *Calidris alpina* and Redshank *Tringa totanus* (Stroud *et.al.* 1987).

Thompson *et. al.* (1988) described fifty-three species of bird associated with British uplands. Curlew were placed on two lists, one being a list of those species potentially at risk from afforestation and the second being a list of species either eradicated or substantially reduced in distribution as a result of afforestation.

As well as the direct loss of breeding habitat, afforestation could have other indirect effects on waders. Plantations provide a refuge for predators such as Foxes, Carrion Crow *Corvus corone* and Stoats *Mustela erminea* (NCC 1986 and Thompson *et al* 1988) which could potentially lead to an increase in adult, chick and egg predation (Thompson *et al* 1988). Avery *et al* (1989) found that nest predation of artificial nests was higher nearer to conifer plantations, which could be because plantations provide a predator refuge (Stroud 1990).

Nationally, upland afforestation is a major threat to Curlew habitat, but County Durham, the region of this study, has seen very little planting (Thompson *et. al.* 1988).

- **Threats from agricultural change**

In upland areas, the major farming activity is sheep rearing, since soils tend to be naturally acidic and generally low in nutrients and are hence unsuited to crop production. Sheep, particularly the hardy Swaledale variety, can forage freely on open moorland and survive harsh winters (Parker & Tallentire 1990). They generally feed on grasses but also on Heather, particularly when grass is in short supply in the winter (ITE 1989). Heavy grazing by sheep tends to result in a reduction of Heather and an increase in invasive species such as Cotton Grass. The conversion of Heather moor to grass heath is well documented (Anderson and Yalden 1981). Heavy grazing has been implicated as one of the major causes of decline of Heather moorland in Northern Britain, with declines of up to 16% in the past twenty years in some areas (ITE 1989).

For those species which use Heather as a nest or feeding site, the loss of suitable habitat may have a detrimental effect on their populations (eg Short-eared Owl *Asio flammeus*, Hen Harrier *Circus cyaneus* (ITE 1989) and Red Grouse (L. Waddell pers comm.)). Sheep also have a direct influence on breeding success, as nests and chicks can be trampled (Harding *et. al.* 1994). However, some species may benefit from increased areas of grassland, which provides suitable nesting habitat (for Golden Plover and Dunlin for example (Harding *et. al.* 1994)) and feeding habitat (for raptors for example (Sutherland *et al* 1995)).

The effect of sheep farming on Curlew is not well documented, though nests sited in marginal farmland have often been found trampled (M. Grant pers. comm.). This will be dealt with in more detail in subsequent chapters.

The drainage and re-seeding of upland areas with pasture grasses has also been suggested as a cause of decline of some species. These activities often result in the loss of the species and structural diversity of the vegetation and can lead to a more uniform habitat with little cover to aid camouflage. In upland fields these activities have been shown to cause a reduction in the densities of Curlew, Redshank and Lapwing (Baines 1988). Whimbrel *Numenius phaeopus* have also been shown to avoid areas of heathland which have been re-seeded (Grant 1992).

- **Threats from windfarm development**

Wind-farm development has dramatically increased since the early 1990's, the UK now having the third largest wind-power generation capacity in Europe with around 400 wind turbines currently operating (Craig 1997).

Twenty percent of the land area of the United Kingdom has the necessary annual wind speed to make it suitable for wind farm development, though not all of this area is suitable for development (due to constraints such as physical, scenic and ecological) (Craig 1997). Inland, upland areas, particularly in Scotland, provide the best areas for future development (Craig 1997) due to their exposure to prevailing winds and their relative remoteness from population centres.

Though the effects of wind-farm development on upland birds have not been extensively monitored, a number of reviews (*e.g.* Crockford 1992 and ETSU 1996) list several potential impacts on bird populations. These include:

- The direct loss or damage of breeding and feeding habitat by the construction.

- A reduction in breeding success due to disturbance, both during construction and operation.

- Increased mortality as a result of collisions with turbines.

Of these three factors, collision risk has been most extensively investigated (see Crockford 1992), but the general consensus appears to be that there is a general lack of information about the long-term effects of wind-farms on bird populations (ETSU 1996). Until long-term monitoring studies have been carried out extensively (suggested in ETSU 1996), the impact of wind-farms on bird populations will remain to be an area of contention between developers and environmentalists.

Though there are no published quantitative studies on the impacts of wind-farms on upland waders, it is this group which could potentially be at risk. For example, both Curlew and Golden Plover breed extensively on open moorland and a wind-farm development may potentially cause a reduction in nesting density and breeding success due to displacement and disturbance. However, no studies have shown a disturbance effect on breeding birds at distances greater than 300m (Gill *et al* 1996).

Golden Plover (Whittingham 1996), Curlew (chapter 6) and Twite *Ancanthis flavirostris* (McGhie *et al* (1994) have also been found to regularly use marginal farmland fields surrounding breeding moorland. Field use takes place in the evening and night in particular and these species may therefore be at risk from collision injury or mortality while flying back and forth between moorland and fields. However, at the site of a wind farm at Ovenden Moor, observations suggested that Curlew flight lines avoided turbines (J. Dale pers. comm.). Curlew were also found to nest within 100m of the turbines, but there was however, a slight decline in Curlew numbers following construction (J. Dale pers. comm.).

In order to address the effects of wind-farms on birds quantitatively, the monitoring of sites before and after development should be paramount. In addition, a sound knowledge of the ecology of those species which may be affected by the development could help to alleviate potential problems. For example, as part of the mitigation measures, habitat enhancement to benefit a particular species could be carried out away from the turbines. Of course, to enhance an area for a particular species, the habitat preferences need to be known.

General methods of data analysis

Since the bulk of the data collected throughout this study was not normally distributed, non-parametric tests have been used in most instances. The works of Campbell (1994), Fowler and Cohen (1988), Zar (1996) and the *SPSS for Windows* user manual were referenced often for statistical methods. The statistical method used for each analysis carried out is mentioned within the text of the thesis, with brief notes of the mechanics of a test where necessary. Detailed accounts of the theory and mechanics of each test used can be found within at least one of the references mentioned above if required.

Chi-squared (χ^2) tests were carried out by hand (with the aid of a spreadsheet into which the formula was entered). Spreadsheets (*MS Excel* version 7) were used for the construction of all bar charts and scatter plots (including regression plots). All other tests and charts were carried out using *SPSS for Windows* (version 6.1). It should be noted that SPSS gives the result of all Kruskal-Wallis H tests as a χ^2 value irrespective of sample size (Campbell 1994). However, to avoid confusion between these tests and χ^2 tests, the results of Kruskal-Wallis tests will be displayed as Kruskal-Wallis H accompanied by the number of cases in the test (n).

Specific aims of the thesis

The specific aims of this thesis were to;

- Investigate nest site selection by adult Curlew.
- Investigate habitat selection by non-incubating breeding Curlew using radio-telemetry.
- Investigate chick habitat preference using radio-telemetry.
- Investigate any relationship between habitat selection and invertebrate prey abundance.
- Investigate the productivity of breeding Curlew.
- Provide management prescriptions for upland areas which would be beneficial for Curlew.

Questions to be addressed

- Do breeding Curlew select particular habitat types to nest in?

The available habitat types will be discussed in chapter 2 and the selection of these habitats as nest sites will be discussed in chapter 4.

- Do Curlew broods show a preference for particular habitat types and if so can prey abundance account for this preference?

Invertebrate abundance will be considered in chapter 3 and this will be related to chick habitat preferences in chapter 5.

- Do adult Curlew show a preference for particular areas as feeding sites during non-incubatory periods?

Chapter 6 will investigate the activity of those Curlew which are not incubating or performing parental duties.

- Which factors influence the productivity of Curlew on their upland breeding grounds?

Chapters 4 and 5 will each have sections dealing with productivity and those factors that influence it.

- Can data obtained in this study be put into use in the implementation of management plans which will be beneficial for Curlew populations?

This aspect of the study will be dealt with in the final chapter (7).

CHAPTER 2.

STUDY SITE SELECTION AND HABITAT AVAILABILITY

Aims of the chapter

The aim of this chapter was to provide a detailed description of the study sites, focussing on the habitat types available to nesting Curlew and their broods in particular. The information collected and analysed in this chapter was utilised in subsequent chapters to assess habitat preferences and their consequences for Curlew breeding ecology.

Introduction

The study was carried out in County Durham which has the greater proportion of its 265,078 hectares lying above 500m (Graham 1988). The study sites were in the west of the county, within the upper Teesdale and upper Weardale areas of the Pennine uplands. The majority of these areas have recently been designated as Areas of Outstanding Natural Beauty and are almost entirely rural, with small farms scattered around the upland landscape (Parker and Tallentire 1990).

The only profitable farming activity in these upland areas is sheep farming (Parker and Tallentire 1990). Teesdale and Weardale are both dominated by expanses of unenclosed moorland used by foraging sheep. The majority of the land surrounding the moors is permanent pasture fields (used for sheep grazing) and hay meadows. The county as a whole supports over half a million sheep (Hillery & Parker 1990).

Another major source of income to the rural economy in Teesdale and Weardale comes from grouse shooting and many of the moors have a history of active management for grouse. Hudson (1992) estimated that the 450,000 grouse (approximately) which are shot each year in Great Britain at a current value of £70 per brace (on driven days) would generate a gross income of £35 million. In reality this is an over-estimate, but cash is also injected into upland economies by the goods and hotel bills of shooters (Hudson 1992). A report by Strathclyde University (mentioned in Hudson 1992) estimated that the total expenditure on grouse shooting in Scotland was £21 million. Clearly grouse shooting is an important part of the upland economy and it is the management for this activity, along with sheep farming, which has shaped landscape and habitats of the majority of Teesdale and Weardale (Parker and Tallentire 1990).

Methods

Selection of study sites

Two major criteria were used to select the study sites:

1. They should support a variety of vegetation patch types with different management regimes, so that the birds' detailed habitat preferences could be investigated.

2. They should have a reasonably high density of breeding Curlew.

As well as these two factors, from a more practical point of view, the sites had to be "manageable" with regards to size, so that an individual field worker could survey all areas thoroughly and efficiently. Therefore, since the study sites had to be relatively small for intensive investigations to be carried out, the density of Curlew had to be reasonably high (criteria 2 above) to maximise sample sizes.

Discussions with gamekeepers (L. Waddell pers. comm.) and other researchers (S. Percival and M. Whittingham pers. comm.), followed by site-visits prior to Curlew laying period initially identified two sites as having satisfied the criteria for selection.

Monk's Moor (National Grid reference NY960280) in Teesdale was a typical Heather moorland, managed primarily for Red Grouse. Heather, in a mosaic of different aged burnt patches dominated the majority of the site. The site also contained large areas of acid grassland and a number of patches of Soft Rush, particularly around blocked drainage ditches. This site was used to graze Sheep, but at a relatively low density (0.44 ha^{-1}) (L. Waddell pers comm.).

The second site, referred to here as Langdon Common (National Grid reference NY840340), was in Teesdale, though it included part of Harthope Moor (National Grid reference NY860360) in Weardale. This site was typical of many areas of heavily sheep-grazed moorland, being dominated by Hare's Tail Cotton Grass

Eriophorum vaginatum, with a localised sparse cover of Heather. It included many patches of Mat Grass-dominated grassland, some relatively dense stands of Heather, and several areas of *Carex/Juncus*-dominated flush and marsh. Prior to October 1993 there were 1500 ewes on Langdon Common (0.93 ha^{-1}). After this date the numbers were reduced to 1000 ewes (0.66 ha^{-1}) (L. Waddell pers comm.).

These two sites were chosen initially to allow a comparison between Heather dominated grouse moorland and grass dominated sheep-walk. Following the analysis of data obtained from Monk's Moor during the first two years of the study, clear habitat preferences by Curlew began to emerge. At this stage it was concluded that a comparison between the results obtained from Monk's Moor with another moorland managed for Red Grouse would be appropriate. This was to determine whether the habitat preferences observed on Monk's Moor would be found on another site with similar habitats (*i.e.* to test predictions of habitat use).

During the first two field seasons only three nests (each year) were found on Langdon Common. This was largely due to a lower Curlew density than on Monk's Moor and in addition, this site was more difficult to survey due to it having a relatively uniform topography with few hills and rises (see nest locating in methods of chapter 4 for the implications of this). In addition, all of the nests that were located were predated and this, coupled with the practical difficulty in covering three large expanses of moorland intensively, led to the conclusion that work on Langdon Common should be terminated and another grouse moor chosen as a new study site. Following consultations with gamekeepers and visits to a number of grouse moorlands, Langlydale Common was selected as a third study site.

Langlydale Common (National Grid reference NZ030240) in Teesdale was a typical Heather moorland, managed primarily for Red Grouse. Heather, in a mosaic of different aged burnt patches, dominated the site. Areas of acid grassland and a number of areas of Soft Rush were also present. The only major difference between vegetation types on Monk's Moor and Langlydale Common was the predominance of Bracken in some areas of Langlydale Common. This site also had a relatively low density of grazing sheep (M. Gibbs pers. comm.).

Vegetation classification on the study sites

Since the production of the ITE classification mentioned in Chapter 1, other classification methods have been designed. Of particular relevance here is the National Vegetation Classification (NVC) scheme (Rodwell *et. al.* 1991). This method of vegetation community classification is based on the most comprehensive vegetation classification surveys carried out in Britain to date and is becoming accepted as standard for describing vegetation communities (Rodwell *et. al.* 1991). In theory, a standardised method of classification allows comparisons between different studies to be made more readily than if two or more different methods were used.

NVC classes were determined following the methods of Rodwell *et. al.* (1991). This involved taking five random 2m x 2m quadrats in visually homogenous vegetation stands and identifying the species present and their cover using the DOMIN scale (see Rodwell *et. al.* 1991).

The program MATCH (Malloch 1990) was then used to assign this data to an NVC class. MATCH produces a score, based on similarity coefficients between the sample vegetation and NVC communities, of the most likely community from where the vegetation came from. It should be noted that using this program on a vegetation sample does not guarantee a perfect match to an NVC community and results can range from 0 to 100 in similarity (100 being a perfect match) (Malloch 1990). As a rule of thumb, the higher the similarity co-efficient, the better the fit to an NVC community, but there is no threshold point for what constitutes a good fit or a bad fit (Malloch 1990). MATCH was therefore used as a tool to narrow down the search for the most likely NVC community type from which the sample was derived. Once the results were produced, the NVC books (Rodwell *et. al.* 1991) were used to compare the vegetation in the samples and the top two or three most likely NVC communities to which MATCH assigned the vegetation. The vegetation was then assigned to an NVC community on this basis.

However, it proved necessary to produce a more detailed classification scheme for this thesis because NVC did not distinguish adequately between some of the habitats on the study site (see discussion for details). The habitat types of this new scheme were kept as close as possible to NVC habitats (see table 2.1 and discussion) to allow comparisons to other studies which may use NVC.

Vegetation structure

The vegetation structure of each habitat type was assessed, as this was considered likely to influence the selection/avoidance of habitats by Curlew, particularly as a nest site.

Ten measurements of vegetation height were taken in each of the five quadrats for each homogenous vegetation type (within the quadrats selected for NVC classification). An arbitrary index of density was also used to assess the vegetation density of each habitat type. Three categories were chosen: low, medium or high. Low density habitats contained less than 75% cover of vegetation. Medium density habitats had between 75% and 100% cover of vegetation, but were either non uniform in height or the vegetation growth was patchy. High density habitats had 100% cover of generally tall, uniform vegetation.

Since the data did not follow a normal distribution, Kruskal –Wallis tests were used to test for differences between vegetation heights in the different habitat types.

Production of initial habitat map for Monk's Moor

A habitat map for Monk's Moor was constructed from the 1994 survey data. A baseline map, based on Ordnance Survey (OS) maps and aerial photographs, was drawn. The map was constructed by drawing the boundaries of all the habitat patches which could be seen from the six aerial photographs onto an OS based map. This map was then used in the field and the vegetation in the outlined habitat patches was identified and coded. Any new habitat patches that had appeared since the aerial photographs were taken (such as new burns) were drawn onto the baseline map. The information from this map was used in the analysis of the data obtained from the first field season (Robson *et al* 1995).

The management practices carried out on grouse moorlands (e.g. burning) lead to a dynamic area of different habitat types. The annually changing nature of the study sites meant that the habitat maps needed to be updated each year. However, the existing map could not be readily manipulated to reflect this, and it was concluded that a computer generated map would be more appropriate for future field seasons.

Production of final habitat map for Monks Moor and Langlydale Common

Originally it was intended that a Geographical Information System (GIS) would be used to produce maps of the study areas and to store spatial data. However this was considered too time consuming and largely inappropriate for the needs of this project. Therefore, a different approach was used to produce a map relatively rapidly and one that could be easily manipulated and have spatial measurements taken directly from it.

In 1995 a computer based map was created. The colour map constructed in 1994 was scanned into a PC and imported into a drawing package (*Corel Draw* version 5).

To allow direct measurement by computer, each habitat type had to have an individual uniform colour. However, once on computer, each habitat patch on the map was not a uniform colour. For example the habitat which was blue on the original map also appeared blue on the scanned map. However, on close inspection the individual pixels which made up the habitat ranged from pale green to navy blue and this prevented direct measurement of spatial features. Therefore each major habitat type had to be individually coloured on computer. The outline of every habitat patch on the computer map was traced on computer using the mouse. These patches were then "filled in" with a uniform colour (the colour depending on habitat type which was known from field vegetation surveys).

Corel Draw has the capability to allow any diagram to be built up using a series of distinct layers which can be manipulated individually (the order of layers can be changed or layers can be hidden for example). For the construction of the habitat map, each habitat type was assigned to its own layer, as were nest locations and chick locations. The map was then easily updated in subsequent years by adding new layers (for new burns for example).

Before new burns were added to the map, their locations and size had to be determined in the field. The new burn was drawn onto paper and its size measured by pacing along its dimensions. The majority of the burns were approximately rectangular and in these cases four measurements were taken (along each of the outer edges). If the burn was non-uniform in shape, each of its edges was measured and other measurements were taken across the burn as appropriate.

The location of the burn was determined by recording its orientation in relation to other features on the site using a compass and by pacing out from the burn edge to other land-marks or habitat patches, again recording the orientation. Using this information, the new burns were added to the habitat map.

Determination of habitat availability

The area of each habitat type was calculated directly from the habitat maps, using an image analysis software package (*PC Image*). Since individual layers of the habitat map could be temporarily hidden, habitat areas could be measured each year (for example, 1995 and 1996 burns were hidden to allow the calculation of habitat areas in 1994).

Since this technique for habitat mapping proved successful it was employed again in 1996 to construct the habitat map of Langlydale Common.

Production of habitat map for Harthope Moor and Langdon Common

A habitat map for Chapel Fell, which covered parts of the adjacent Langdon Common and Harthope Moor, was produced during research on Golden Plover in Upper Teesdale (Whittingham 1996), using the same technique as for the initial Monk's Moor map.

Following pilot surveys for Curlew nests on Harthope Moor and Langdon Common it was found that the existing study area would have to be extended to cover further down the hill sides, since this was where most Curlew were observed and nests found. However, since so few nests were found and all were predated (see chapter 4), no detailed analysis of habitat preferences could be carried out on this site and therefore a more detailed habitat map was not constructed.

Results

Vegetation classification using NVC

Table 2.1 shows the results of the NVC habitat classification using the program MATCH (including the top three most likely matches and their scores as explained in the methods) and the equivalent habitat types using a scheme designed specifically for this project.

Table 2.1. Vegetation communities on Monks Moor and Langlydale Common

Habitat	Thesis description	NVC community	NVC code	MATCH score %
1	*Calluna vulgaris* moor	*Calluna vulgaris-Deschampsia flexuosa* heath	H9	H9 44.8 H9c 42.3 H2b 42.3
2	*Calluna/ Eriophorum* moor	*Calluna vulgaris- Eriophorum vaginatum* blanket mire : *Erica tetralix* sub-community	M19a	M19a 43.0 M20 40.0 M2 37.7
3a	*Calluna* dominated old burn	*Calluna vulgaris - Deschampsia flexuosa* heath: species-poor sub-community	H9c	H1e 41.7 H9c 37.9 H9d 37.0
3b	Acid grass dominated old burn	*Eriophorum vaginatum* blanket and raised mire	M20	M20 31.8 M20a 31.7 M2 31.2
4	Grey burn	*Calluna vulgaris - Deschampsia flexuosa* heath: species-poor sub-community	H9c	H1e 41.7 H9c 30.2 U2b 30.1
5	Black burn	*Calluna vulgaris-Ulex minor* heath: typical sub-community	H2a	H2a 29.4 U2 27.1 H9d 26.4
6	Acid grassland	*Nardus stricta - Galium saxatile* grassland: species-poor sub-community	U5a	U5a 37.5 U4a 36.1 U6d 34.1
7	Acid grassland/ *Calluna* mosaic	A mosaic of habitat 1 and 6	H 9 and U5a	N/A
8	*Juncus effusus* flush	*Carex echinata-Sphagnum recurvum/ auriculatum* mire: *Juncus effusus* sub-community	M6c	M6c 44.2 U2b 36.6 U6d 34.3
9	*Pteridium aquilinum*	*Pteridium aquilinum-Gallium saxatile* community: species-poor sub-community	U20c	U20c 31.8 H1e 31.7 W25b 31.2
10	*J. effusus* dominated acid grassland	*Juncus effusus/acutiflorus-Galium palustre* rush pasture	M23	N/A

It should be noted that, for the purposes of NVC classification, old burns were split into two distinct categories as described above. However, the vast majority of the old burns were dominated by Heather, with few dominated by acid grass. Therefore these two types of old burns were grouped together for the purpose of this thesis.

It should also be noted that habitat 10 was found on Langlydale Common alone. By the time this area had been selected as a study site, the use of NVC categories had been modified, with some habitats split and others pooled in favour of new habitat types. Therefore, this habitat was not classified to NVC (hence N/A in MATCH score box), though an approximate NVC equivalent based on the dominant plant species was included in the table.

Vegetation classification using newly devised scheme

The habitat classes used for this thesis are explained below. All of the habitat types mentioned hereafter will refer to this classification scheme.

Definition of habitat classes used for this project

Calluna vulgaris moor

Dry areas of mature Heather which form dense stands of tall vegetation (>25cm).

Calluna/ Eriophorum moor

Areas of mature Heather with greater than 10 % Cotton Grass. This type of habitat was found in relatively damp areas, often characterised by small open pools of water.

Acid grassland

Areas dominated by grass species characteristic of acidic soils, such as Mat Grass, Cotton grass and Wavy hair grass. Individual grass species may have dominated in certain areas, but were not distinguished between because the overall appearance and structure (uneven, tussocky vegetation) was similar on all areas of these study sites.

Acid grassland/ *Calluna* mosaic

A mosaic of distinct, generally short, Heather patches of various shapes and sizes in an area of acid grassland. This habitat was found in the more intensely grazed areas of the moor and often formed the interface between acid grassland and *Calluna vulgaris* moor.

Juncus effusus dominated acid grassland

Areas of acid grassland which had a uniform covering (>20%) of Soft Rush. This habitat type was generally damper than acid grassland and the vegetation was taller due to the Soft Rush presence.

Juncus effusus flush

Damp areas dominated by tall, dense patches of Soft Rush, which also generally included species of *Sphagnum* and *Polytrichum* mosses.

Pteridium aquilinum

Areas dominated by a dense brown matt of dead Bracken fronds (previous year's growth).

Classification of burnt patches

Burnt patches of Heather were classified as being one of three types, either Old, Grey or Black. The latter two habitat types were structurally very similar to one another, the only major difference being the odour and appearance of the burnt material.

Black burns

These were classified as being up to 2 years old, at which age the burnt heather branches remain charred and the acrid burnt odour was strong. These patches contained very little, if any, re-growth of vegetation.

Grey burns

These were classified as being between 2 and 4 years old, at which age there was still very little, generally patchy, re-growth of vegetation. The burnt Heather branches in these patches were weathered by this age, with the black charcoal having been washed away, resulting in grey branches with little odour.

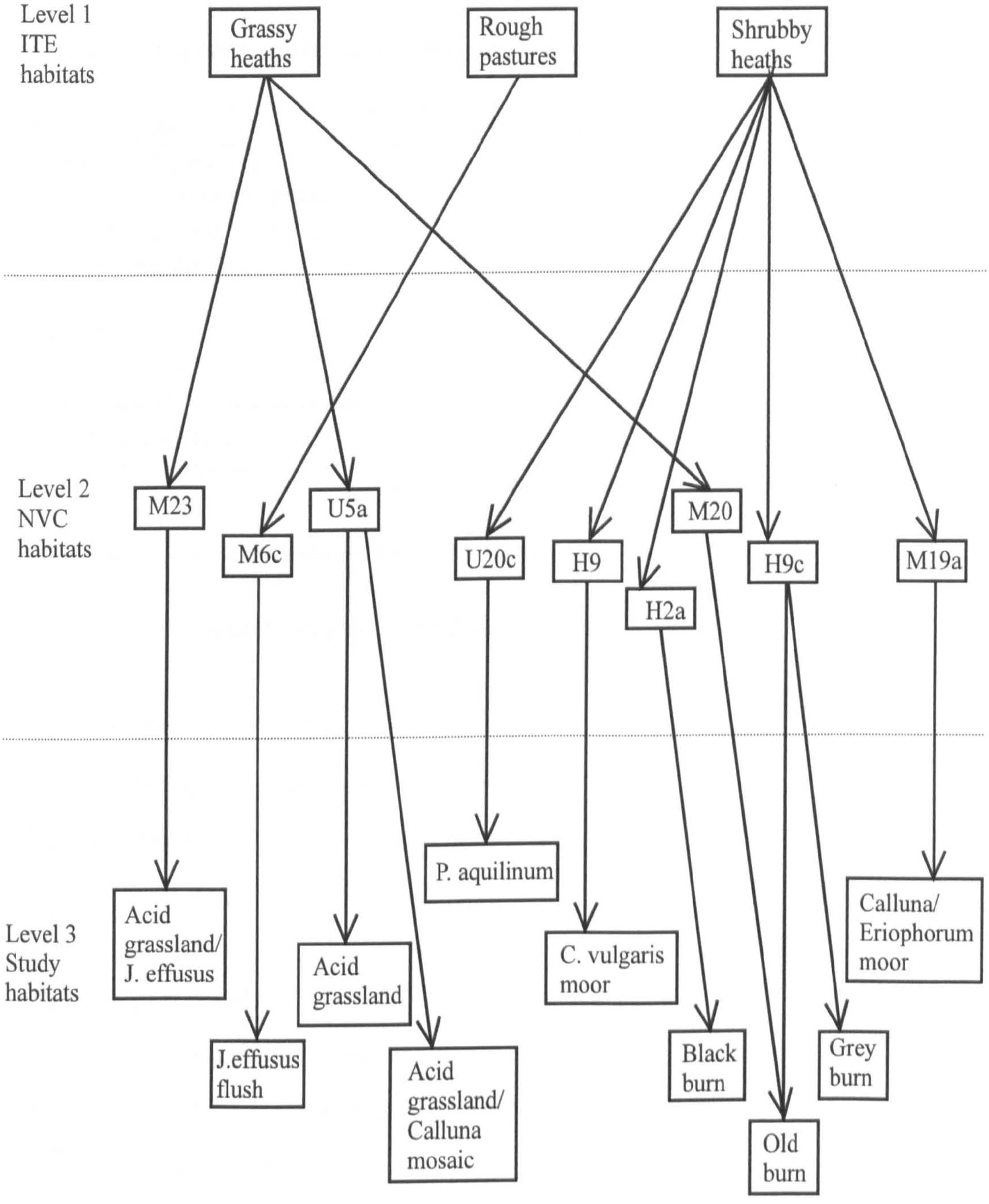
Old burns

These were classified as being between 5 and 10 years old, when the vegetation height is generally shorter and more uniform than the surrounding mature moorland.

Flow diagram of all vegetation classification schemes mentioned

Figure 2.1. was constructed to show the links between habitat types in the three vegetation classification schemes mentioned.

Figure 2.1. Habitat classification flow diagram



Vegetation structure

The heights of the vegetation in each habitat were found to vary significantly (Kruskal Wallis H=153.26, n=450, p<0.001). The median vegetation heights and index of density for each habitat type are shown in table 2.2.

Table 2.2. Vegetation structure of the major habitat types

Habitat type	Median height (cm)	Density index
Calluna vulgaris moor	26	High
Calluna/ Eriophorum moor	19	High
Calluna dominated old burn	12	Medium
Acid grass dominated old burn	18	Medium
Grey burn	24	Low
Black burn	5	Low
Acid grassland	15	High
Acid grassland/ *Calluna* mosaic	19	High
Juncus effusus flush	51	High
Pteridium aquilinum	17	High

Habitat maps for Monk's Moor and Langlydale Common

The key for the habitat maps of Langlydale Common and Monk's Moor can be seen below:

🟪 *Calluna vulgaris* moor

🟨 *Calluna/Eriophorum* moor

⬛ Old burn

🟫 Grey burn

🟥 Black burn

🟩 Acid grassland

⬜ Acid grassland/*Calluna* mosaic

🟩 *Juncus effusus* dominated acid grassland

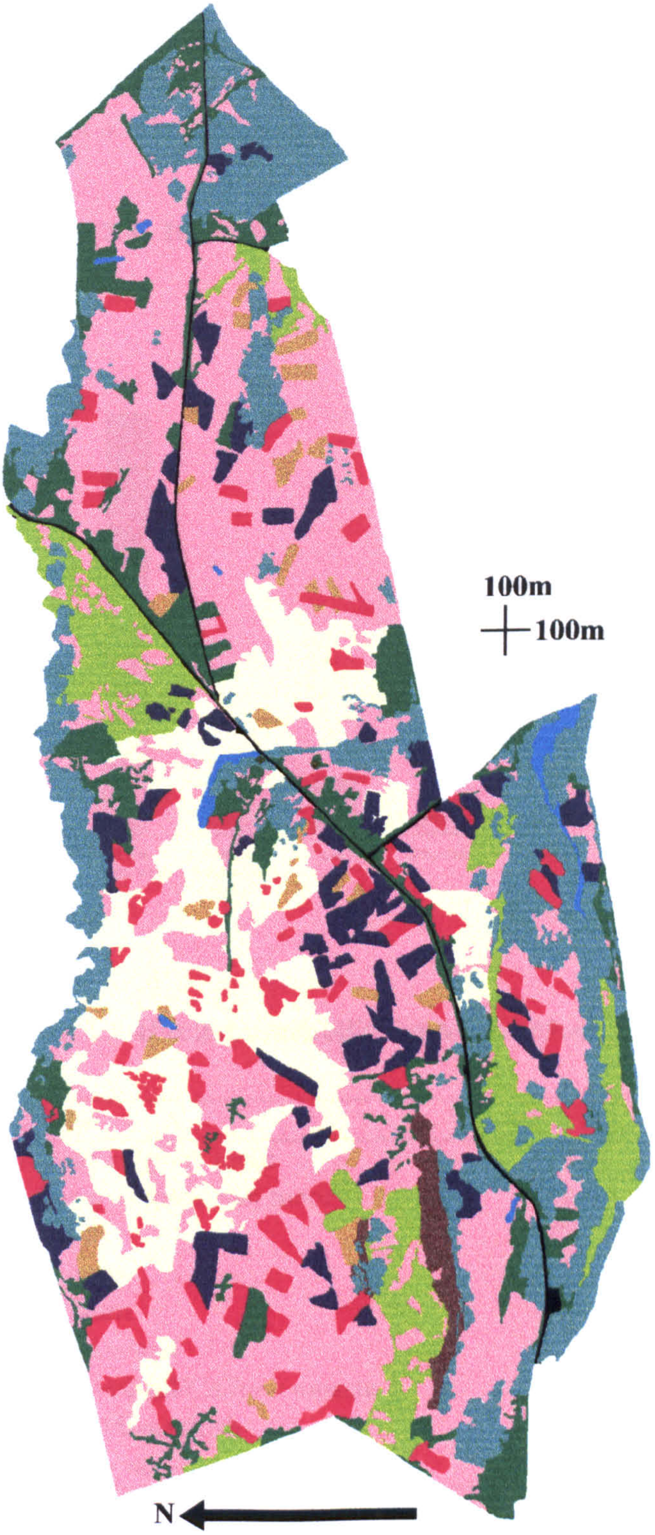
🟦 *Juncus effusus* flush

🟦 *Pteridium aquilinum*

🟫 Bare earth

Figure 2.2. Monk's Moor habitat map (at 1996).

Figure 2.3. Langlydale Common habitat map.



Habitat availability on Monk's Moor

The total area of the Monk's Moor study area was 4.28km². The mean area of the habitat types available over the three year study period are shown in figure 2.4. The habitat availability for each year is summarised in table 2.3.

Figure 2.4. Habitat availability on Monks Moor (mean of 1994-1996)

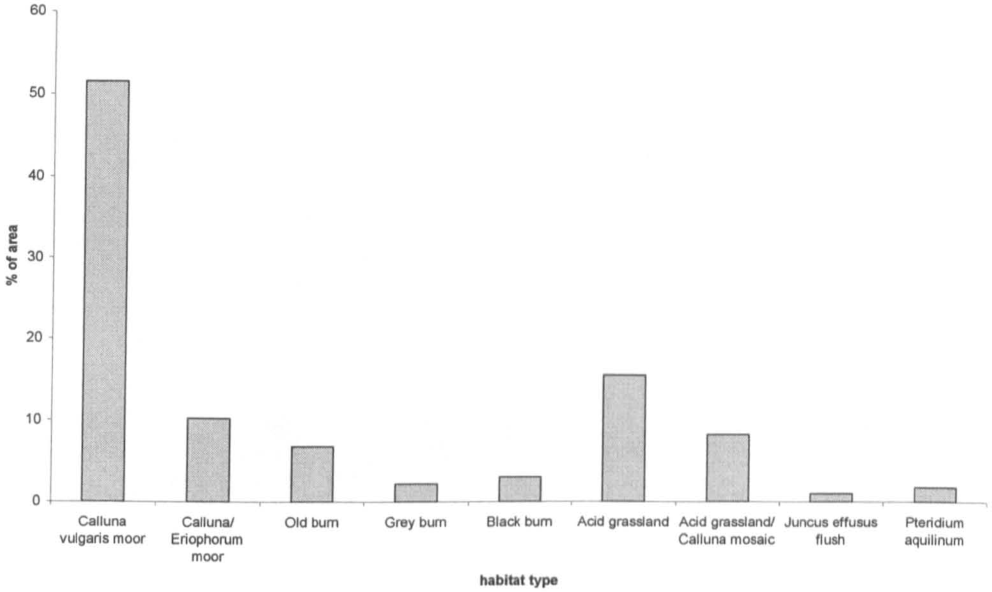


Table 2.3. Habitat availability on Monks Moor from 1994-1996.

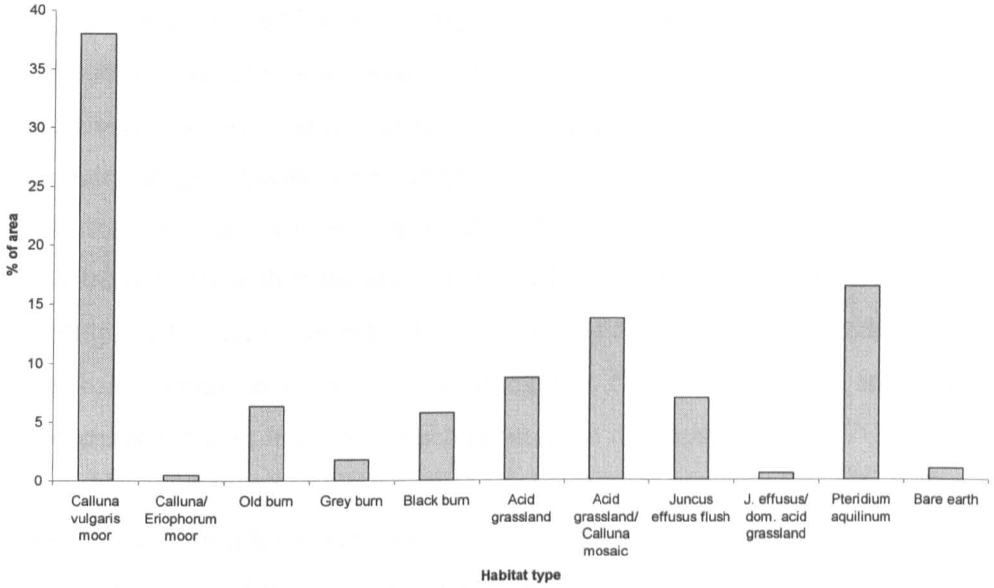
Habitat	% area (94)	% area (95)	% area (96)
Calluna vulgaris moor	54.4	51.9	48.3
Calluna/ Eriophorum moor	10.4	10.3	9.9
Old burn	6.9	6.8	6.5
Grey burn	0.2	0.4	5.8
Black burn	1.9	4.3	2.8
Acid grassland	15.4	15.4	15.4
Acid grassland/*Calluna* mosaic	8.0	8.2	8.4
Juncus effusus flush	1.0	1.0	1.0
Pteridium aquilinum	1.7	1.7	1.7

The main point to note is that the percentage area of each habitat was very similar each year.

Habitat availability on Langlydale Common

The total area of the Langlydale Common study area was 2.36km². The areas of habitat types available in 1996 are shown in figure 2.5

Figure 2.5. Habitat availability on Langlydale Common.



The main point to note is that the majority of the habitats were available on both sites, each being dominated by *Calluna vulgaris* moor.

Discussion

Vegetation classification

Initially, it was intended that habitat types would be classified according to NVC. However, it proved necessary to use more specific descriptions of habitat types since NVC classes failed to distinguish between habitats of similar vegetation species, but of different density and structure. This was particularly the case with the different aged Heather stands which varied from structurally open, recently burnt patches, through to structurally dense, mature patches. This can be seen in table 2.1 with *Calluna vulgaris* moor being classified as being part of the same overall vegetation community as grey burns, albeit grey burns being a species poor sub-community. Clearly these habitats will be perceived by Curlew as being different, as grey burns were open habitats with little vegetation and Heather moor was composed of dense vegetation. The major difference between these habitats is the vegetation structure rather than species composition, something that NVC did not take into account. Ecological differences in habitat structure were not differentiated by NVC.

There were also problems with assigning new burns to an NVC community. If the patch of Heather had been burnt within a few weeks of a field season beginning, there was no living vegetation visible. Therefore, strictly speaking, this patch could not be assigned to any NVC community type. If the burns were over a year old, there was often regrowth of vegetation, but it was not sensible to assign it to an NVC community when the bulk of the habitat consisted of bare earth and burnt Heather branches.

As described in the methods, MATCH does not produce a perfect fit to NVC communities. For two habitats, MATCH produced the highest similarity coefficients between vegetation samples and an unlikely NVC community. Habitat 3a and 4 were most closely matched to H1e (*Calluna vulgaris- Festuca ovina* heath) which is considered to be a lowland heath community (Rodwell *et al* 1991). Following consultations with the NVC text, both habitat types were assigned to H9c which is characteristic of frequently burned upland moor (Rodwell *et al* 1991). H9c produced the second highest similarity coefficient and, in the case of habitat 4, was substantially lower than that of H1e (28% lower)

Clearly, if one is attempting to gain an insight into which habitats are preferred by Curlew then the most appropriate classification scheme available had to be used and in this case it was not NVC. Therefore, each major habitat type on the study sites was assigned to a classification scheme devised for this thesis, but the habitats were kept as close to the NVC classes as possible to allow comparison.

The vegetation classification scheme devised for this thesis was based on the dominant plant species and structure of the vegetation within homogenous habitat types (using vegetation data collected for assignment to NVC classes). Less heed was taken to plant species at low abundance which provided little to the overall structure and appearance of a habitat (those species were important for NVC classification). The habitat types were named on the basis of the dominant vegetation within the samples.

The rationale behind this was that an attempt was made to classify habitats on the merit of those features that were likely to be important to Curlew. The major features of a habitat, which would influence its selection/ avoidance by Curlew were likely to be the dominant vegetation type(s) and its associated structure, density and invertebrate community (if used for feeding). For example, if a Curlew chose to nest in an patch of mature Heather, the presence of a few Bilberry plants and a particular species of moss and lichen in the under-storey were not likely to be important in governing its choice (all of which are important in assessing NVC communities). Rather, it would be the Heather itself and its structure (for aiding camouflage for example) that would have been important.

The effect of management on vegetation communities

The sites selected for this study were dominated by dwarf shrubs and grasses because of the management regimes which have taken place in the past (e.g. deforestation, grazing and burning). Generally, since most moorlands fall below the tree-line (Mowforth and Sydes 1989), grass-dominated and dwarf shrub-dominated habitats are not the climax community. Rather, these moors are transitional communities, and it is grazing and burning which prevent these areas from becoming woodland once again (Mowforth and Sydes 1989). Therefore, the continuation of the main regimes of burning and sheep grazing is essential (though the two must be balanced – see below and grazing in chapter 7) if grouse moorlands are to be maintained to a high standard, both as a source of income from sheep and grouse.

Maintaining an area of moorland which comprises a mosaic of different aged Heather patches and other vegetation types, is generally considered desirable from a conservation point of view (see Mowforth & Sydes 1989, Sutherland & Hill 1995, Thompson *et al* 1995 and EN Wildlife Enhancement Scheme, for example).

The mixture of different aged and structured stands of Heather is well documented as being beneficial to Red Grouse (Miller 1980). There is also evidence that grouse management is beneficial to non-target species, providing niches for different species which require different habitats. For example, Hen Harrier require areas of tall heather (>60cm) to nest in (Watson 1977). However at this height the Heather is unsuitable for nesting Golden Plover which prefer shorter Heather (<15cm) (Ratcliffe 1976). Therefore, an area of moorland is more likely to hold both species if there is a mosaic as heather stands at a range of heights, rather than in an area of uniformly tall or uniformly short Heather.

A balance between burning and grazing must also be met if the quality of a grouse moorland is to be maintained. Sheep preferentially feed on grass species but in the winter months Heather is one of the few sources of food on moorlands (Mowforth and Sydes 1989). In the absence of palatable grasses, sheep tend to congregate in areas of burnt Heather, feeding on nutritious new shoots (Grant & Hunter 1968). Heather is less tolerant of intensive grazing than grasses. This is largely due to Heather meristems being on the shoot tips as opposed to being at ground level in grasses. This results in Heather meristems being more accessible than those of grasses which are also often protected within tussocks (Coulson *et al* 1992). Therefore, as the Heather is killed, grass species begin to invade and dominate in areas of heavy grazing (Mowforth and Sydes 1989).

The information on habitat availability will be used in subsequent chapters to assess habitat selection by Curlew. The implications of moorland management practices on Curlew will also be addressed in chapter 7.

CHAPTER 3.

CHICK DIET AND INVERTEBRATE ABUNDANCE ON MONK'S MOOR

Aims of Chapter

The major aim of this chapter was to assess the availability of those invertebrates that were potential prey for Curlew chicks. Differences in invertebrate abundance in each of the major habitat types and through time were assessed. This information was then used to aid in the interpretation of chick habitat preferences and timing of the breeding season in chapter 5.

Introduction

Invertebrates form the basis of the diet of both adult Curlew and their chicks (Cramp *et. al.* 1983). Therefore, it seems reasonable to suggest that feeding Curlew may show preferences for those habitats that have the most abundant prey items. Berg (1993) for example, found that greater availability of food accounted for higher Curlew densities on some farmland habitats. This has been shown to be the case in a number of species such as Redshank and Oystercatcher *Haematopus ostralegus* (see Goss-Custard (1985) and Kacelnik and Krebs (1985) for example). Therefore invertebrate prey availability was investigated as part of this study.

Visual observations of birds can provide information on the type of prey consumed, as well as the rate of consumption. The problem with this method of assessing prey items is that it can be very time consuming and the identification of prey items from a distance is difficult. This can be particularly true when observing chicks in tall vegetation as they often consume their prey while obscured from sight (pers. obs.).

An alternative method for assessing which prey items are consumed, and the proportion of the diet they constitute, is to examine the faeces of the study animal. A number of studies have demonstrated the value of faecal analysis when attempting to determine the prey items of birds. For example, faecal analysis has been used to investigate the diet of Lapwings *Vanellus vanellus* (Galbraith 1989), Dotterel *Charadrius morinellus* (Galbraith *et. al.* 1993) and Golden Plover (Whittingham 1996).

Once it had been established which invertebrates were consumed, an investigation into their abundance could be carried out to investigate whether there was any link between habitat selection and food availability.

Invertebrate communities have been extensively studied in their own right (see Butterfield & Coulson (1983), Buse (1988), Coulson & Butterfield (1985) and Gimingham (1985) for example). The effects of moorland management on invertebrates have also been well documented. Usher (1992), for example, found that the growth phase of Heather was the main influence on spider and beetle assemblages and that some nationally rare species were associated with recently burned areas. Gardner (1991) also suggested that the creation of open areas on moorlands (i.e. burns) would lead to an enhanced diversity of Carabids.

A detailed investigation of invertebrate communities on the moor was not required for this study. Rather, an index of invertebrate abundance in each habitat type and data on how the abundance changed through the season was required. Therefore a suitable sampling regime which was not a major drain on time and resources, but still provided the data required, had to be established. Pitfall trapping and Tipulid transects met these criteria and were therefore used to assess invertebrate abundance. Invertebrate sampling was only carried out on Monk's Moor because chick habitat preference could not be carried out on the other two study sites because of either complete egg predation or prohibited access.

Methods

Determining chick prey by faecal analysis

Faecal samples were collected opportunistically during the handling of radio-tagged chicks (see chapter 5). Thirteen faecal samples were collected throughout the study, each being stored in a small vial containing alcohol preservative for analysis at a later date.

The invertebrate remains in the faeces were identified under a binocular microscope with the aid of a key of arthropod fragments (Moreby 1987).

Determination of invertebrate abundance in each habitat by pitfall trapping

Pitfall traps were used to determine invertebrate abundance. This method was not particularly labour intensive, an important consideration at a time when other labour intensive activities such as nest finding and radio-tracking chicks and adults were taking place. From observations of chicks it was also apparent that they were largely visual predators. Therefore reasonably sized, motile invertebrates were likely to constitute a major part of their diet, being relatively more visible than smaller more sessile species. Therefore, since pitfall traps tend to capture more motile species (Halsall and Wratten 1988), this method sampled those invertebrates most likely to be part of the diet of Curlew chicks.

There are numerous papers which highlight problems with sampling invertebrates using pitfall traps (Southwood 1978 and Baines 1988 for example). The criticism that pitfalls trap the more motile species, while sessile species will tend to be under-represented (Halsall and Wratten 1988, Topping and Sunderland 1992) has already been mentioned. With beetles, size has also been shown to influence capture rate (van der Drift 1951) and some invertebrates have been found to be attracted to the traps by the alcohol/ethylene glycol solution (Holopainen 1992).

Vegetation structure can also effect the outcome of pitfall trapping (Greenslade 1964, Topping and Sunderland 1992). This was a particular source of potential bias in this study, where vegetation structure varied widely from bare burns to dense Heather. For example, there was potential that the number of invertebrates caught in mature Heather could be low, not because of there being few invertebrates, but because the invertebrates were in, or on top of, the dense canopy. Indeed Curlew chicks have been observed foraging on top of the canopy of mature Heather, rather than at ground level.

However, there is no one completely satisfactory method for sampling invertebrates, each method having its own inherent problems. For example blow vaccing is often used to sample invertebrates within a given area and can collect most invertebrates, including more sessile ones which may be under-represented by pitfall trapping. However, blow vac samples are collected for a given time period (often only a few minutes) at a given point of day and for given weather conditions (generally not in very adverse conditions). Pitfall trapping on the other hand is carried out in all conditions and over a longer period.

As long as one is aware of the potential biases of pitfall trapping, care can be taken when interpreting the results. Unfortunately, this is often overlooked in many studies as demonstrated by Topping and Sunderland (1992), who found that of 185 studies from 23 countries, published since 1983, less than 40% of the authors had fully appreciated the limitations of pitfall trapping.

Pitfall trapping was carried out throughout the breeding seasons of 1995 and 1996 (pitfall trapping was not carried out in 1994 as this was considered to be a pilot year to determine the viability of carrying out more in-depth research). Trapping commenced in mid-April and was completed in mid-July and therefore included the time periods previous to and during chick activity (so that timing of the breeding season in relation to invertebrate abundance could be investigated). The pitfall traps were collected every 28 days over this period and replaced with fresh ones.

Ten pitfall traps were placed in each of the nine major habitat types identified from vegetation sampling (see chapter 2). This was repeated monthly, for three months, resulting in a total of 270 traps per year being set. The traps were placed in a line transect, one metre between each. A line transect was used because grouping the traps close together could have resulted in a lack of independence in the sampling. Each trap consisted of a 120ml plastic pot, which was placed into a hole dug into the soil such that its rim was flush with the ground level. Each pot was then 1/3 filled with a solution of 70% ethanol and glycerol in a ratio of 9:1 respectively. Ethanol was used to preserve any captured invertebrates and the glycerol caused them to sink and also helped to reduce the evaporation of the alcohol (A. Douglas pers. comm.).

Since the traps were left in place for a relatively long time, washout by excessive rain had to be prevented. This was achieved with the aid of petri dish lids attached to four wooden stakes. In tests carried out prior to a field season, sample pots were set up in a garden. Some pots had covers placed a few centimetres above them (achieved by inserting the wooden stakes into the soil) and some were left with no covers.

Both treatments were equally as effective at capturing invertebrates, but none of the pots with covers suffered from washout, whereas the majority of those without did. Therefore, each pitfall trap set out on the study site had a petri dish cover placed a few centimetres above its rim.

In order to gain a broad-scale indication of the relative abundance of potential prey items among different habitats, invertebrates were identified to order. The contents of each pitfall trap were placed under a binocular microscope. All inorganic material and vegetation debris were removed from the sample and each invertebrate was identified with the aid of a key. A piece of 1mm squared graph paper was placed under the sample and each invertebrate had its length measured. This was carried out to determine whether there was any variation in the numbers of different sized invertebrates in each of the different habitats.

Determination of Tipulid abundance using transects

From visual observations and from studies of other wader species (e.g. Dotterel, Galbraith *et. al.* 1993, Black-tailed Godwit *Limosa limosa*, Beintema *et. al.* 1991 and Golden Plover, Whittingham 1996), Tipulids were known to be important prey items of chicks. Pitfall traps are designed to trap surface active invertebrates and were therefore inappropriate to assess Tipulid abundance in each habitat.

Water traps have been used in other studies to assess flying arthropod abundance in different habitats (e.g. Usher 1990). However, this technique can be relatively intensive as traps need to be set and collected frequently (traps cannot be covered to prevent wash-out by precipitation) and the invertebrates in the samples identified. This method also has inherent problems which need to be taken into account. For example, the height the trap is set above the canopy and the colour of the traps can influence what is caught (Usher 1990).

Since it was Tipulid abundance alone which was to be assessed, transects were chosen as the sampling method. Tipulid transects had also been used successfully in other studies (e.g. Galbraith *et. al.* 1993 and Whittingham 1996) and could be carried out rapidly, with no lab based invertebrate identification (which would have been necessary if water traps were used).

Tipulid transects were carried out weekly in each of the nine major habitat types following the basic method of Galbraith *et. al.* (1993). This was a rapid method for collecting data on Tipulid abundance and involved placing out five sets of two marker posts, ten metres apart, in each of the nine habitats. These transects were then paced slowly from one post to the other. The vegetation was also disturbed to one metre either side of the transect with a metre rule, and the numbers of Tipulids observed were counted. Tipulid transects were carried out in each of the nine major habitat types on a weekly basis from the time of emergence (variable from year to year).

Analysis of data

From observations of chicks it was apparent that they were largely visual predators. While feeding, chicks were observed suddenly changing direction and darting for prey items and they were also observed attempting to catch Tipulids from the air. It was concluded, therefore, that larger motile invertebrates were likely to constitute a major part of their diet, being relatively more visible than smaller or more sessile species (also found for Black Godwit chicks (Beintema *et. al.* 1991)). Therefore the numbers of individuals in each size class were compared between habitats. Size class numbers, rather than biomass, were compared because the habitat with the largest biomass may not always result in the largest number of individuals of "optimum" sized prey items. For example, a high biomass in one habitat may be due to a vast number of tiny invertebrates that are below a size threshold which determines whether they will be consumed (they may be too small to be observed easily for example). A different habitat may have less biomass, but contain more individuals that fall within the size range of prey items.

Invertebrates were grouped into one of three size categories. The size range in each size class were kept as close as possible to 10mm ranges (e.g. 1mm-10mm) because most invertebrates were between 1-30mm and three size classes were compared (30/3=10). However, to satisfy the criteria for Chi-square analysis (none of the expected values should fall below 1 and no more than 20% should fall below 5 (Fowler and Cohen 1988)), the size ranges had to be adjusted by 1 or 2mm. The size categories used were;

1. Small

Invertebrates in this class were between 3mm and 10mm in size. (Those invertebrates less than 3mm were mainly Acari (mites) and Collembola (springtails) and were considered unlikely to be prey items on the basis of their size and lifestyle (generally in soil). There was also no evidence of either in the faeces of chicks.

2. Medium

Invertebrates in this size class were between 11mm and 18mm.

3. Large

Invertebrates in this size class were between 19mm and 30mm. The vast majority (>99%) of the invertebrates captured were less than 30mm and the several individuals (mainly Coleoptera) which were above this size were not included as they were considered too large for a chick to consume.

Only the orders known to be consumed by chicks were used in the analysis. It should be noted however, that these orders made up the vast majority of the invertebrate numbers, so little data were discarded.

Initially, the mean numbers of invertebrates per trap were compared, but it was found that several of the expected values fell below 1 (particularly in the large size class). Rather than group size classes (which still did not totally eradicate the problem), the total numbers of invertebrates caught from the ten traps in each habitat were used as the basis of comparison. For those habitats that had missing traps, the mean number of invertebrates per pot was calculated. This value was multiplied by the number of missing pots and added to the total number of invertebrates for that habitat to produce a total for a standardised number of pit-fall traps.

Since it was first suggested by Lack (1954), a number of studies have shown that breeding is timed to coincide with the period of peak prey availability (see Perrins 1970 and Perrins & Birkhead 1983 for example). Therefore invertebrate abundance in each size class was compared between sampling periods, to determine if it peaked when chicks were active (the results of which will be discussed in chapter 5).

Results

Faecal analysis

Faecal analysis showed that Curlew chicks fed on a range of invertebrate orders, particularly beetles and crane flies (table 3.1).

Table 3.1. Invertebrates identified as chick prey items using faecal analysis

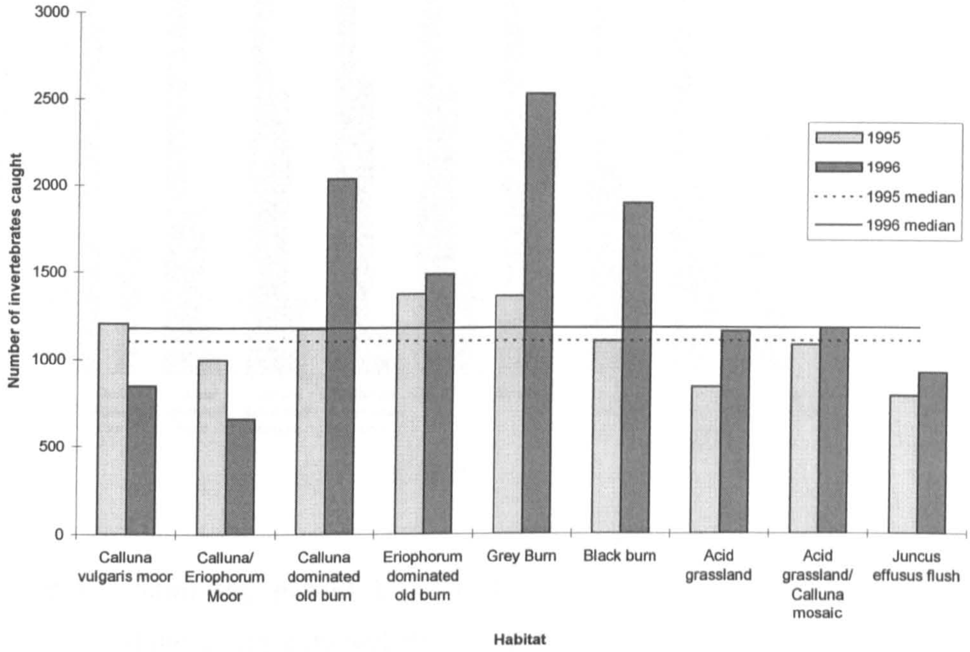
Taxa	Number of samples containing taxon (N=13)
Araneae (Spiders)	2
Coleoptera (Beetles)	12
Coleoptera larvae	2
Diptera (mainly Tipulids) (Crane flies)	7
Hemiptera (Bugs)	1
Hymenoptera (ants and wasps)	2

As the number of faecal samples obtained was small, a more detailed analysis was regarded as inappropriate (i.e. results only give a broad indication of diet).

Determination of invertebrate prey availability in each habitat and through time using pitfall traps

Invertebrate abundance in each habitat, as identified by pitfall trapping, is shown in figures 3.1-3.7. Tipulid abundance in each habitat, as identified by transects can be seen in figure 3.9. The timing of peak prey abundance is shown in figure 3.8 and 3.10 for pitfall traps and Tipulid transects respectively. It should be noted that the numbers of invertebrates were converted to a log scale in figures 3.2-3.7 so that each bar on the charts was clearly visible. Before log transformation the range of invertebrate numbers between size classes was so large that bars for both medium and particularly large invertebrates were difficult to read with any accuracy.

Figure 3.1. Summary chart of standardised total number of invertebrates captured in each habitat in 1995 and 1996. Note that the horizontal lines on the following charts represent the median of all habitats.



The numbers of invertebrates caught in each habitat type were found to vary significantly between habitats for both years (χ^2=299, df=8, p<0.001 in 1995 and χ^2=2211, df=8, p<0.001 in 1996).

To look at invertebrate numbers on a more detailed scale, the total was split by size classes and by sampling period. Figures 3.2. to 3.7. compare invertebrate numbers in each size class in each habitat sampled, in each sampling period. The horizontal lines represent the median numbers of individuals caught in each size class for that sampling period.

Figure 3.2. Sampling period 1 (mid-April to mid-May 1995).

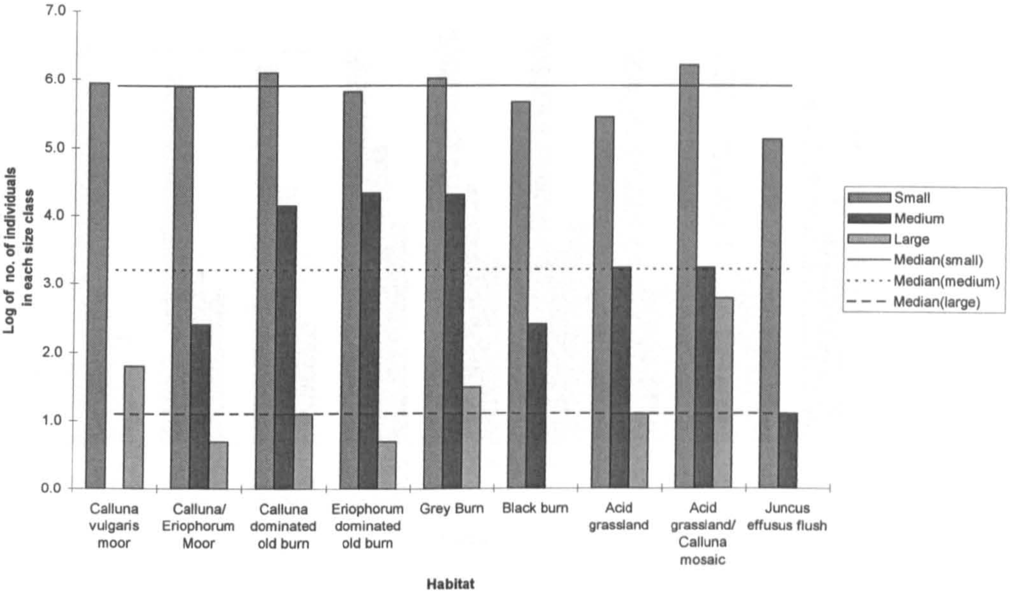


Figure 3.3. Sampling period 2 (mid-May to mid-June 1995). Note Calluna dominated old burn, grey burn and black burn are absent due to traps being excavated by foraging sheep.

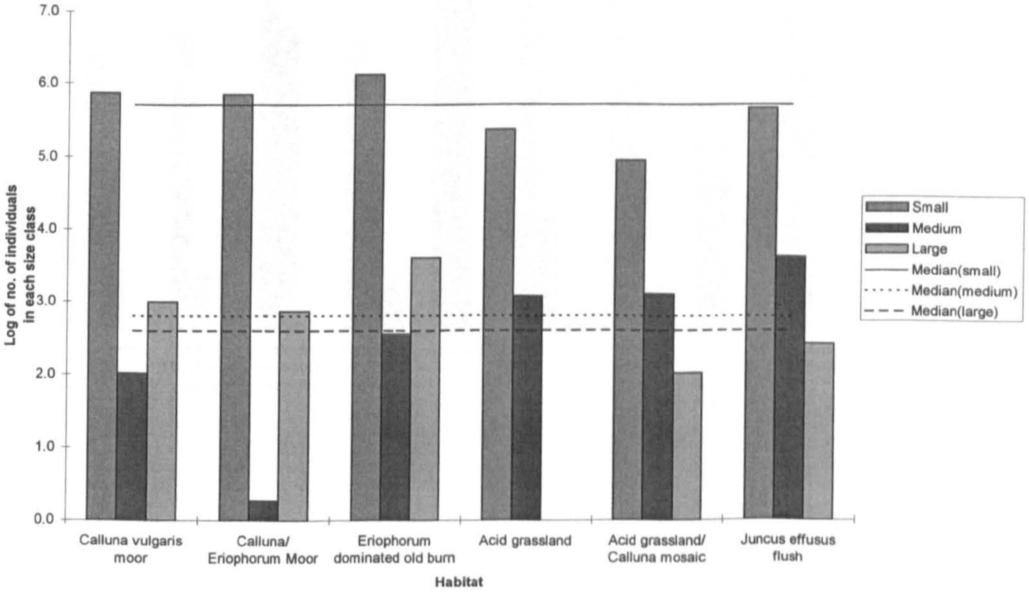


Figure 3.4. Sampling period 3 (mid-June to mid-July 1995).

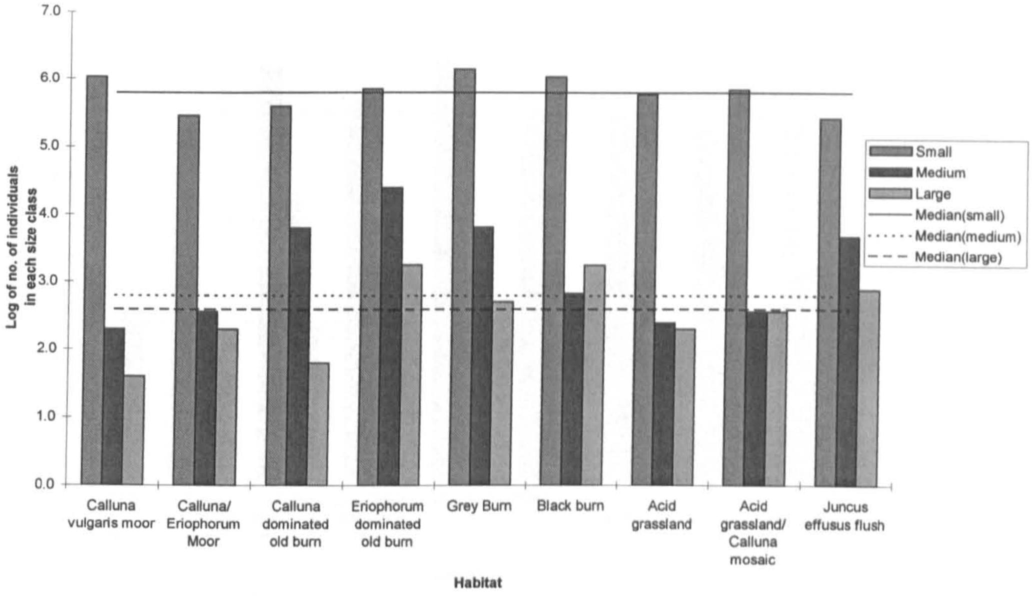


Figure 3.5. Sampling period 1 (mid-April to mid-May 1996).

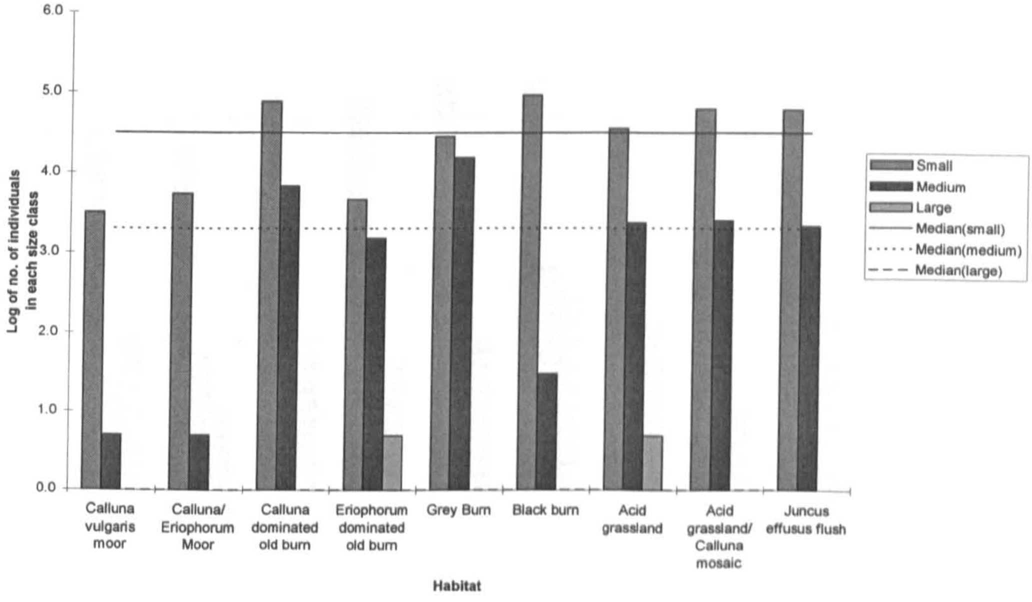


Figure 3.6. Sampling period 2 (mid-May to mid-June 1996).

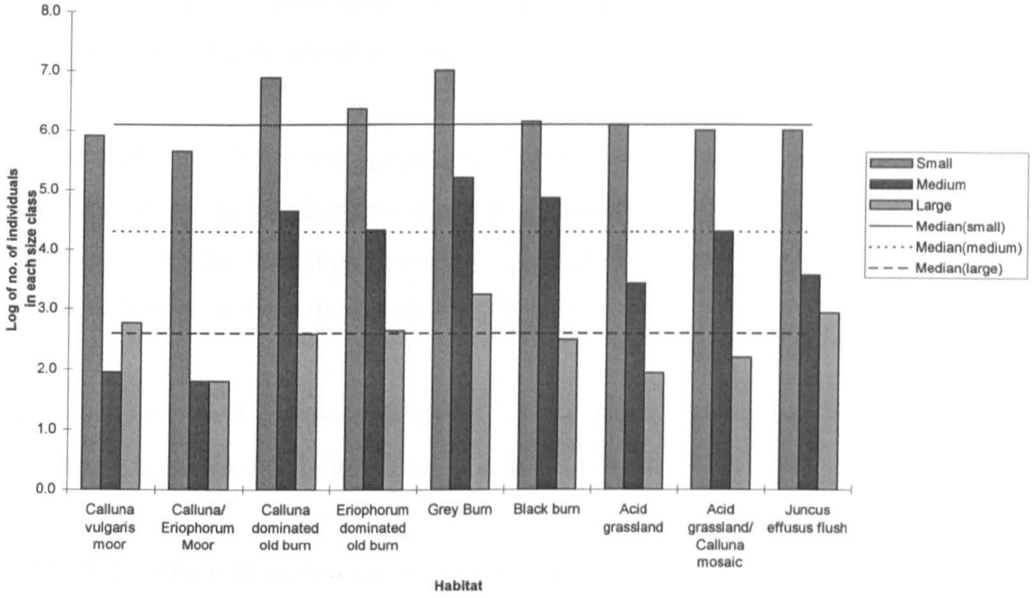
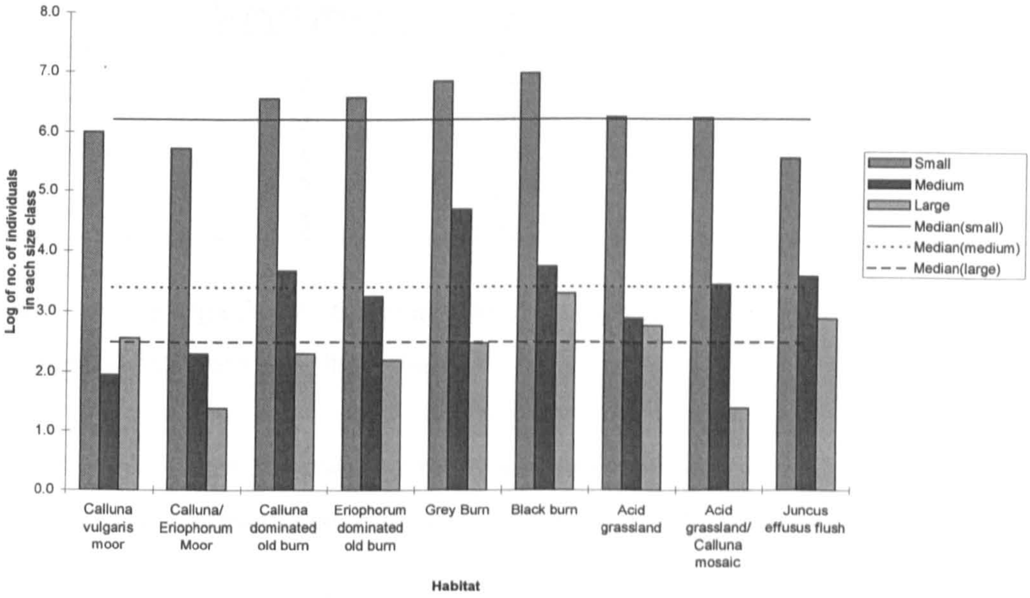


Figure 3.7. Sampling period 3 (mid-June to mid-July 1996).



The main points to note from figures 3.1-3.7 were that the order of invertebrate abundance in each size class was small>medium>large and overall, invertebrate abundance was greatest in grey burns (fig 3.1). In general, grey burn invertebrate abundance was above the median in each size class in each of the sampling periods (figs 3.2-3.7). Heather dominated old burns also had relatively high invertebrate abundance (fig 3.1), with small and medium size class abundance generally being above the median throughout the sampling periods (figs 3.2-3.7).

Invertebrate abundance was generally lowest in each size class throughout each sampling period in Heather moor, Heather/Cotton grass moor and flushes (though this was always the case (figs 3.2-3.7)). The overall invertebrate abundance was also generally lowest in these three habitats (fig 3.1).

The results of the Chi-square analysis, testing for differences in total invertebrate abundance between different habitats can be seen below in table 3.2.

Table 3.2. Overall summary of the χ^2 results testing for differences in total invertebrate abundance between habitats in each sampling period. Note *** p<0.001, ** p<0.01, *p<0.05, n.s. = not significant

Year	Sample period	χ^2	d.f.	Significance
1995	1	522	8	***
	2	307	5	***
	3	361	8	***
1996	1	313	8	***
	2	1598	8	***
	3	1270	8	***

There was a significant difference between invertebrate abundance in different habitats during every sampling period

Tables 3.3-3.5. show the results of the χ^2 analyses from each sampling period, testing for differences in invertebrate abundance between habitats for each size class.

Table 3.3. Sample period 1

Year	Size class	χ^2	d.f.	**Significance**
1995	Small	249.09	8	***
	Medium	232.19	8	***
	Large	40.82	8	***
1996	Small	162.10	8	***
	Medium	141.94	8	***
	Large	8.59	8	ns

Table 3.4. Sample period 2

Year	Size class	χ^2	d.f.	**Significance**
1995	Small	206.60	5	***
	Medium	48.01	5	***
	Large	52.09	5	***
1996	Small	1178.60	8	***
	Medium	396.05	8	***
	Large	23.04	8	**

Table 3.5. Sample period 3

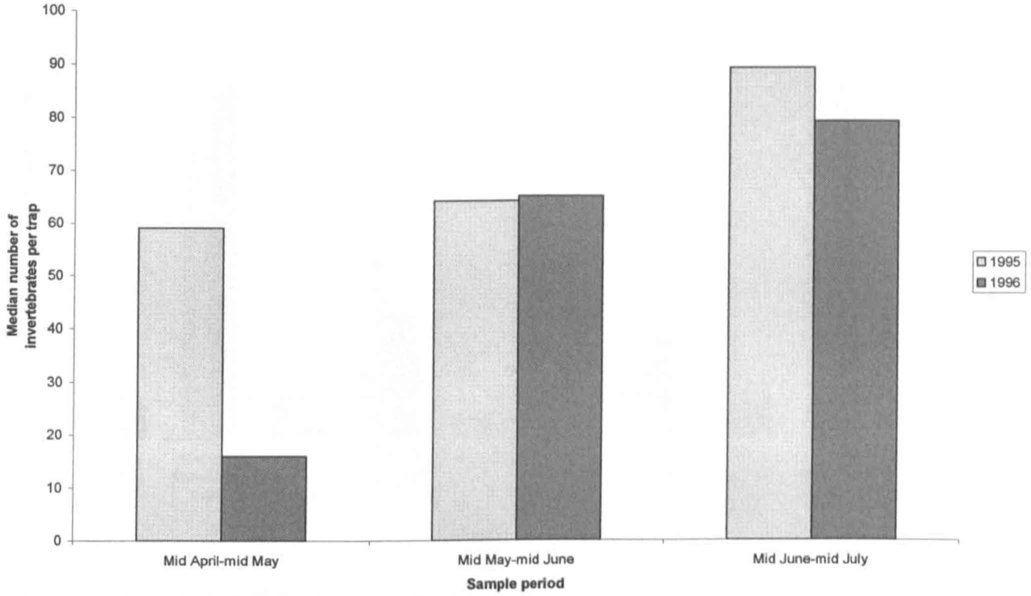
Year	Size class	χ^2	d.f.	**Significance**
1995	Small	171.41	8	***
	Medium	155.54	8	***
	Large	33.71	8	***
1996	Small	1029.63	8	***
	Medium	207.64	8	***
	Large	33.03	8	***

There was a significant difference in invertebrate abundance between habitats and this was observed for all size classes except for large invertebrates in sample period 1.

Investigation of variation in invertebrate abundance through time using pitfall traps

Variation in invertebrate abundance through time was investigated to determine if there was a link between timing of the breeding season and peak invertebrate abundance.

Figure 3.8. Change in invertebrate abundance through time.

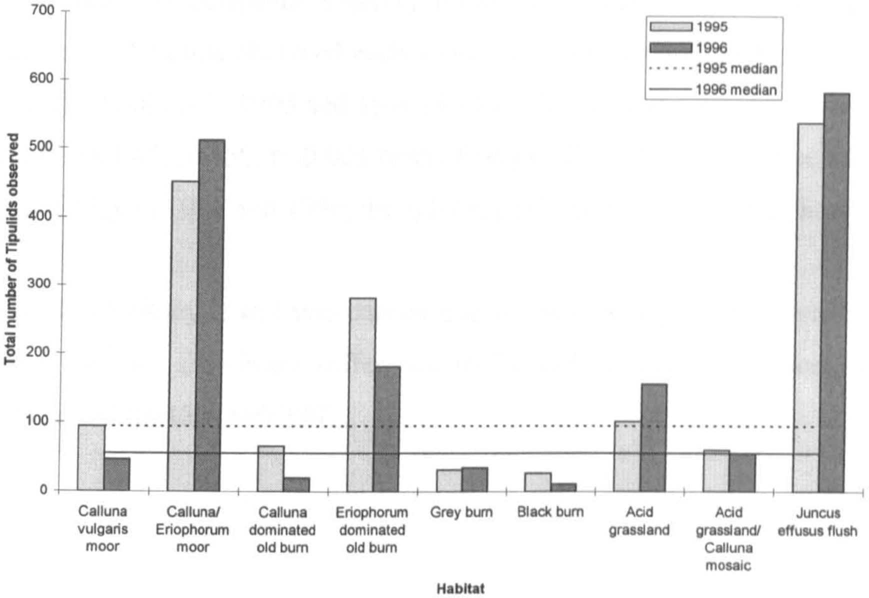


There was a significant difference in invertebrate abundance between sampling periods in 1995 and 1996 (Kruskal-Wallis tests, H=16.53, n=209, p<0.001 and H=126.43, n=265, p<0.001).

Investigation into Tipulid abundance between habitats and through time

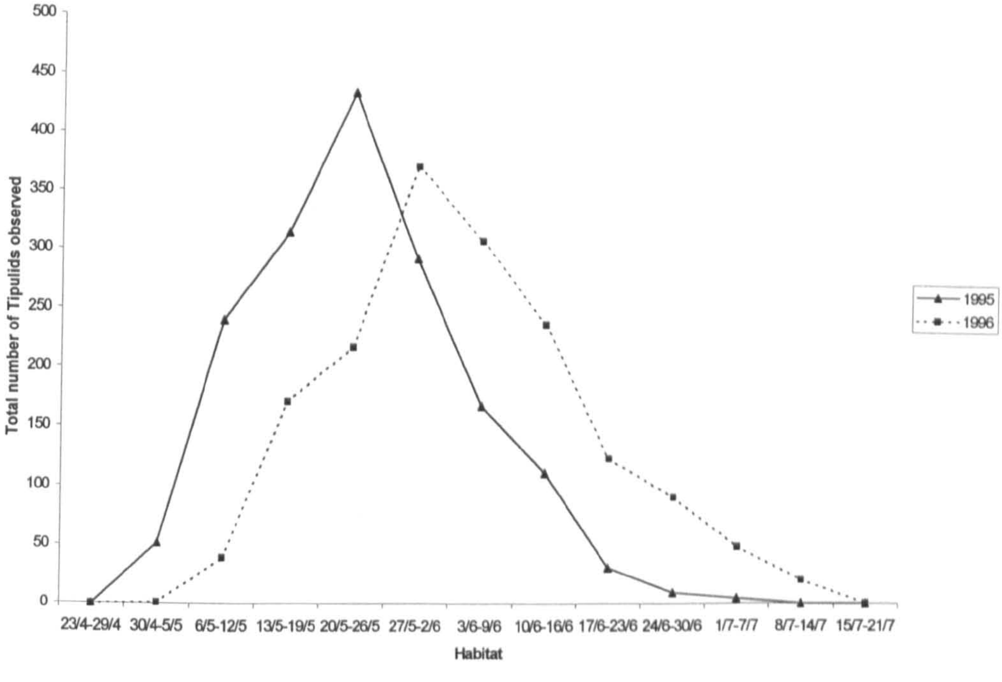
Tipulid abundance in each of the different habitats was investigated to determine whether Curlew chicks selected habitats on the basis of prey (Tipulids could not be effectively sampled using pitfall traps). Tipulid abundance through time was also investigated to determine whether the timing of peak abundance coincided with the timing of hatching.

Figure 3.9. Number of Tipulids observed in each habitat during 1995 and 1996.



The numbers of Tipulids were found to vary significantly with habitat type (Kruskal-Wallis tests, H=106.14, n=450, $p<0.001$ in 1995 and H=177.20, n=450, $p<0.001$ in 1996). Tipulids were most abundant in the damper habitats of the moor, i.e. *Juncus effusus* flushes and areas *of Calluna vulgaris/ Eriophorum vaginatum.*

Figure 3.10. Total number of Tipulids per sampling week in 1995 and 1996.



Kruskal-Wallis tests were carried out on the Tipulid data for 1995 and 1996 respectively to determine whether there was a significant difference between the number of Tipulids observed each week. The was a significant difference in weekly Tiplulid numbers in 1995 and 1996 (Kruskal-Wallis tests, H=169.52, n=450, p<0.001 and H=104.44, n=450, p<0.001 respectively). Tipulid abundance peaked towards the end of May in 1995 and 1996, though the peaks were a week apart between years.

A Mann-Whitney U test was carried out to compare Tipulid numbers between years. There was no significant difference in Tipulid abundance between years (Mann-Whitney U=98125, p=0.3987).

Discussion

Faecal analysis

Insufficient data were obtained to reliably determine the proportion of the diet that each taxon contributed. However, determining the proportion of the diet can be misleading as the taxon which appears to contribute the largest proportion to the diet, may not necessarily be the preferred prey. Rather, the proportion of the diet made up by one taxon may reflect the availability of that taxon rather than a preference for it. This has been shown to be the case with Lapwing chicks (Galbraith 1989), which fed on more surface active invertebrates when soil invertebrates were less abundant and were concluded to feed opportunistically rather than selectively.

However, the most important finding from the faecal analyses was the determination of which invertebrate taxa were consumed, to allow the comparison of habitat selection and total prey abundance.

Invertebrate abundance in different habitats

The results indicated that there was a significant difference between invertebrate abundance in the different habitats. Pitfall trapping indicated that grey and old burns generally had the greatest invertebrate abundance. Those habitats that had the least invertebrate abundances were Heather moor, Heather/Cotton grass moor and Soft Rush flushes. The fact that the two Heather dominated habitats had the lower invertebrate abundances was not totally unexpected since much of the fauna was likely to be found within the dense canopy rather than at ground level where there was no under-story vegetation. However, the finding that invertebrate abundance was low in Soft Rush flushes was not expected since this habitat is often quoted as being rich in invertebrates and as such provides good foraging areas for grouse and wader chicks (English Nature 1996, Hudson 1992 and Whittingham 1996).

However, Tipulid abundance was found to be highest in Soft Rush flushes, followed closely by Heather/Cotton grass moor. Tipulidae tend to be most abundant in wetter areas, which provide suitable larval habitat (Coulson 1959). Therefore, this result was to be expected since the two habitats most abundant with Tipulids were the wetter of the habitat types on Monk's Moor.

Tipulids are well documented as being an important food source of Grouse and wader chicks (Grant *et al* 1992(b), Galbraith *et al* 1993, Whittingham 1996 and Lindsay Waddell pers. comm.) due to their nutritional value and relative ease of capture (Galbraith *et al* 1993). Therefore, Tipulid abundance may be the major draw of foraging chicks to a particular habitat rather than the abundance of other invertebrates.

The implications of these results will be discussed in relation to chick habitat selection in Chapter 5.

Invertebrate abundance through time

In both years of the study there was a significant difference in invertebrate abundance (as assessed by pitfall traps) during each sampling period, with a general increase in abundance from early to late in the season. There was also a significant difference in Tipulid abundance between sampling periods during both years, with abundance increasing to a peak towards late May/early June and then declining again.

Whittingham (1996) observed similar patterns of invertebrate abundance to this study, finding that peak abundance coincided with peak hatching period of Golden Plover. Nethersole-Thompson and Nethersole-Thompson (1986), Baines *et al* (1996) and Green *et al* (1977) also found that timing of the breeding season of a number of precocial species coincided with peak prey availability.

The implications of these results will be discussed in relation to the timing of the Curlew breeding season in chapter 5.

CHAPTER 4.

NEST HABITAT SELECTION

Aims of Chapter

The major aim of this chapter was to determine whether Curlew select or avoid particular habitats in which to nest and to determine which characteristics of the preferred habitats influence selection. The consequences of nest site selection with regards to survival was also investigated.

Introduction

Before an area can be managed to benefit any species of interest, the ecological requirements of that species must be understood. One of the major aims of this thesis was to provide management prescriptions that could be implemented to provide suitable nesting habitats for Curlew. The question raised, however, is what actually constitutes suitable nesting habitat for Curlew? Once it has been established what constitutes suitable habitat, the next questions that need to be addressed are; a) which habitats are preferred, b) why are those habitats preferred and c) what are the consequences of selection.

Quantitative studies of Curlew nesting habitats have been carried out elsewhere, but mainly on farmland rather than upland habitats. Berg (1992) studied nest site selection on mixed farmland in Sweden and found that Curlew preferred to nest on grassland and fallow fields. Several studies on similar species have also been carried out elsewhere. Pampush and Anthony (1993) studied Long-billed Curlew *Numenius americanus* in Oregon, USA. They found that nest density was highest in Cheatgrass *Taeniatherum asperum* which was characteristically less dense than other habitats. Grant (1992) studied the effects of re-seeding heathland in Shetland and found that heathland was the preferred nesting site of Whimbrel, but no distinction was made between different vegetation communities within the heathland. Since these studies were either carried out on habitats not found in upland areas or their level of vegetation characterisation did not take different moorland communities into account, they provide little insight to nest habitat preferences of Curlew on upland moorland, a favoured habitat in Britain (Cramp *et al* 1983 and Nethersole-Thompson & Nethersole-Thompson (1986)).

As for British Curlew breeding in upland habitats, there are a number of general statements to be found in various species accounts in texts, but no quantitative studies of nest habitat selection have been published. Cramp *et. al.* (1983) reported that Curlew favour upland moors (rather than farmland), both grass dominated and Heather dominated, and that they nest in open burnt patches. The account also goes on to mention several other upland habitats in which Curlew will nest, including Bracken, rough grass fields and hay meadows, essentially covering the whole scope of upland habitats in Britain. Nethersole-Thompson and Nethersole-Thompson (1986) mention an equally comprehensive list of nesting habitats.

Haworth and Thompson (1990) and Stillman and Brown (1994) go into greater detail about breeding Curlew and habitat associations. However, nesting habitats were not identified by the location of nests alone. Both studies used census methods either the same as or similar to those described by Brown and Shepherd (1993). This method involved plotting the location of any bird that was either breeding (nest located) or suspected to be breeding (assessed by its behaviour) onto a map.

Identifying habitat preferences using such census methods is wrought with problems, however, since a Curlew could have walked several metres unobserved, crossing different habitats (Philipson 1954 and pers. obs.), before taking to the air. The Curlew could also have been merely loafing or feeding in the area where it was observed. Clearly, this method does not give an accurate determination of nest location. The definitive method of identifying nest habitat selection is by locating nests, since only then can the habitat be accurately identified.

The major management practice on grouse moorland is the use of fire to produce a mosaic of different aged Heather patches (see chapter 1). If quantitative data were collected on nest habitat selection/avoidance, particular habitats could be encouraged or discouraged by appropriate management to improve an area of moorland for Curlew. For example, Cramp *et. al.* (1983) and Nethersole-Thompson and Nethersole-Thompson (1986) both mention that Curlew will nest in recently burnt patches of Heather and therefore the provision of new burns may be of benefit to breeding Curlew.

Spatial features such as length and area may influence whether a burn is utilised as a nest site (for example there may be a minimum area below which Curlew will not nest in a burn). From a management perspective the area and dimensions of burns can be readily controlled and manipulated (as long as weather conditions such as wind speed and direction are suitable (L. Waddell pers. comm.)).

Since Curlew also tend to leave and return to the nest on foot (Philipson 1954 and pers. obs.) it may be beneficial for them to use the boundary between habitat types as cover. For example, if a Curlew was nesting in a relatively exposed burn surrounded by tall Heather it could leave the nest and walk directly to the edge of the burn. The Curlew would only be visible while walking between the nest and burn edge, as the tall Heather at the edge would obscure the Curlew from the vision of a distant observer (pers. obs.). The shorter the distance between the nest and the burn edge, the less the distance that a Curlew would be visible. Therefore we may expect to see most nests close to habitat boundaries (or other cover such as drainage ditches). This aspect is clearly important from a management perspective as the larger the burns, the more distant some areas become from the edge.

In general terms, the pattern of a habitat mosaic is not uniform across a moorland since where patches are burnt is largely dictated by weather conditions during the burning period (L.Waddell pers. comm.). Therefore if two or more sites are compared, or if different sections of one site are compared, each site or section is likely to have different habitats within the mosaic. Habitats that are common to different sites or sections may also have different areas and a different number of patches. If Curlew do prefer to nest in an area with a particular mosaic "make-up" (several burns, patches of flush and some acid grassland for example), this could again be manipulated by appropriate management and could therefore be utilised to benefit breeding Curlew. If the particular features of a habitat mosaic influenced

Curlew, this could be used to predict where it is most likely that Curlew will be on a moor.

As for the reasons for, and consequences of, habitat selection, predation risk reduction is an important aspect, since nest predation is likely to be the most significant cause of reproductive failure (Martin 1988 and Côté & Sutherland 1995).

Other studies have found a relationship between habitat selection and a reduction in predation risk. For example, Whittingham *et al* (in prep.), found that Golden Plover showed a preference for nesting on plateaux areas rather than slopes and that nest survival rates were higher on the former. The higher survival rate on plateaux was considered to be attributable to better all round visibility than on slopes. Having good visibility allowed incubating birds to leave the nest at a greater distance from an approaching predator and hence reducing the risk that the nest was found (Whittingham *et al*, in prep.). Other studies have also found an association with slope and nest habitat selection of upland breeding waders (Haworth and Thompson 1990 & Stillman and Brown, 1994).

Since Curlew are a ground nesting species that lay eggs in a relatively exposed scrape, they can be prone to predation (though not necessarily more prone to predation than non ground nesters (Côté & Sutherland 1995)). Curlew eggs and those of other ground nesting waders such as Golden Plover, Dunlin and Lapwing are prone to predation from a number of animals. In particular, Foxes, Stoats, Weasels *Mustela vulgaris*, Carrion Crows, Rooks *Corvus frugilegus* and gulls such as Lesser Black-backed Gulls *Larus fuscus* pose a threat to eggs (Berg 1992a, Parr 1993, Whittingham 1996, Parish & Coulson in prep, M. Grant & L. Waddell pers. comm.)

Since Red Grouse are ground nesters they suffer from similar predation problems as Curlew (though grouse have the advantage of reducing their scent production while incubating, therefore reducing the likelihood of detection by predators on the ground (Dobson & Hudson 1994)). Therefore, part of the management regime on grouse moorland is the employment of gamekeepers who attempt to keep the number of predators under control (Watson & Miller 1977). Gamekeeping should therefore benefit the nest survival of other species which breed on grouse moorland. A reduction in gamekeeping has been implicated as a possible cause of the decline in the numbers of Black Grouse in some areas of Britain (Baines 1991). D. Baines (pers. comm.) has also suggested that the maintenance of gamekeeping is a possible reason behind the healthy populations of Black Grouse found in some areas of Northern England.

In summary, this chapter aimed to fill gaps in current knowledge of Curlew by providing quantitative data on nest habitat selection and by investigating the consequences of habitat selection from the point of view of nest survival. This information could then be used to provide a basis for the production of a series of management prescriptions (chapter 7). The management prescriptions produced could be utilised by land owners and land managers for the benefit of Curlew, a primary aim of this thesis (see chapter 1).

Methods

Proportion of nests found

To determine nest site preference/avoidance, one would ideally locate every nest on a study site. If some nests are not located, a bias in apparent habitat preferences/avoidances can result. Take, for example, a site composed of two habitats in equal proportions. If only 40% of nests were located and of these, 80% were in habitat (a) and the remainder were in habitat (b), then it could appear that there was a preference for habitat (a) and an avoidance of habitat (b). If however, all of the remaining 60% of the nests were located in habitat (b), then clearly the initial result of an apparent avoidance of habitat (b) would be incorrect.

While it would be ideal to find every nest on a study-site, it is probably not likely. Therefore an estimate of the proportion of nests located was carried out. Estimates of the number of breeding pairs were calculated by adding the actual number of nesting pairs found to the number of other possible nesting birds for which a nest was not located. Curlew were determined as being breeding birds by their behaviour (display flights and consecutive sightings within the same area for example). The estimated proportion of nests found was then calculated for each site using the actual number of breeding pairs and the estimated number of breeding pairs.

Finding nests

Most nests were found by scanning ahead while walking across a moor, and intensively searching any area from where a Curlew was flushed. This method was most successful in undulating terrain, where Curlew would often be flushed at relatively close distances as an observer walked over a rise. However, large areas of the three study sites were relatively flat and it was more difficult to locate nests in these areas. In such areas incubating Curlew usually flushed at distances in excess of 500m, making it difficult to pin-point where the bird flew from. To complicate matters further, at the first sign of approaching danger, either from observation or a warning call from other waders, incubating Curlew often walk quickly from the nest with their head down, utilising natural cover (Philipson 1954 and pers. obs.). It is only when the Curlew is some distance from its nest that it takes flight. Therefore, when attempting to locate nests on areas of flat terrain a hide was used to observe Curlew returning to a nest.

Another method utilised when the exact location from where Curlew rose was not identified was to hide in a gully or other suitable cover for around thirty minutes. In this time the incubating adult had usually returned to the nest area and could be flushed for a second time, allowing the nest location to be more accurately pinpointed. This technique proved very efficient, with the majority of the nests of re-flushed Curlew being located.

The maximum number of nests located in one day was achieved on Langlydale Common. This was largely due to the fact that a car could be used as a hide to locate nests. Langlydale Common was trisected by two roads that allowed a car to be driven through the study site to various vantage points, from where birds could be flushed and then observed returning to the nest.

However, nest finding by two people was generally found to be the most efficient method. As well as increasing (doubling) the likelihood of observing a flushed Curlew, two people could also search the area of departure more rapidly. Additionally, one observer could look to the right and the other to the left when rising over a hill, increasing the area of view that could be observed.

When a nest was located its location was recorded so that it could be monitored throughout the incubation period. Where possible natural markers such as rocks or fence posts were used as reference points to a nest. A compass bearing was taken from such reference points to the nest and the distance was measured (paces) so that the nest could be easily found again. Where natural markers were not available 50cm lengths of 1cm diameter dowel were inserted into the ground at least 30m from a nest. These marker posts relatively unobtrusive as they were not brightly coloured or flagged and had approximately half their length inserted into the ground. This reduced the likelihood as them being observed by predators, which could learn to use them as an indicator of a nest. In addition nests were not visited when any potential egg predators were observed in the vicinity of the nest and any vegetation that was disturbed when the nest was visited was restored so that no obvious trails to the nest were visible. These practices reduced the likelihood of the researcher being used by predators as a cue to a food source (eggs).

In summary, a single observer searching over an area of moorland can readily locate nests. However, the efficiency of nest locating was found to increase with the utilisation of a hide from where birds could either be re-flushed or observed returning to the nest. The efficiency of nest locating was found to increase further if two observers carried out the searches.

Data recorded on nest location

To determine nest habitat selection, the available area of each habitat was measured (see chapter 2) and the number of nests in each habitat recorded. Then, to gain an insight into the factors that influenced nest site selection, a series of quantitative measures of the habitat were taken when a nest was located. A 2m by 2m quadrat (following the NVC classification methodology (Rodwell *et al* 1991)) was placed around the nest (with the nest at its centre) and the following features recorded:

1) **Habitat type** - to determine nest habitat preferences of Curlew.
All plant species were identified and their cover estimated using the DOMIN scale (Rodwell *et al* 1991). Nest habitat was assigned to one of the habitat categories identified in chapter 2 on the basis of the dominant plants within the quadrat (see chapter 2 for details).

2) **Vegetation height** - to determine whether Curlew were selecting a specific nest site within a habitat type on the basis of vegetation height.
Ten vegetation height measurements (tallest plant in contact with vertical metre rule) were taken from random points within the nest quadrat and ten vegetation height measurements were taken from random points outside the quadrat (within the same habitat patch).

3) **Distance to next nearest habitat** - to determine whether Curlew showed a preference for being close to the edge of a habitat type. The rationale behind this was that, since Curlew tend to leave and return to the nest on foot (Philipson 1954 and pers. obs.), the boundary between different habitats might provide cover from approaching predators. This is best visualised if the case of a nest in a burn, surrounded by tall Heather, is considered. There is little cover from vegetation in the burn, but if a Curlew was relatively close to the edge it could walk along the Heather boundary, using it for cover.

4) **Index of slope** – to determine whether Curlew showed a preference nesting on a plateau or a slope. Nests were categorised as being on a plateau (<5°) or a slope (>5°) as Curlew may show a preference for nesting on a plateau. The rationale behind this was that the observation of a predator, approaching from behind a slope face, would be impossible until it breached the hill rise (nests were easier to locate if approached over a rise – see previous section). Therefore all round visibility to observe approaching predators would be greater on a plateau.

5) **Measurements from eggs** – the length and breadth of each egg was measured on the first visit, and weighed on all visits to predict hatch date (by estimating their state of development (Hoyt 1979)). Hatch dates were predicted so that nests could be visited before chicks left them (see chapter 5).

Habitat utilisation by nesting Curlew

Habitat utilisation, in terms of both selection and avoidance, was investigated by comparing the utilisation of each habitat with the availability of each habitat, using Chi-square analysis. The number of nests in each habitat was compared to the number of nests that would be expected in each habitat if they were distributed according to habitat availability (see results in Chapter 2 for habitat availability). The rationale behind this was that if Curlew had no nest habitat preferences (i.e. nests distributed randomly), more nests would be expected in those habitats that were more widespread.

Investigation into burn size as an influence on its selection as a nest site

Spatial features of burns were investigated to determine what influences the selection or avoidance of a burn by Curlew.

The area, length, width and perimeter of every burn was measured directly from the computerised habitat maps (see methods in Chapter 2) using *PC Image*. The burns were divided into two categories of occupied and unoccupied. Differences between the spatial variables of occupied and unoccupied burns were examined using Mann-Whitney U tests. A logistic regression analysis was also carried out to determine whether any of the spatial features recorded had a significant effect on the probability of a burn being occupied. The logistic regression model, which is a multivariate technique for estimating the probability of whether or not an event will occur (in this case whether or not a burn will have a nest in it), was carried out using SPSS.

Occupied burns were also assigned to a size class (see results for classes) and a Chi-square analysis carried out to determine whether each class was utilised to the same proportion as they were available.

Distance of nests located in burns from edge

Burnt patches that contained nests were used to determine whether Curlew showed any preference for nesting near the edge of a habitat. The distance of a nest from the burn edge was measured in the field and the distance of the nest from the burn centre was measured using the habitat maps (see chapter 2 results) using *PC Image*. For each nest, the distance from the centre of its burn was compared to the distance from the edge of that burn.

Using habitat mosaic features to predict the presence/absence of Curlew

A logistic regression model predicting the probability that Curlew will breed on a patch of moorland on the basis of habitat mosaic features was carried out. Error plots of the model variables showing the upper and lower 95% confidence limits were included for those variables for which there was no overlap in the error bars (indicating a significant difference between the two "treatments").

The habitat mosaic features within sections of Monk's Moor and Langlydale Common were measured from the nest habitat maps (figures 4.1 and 4.2). A grid of 500m x 500m squares was used to section each map and the habitat mosaic features and the presence of nests in each were recorded. A 500m x 500m grid size was used because this was considered a "manageable" size with regards to providing the appropriate management on the ground. This is also the grid size adopted by the Brown and Shepherd (1993) survey method for upland breeding waders, allowing this method to be utilised in future to test predictions made by logistic regression analysis in this section.

The habitat mosaic variables recorded by direct counting from the habitat maps with the grid overlay were:

- Number of different habitat types.
- Number of different habitat patches (a patch being a habitat completely surrounded by different habitat(s)).
- Number of burnt patches.

The total area of burns in each grid was also recorded, which required the use of *PC Image*. A "region of interest" (ROI) was created individually around each grid square of the habitat maps. *PC Image* then calculated the total area of burns within each ROI.

Nest survival

Cox regression (Cox 1972) (also known as proportional hazards regression) is a commonly used medical statistic which was developed to allow the analysis of survival data which can often have two particular characteristics. One characteristic is that observations may be incomplete, i.e. in the case of medical patients, some individuals may be alive at the end of a clinical trial for example, and therefore the survival information is incomplete. The second characteristic is that the distribution of survival times can vary widely between diseases and mortality rate is not often even through time (Matthews and Farewell 1996). This second characteristic of survival data was the main reason for using this analysis technique to examine nest survival.

The more traditional analysis used to calculate nest success is the Mayfield method (Mayfield 1961 and Mayfield 1975). However, the Mayfield method assumes that mortality is even through time. While this may be true for some species (presumably Kirtland's Warbler *Dendroica kirtlandii* used in Mayfield 1961 and Mayfield 1975), for others it is not (e.g. Golden Plover (Whittingham 1996) and Mourning Dove *Zenaida macroura* (Woolfenden and Rohwer 1969)). There is little published data on whether Curlew egg survival rates are even through time, but it is possible that they are not. M. Grant (pers. comm.) suggested that trapping of adult Curlew on the nest should only take place towards the later part of the incubation period as desertion is less likely, probably due to the time investment and the lateness of the season at this stage. By inference, it may also be possible that Curlew are willing to defend their nests from predators more vigorously as the incubation period progresses and therefore survival rates may increase during the later part of incubation. Whether this is the case or not, to err on the side of caution, Cox regression was used as no such assumptions are made.

Cox regression was carried out on the data to examine whether any of several variables had a significant relationship with nest survival. This analysis allows the examination of the relationship between time to an event (predation in this case) and a set of independent variables (nest habitat and distance to nearest neighbour for example). Cox regression had the advantage over the Mayfield method in that it allowed all of the measured variables to be included in the analysis simultaneously. The final stage of the analysis indicated those variables that were significantly related to nest survival. The Mayfield method only allows nest survival to be compared between categories of one variable at a time (e.g. nest survival rates may be compared between different habitats). Therefore survival rates between different categories of each variable must be calculated one by one.

The output of the Cox regression analysis in SPSS is similar to that of a logistic regression. A list of variables which have a significant influence on nest survival are tabulated along with the relevant statistics. The inclusion of a time dependent variable in the model allowed for variation in nest survival rates throughout the incubation period for nests found partially through incubation.

The relationship between nest survival rate and any variable that had a significant influence on whether or not a nest was predated was examined using Kaplan-Meier survival curves (also known as Actuarial survival curves) (Kaplan and Meier 1958). Again, this is a well documented analysis technique used in medical research (see Matthews and Farewell 1996, for example) which graphically displays the summary of the survival experience of a group of individuals (survival curve) and calculates median survival times and standard errors (Matthews and Farewell 1996). In medical use, Kaplan-Meier survival curves are generally used as a pictorial representation of observed survival experiences (Matthews and Farewell 1996) and may be used in cases such as when examining the survival rates of groups of patients taking different medication to combat the same disease. In the case of this study, this analysis technique can be used to compare the survival curves (and median survival times) of nests in different habitats, for example.

Though these two analyses techniques have been used extensively over a relatively long time period in medical research, their use in other areas of research is less common. Why this should be the case is unclear, since carrying out survival analyses for any group, whether human patients or Curlew populations, is based upon the same principles and uses similar raw data. For example, in the case of human populations Kaplan-Meier survival curves may be used to compare mortality rates due to murder between major cities, whereas in Curlew populations mortality rates between different habitats may be compared. Clearly the raw data will be similar.

When carrying out survival analyses, a nest was described as being predated if any egg(s) went missing or were found consumed, otherwise nests were described as successful. All of the eggs of one nest were infertile and this was excluded from all survival analyses. The variables used to determine whether they had any influence on the likelihood of a nest being predated were:

1) Habitat type – included because nest predation risk may vary between habitats. Habitats were pooled as either "burns" or "other moor" (see nest habitat preferences in results for rationale behind choosing these two groups).

2) Distance of nest from a potential predator refuge – included because nest predation risk may be increased in nests close to a dry-stone wall or rocky outcrop since Stoats and Weasels use the cavities within them as refuges (pers. obs. and L. Waddell pers. comm.).

3) Distance to the nearest Curlew nest – included because nest predation risk may be reduced if there was another nest close by since there would be more Curlew to mob and distract a predator.

4) Whether a nest was situated on a plateaux or a slope (>5°) – included because all round visibility for approaching predators could be reduced if a nest was on a slope (a predator could approach a nest over a rise from close-by).

5) Nest cup vegetation height – included because nests that were situated in tall vegetation may have a reduced predation risk due to increased concealment.

6) Clutch size when nest initially located – included because those nests with clutches of one or two eggs may have been partially predated before the nest was found and may therefore have an increased chance of being revisited by the same predator.

Those variables that were linear distances were measured from the habitat maps using *PC Image*. Clutch size, nest cup vegetation height, slope and number of visible walls were taken in the field during nest visits.

Results

Number of nests located

Table 4.1. Number of nests located on each of the study sites. NS = not searched.

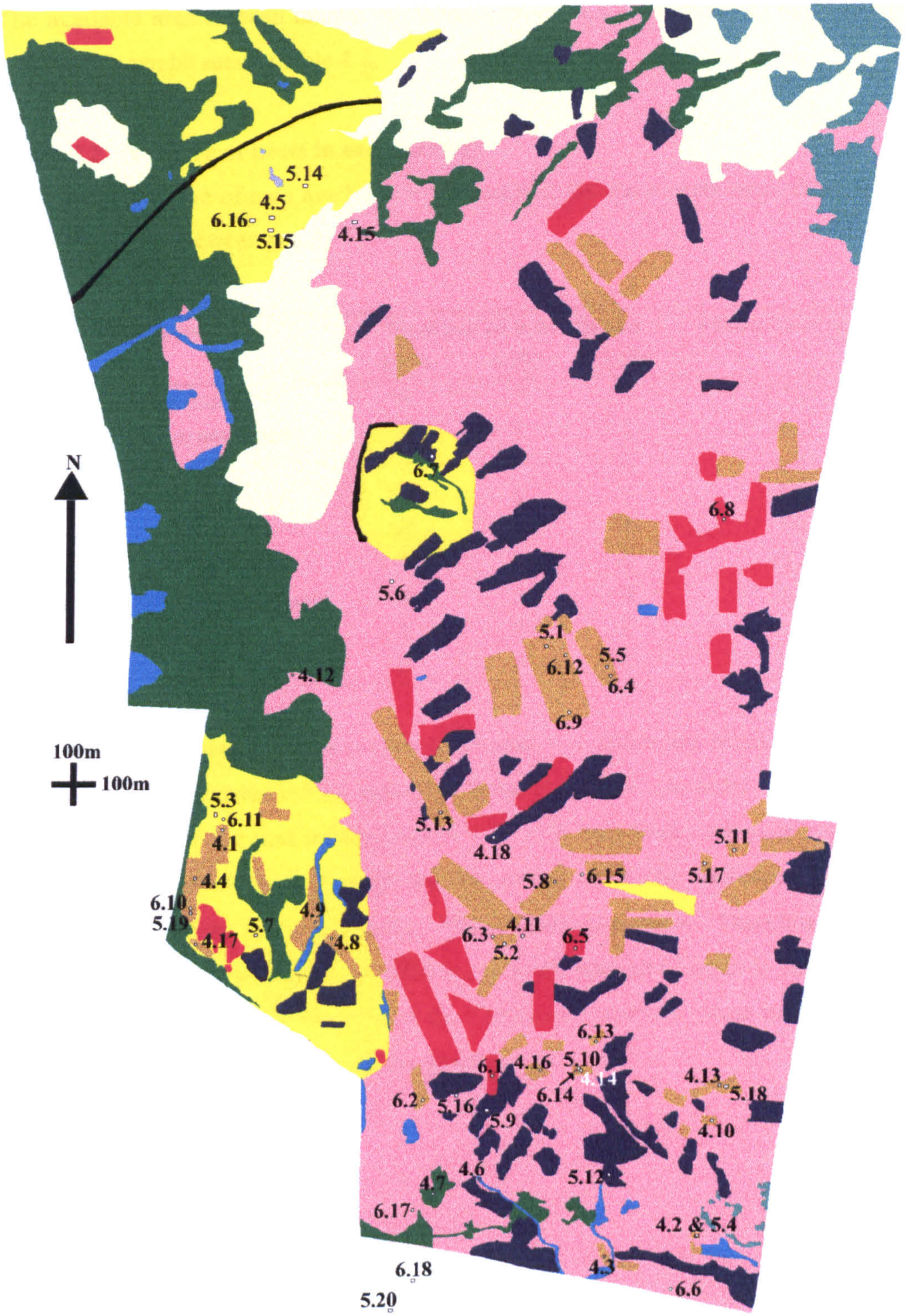
Year	Monk's Moor	Langdon Common	Langlydale Common
1994	17	3	NS
1995	19	3	NS
1996	17	NS	18
total	**53**	**6**	**18**

Since only six nests were located on Langdon Common, the sample size was too small to allow any analysis of habitat selection or nest survival to be carried out. Langlydale Common was used to test predictions from the Monk's Moor data.

Nest locations on Monk's Moor

Figure 4.1 shows the habitat map constructed for Monk's Moor with each nest found during the study period overlaid. Each point represents a nest and a two-figure number accompanies each point. The first number represents the last digit of the year in which it was found and the second represents the nest number (which simply reflects the order in which they were located). For example 5.4 represents nest four found in 1995).

Figure 4.1. Monks Moor nest location map (scale bar 100m). Note habitats as present in 1996. (See chapter 2 results for key)



Nest habitat selection on Monk's Moor

The available area of each habitat on Monk's Moor and the number of nests found within each can be seen in table 4.2.

Table 4.2. Number of nests in each habitat.

Note the percentage of area available is the mean of the three years since there were small variations between years.

Habitat	**Number of nests found**			**Mean % of area**
	1994	**1995**	**1996**	
Calluna vulgaris moor	4	3	3	51.5
Calluna/ *Eriophorum* moor	1	3	2	10.2
Old burn	0	0	2	6.7
Grey burn	0	5	7	2.1
Black burn	10	7	3	3.0
Acid grassland	1	0	0	15.4
Acid grassland/*Calluna* mosaic	0	1	0	8.2
Juncus effusus flush	1	0	0	1.0
Pteridium aquilinum	0	0	0	1.7

Since the sample size of nests located each year was relatively small, no detailed analyses could be carried out on data from individual years. In order to carry out a Chi-square analysis on nest habitat selection the nest data from each year needed to be pooled. However, pooling could only be carried out if the distribution of nests between habitats was not significantly different between years. Therefore, a Chi-square analysis was used to test for differences in the number of nests in each habitat between years. To satisfy the criteria for Chi-square analysis, some habitats were pooled, resulting in four groups. Those groups were:

1) *Calluna vulgaris* moor

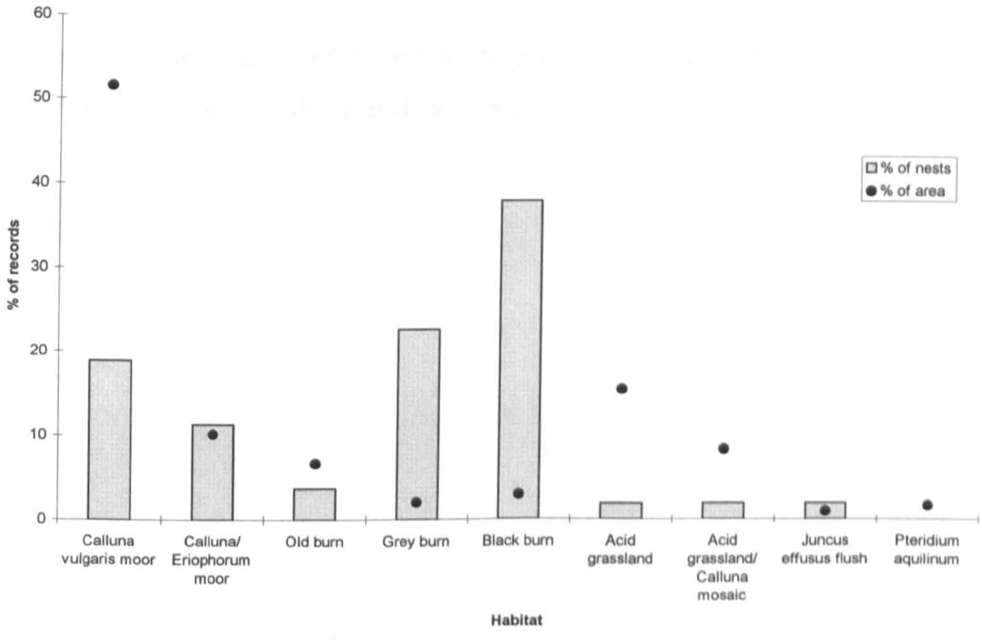
2) *Calluna/Eriophorum* moor

3) Burns- all burns

4) Other moor – remainder of habitats

There was no significant differences between the number of nests in each habitat group between years (χ^2=2.29, d.f=6, p>0.05). Since there was no significant difference, the nest data were pooled between years. It should be noted that pooling data across years could result in a lack of independence since the same individuals could select the same nest habitat each year. However, the observations that only one nest scrape was occupied in two consecutive years and the fact that the same birds have been found nesting in different habitats in different years indicated that the chance of lack of independence was likely to be minimal.

Figure 4.2. Comparison of the proportion of area each habitat contributes to Monk's Moor and the proportion of nests found within them



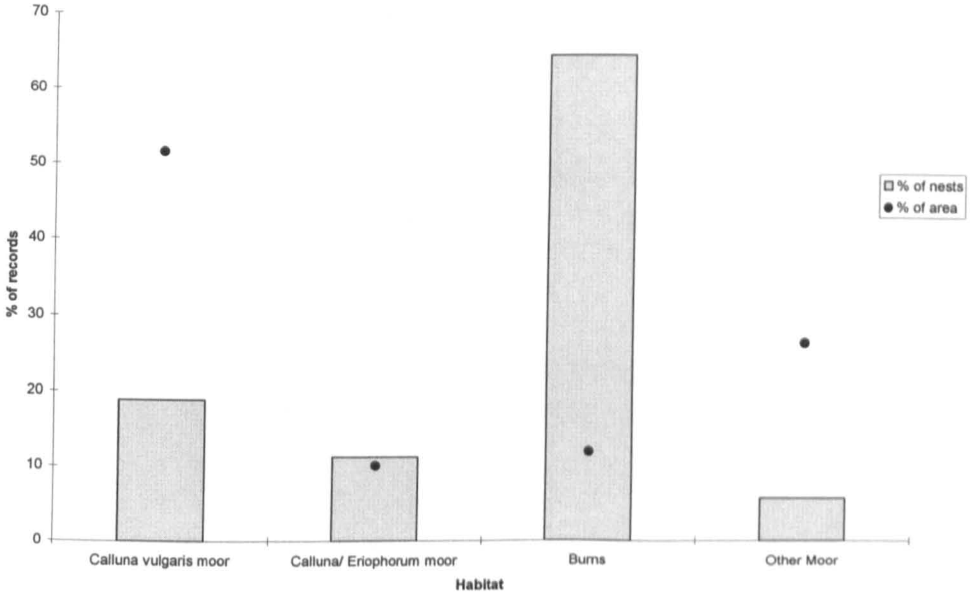
Chi-square analysis was used to determine whether there was any significant difference in the number of nests in each habitat. The numbers of nests in each habitat were compared to expected number of nests (derived by taking the proportion of available area of each habitat into account). This was to determine whether habitats were utilised as a nest site in the same proportion as they were available (i.e. a habitat with relatively little available area may be expected to have relatively few nests).

Since expected numbers were calculated using habitat availability, the expected numbers of nests for some of the less widespread habitats were below five. Therefore data were pooled into the same groups used for determining whether there was any difference in the numbers of nests between years (see table 4.3 below).

Table 4.3. Summarised habitat groupings for χ^2 analysis.

Habitat Group	Component habitat(s)	No. of nests	% of nests	% area
Calluna vulgaris moor	*Calluna vulgaris* moor	10	18.9	51.5
Calluna/ Eriophorum moor	*Calluna/ Eriophorum* moor	6	11.3	10.2
Burns	Old, grey and black burns	34	64.2	11.9
Other moor	Acid grassland, acid grassland/*Calluna* mosaic, *Juncus effuses* and *Pteridium aquilinum*	3	5.7	26.3

Figure 4.3. Comparison of the proportion of area each habitat group contributes to Monk's Moor and the proportion of nest found within them



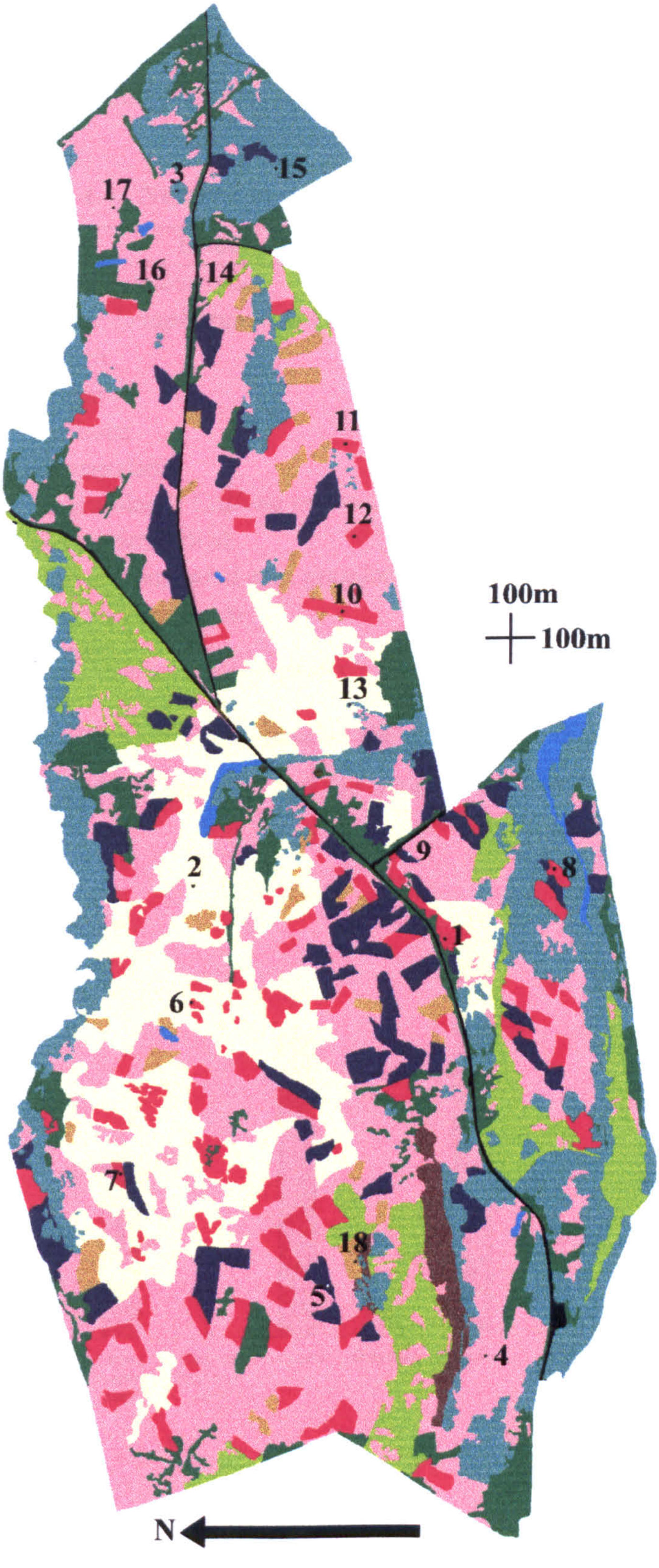
A significant Chi-square result was obtained demonstrating that Curlew were not utilising habitats to the same proportion as they were available (χ^2=141.3, d.f.=3, p<0.001) (i.e. some preference/avoidance of habitats was taking place).

Burns were utilised to a higher proportion than they were available and contributed 121.6 (86%) of the Chi-square result indicating a significant preference for these habitats. Heather moor was utilised to a lower proportion than was available and contributed 11.0 to the Chi-square value. Though not as spectacular as the burns result, this value alone would have given a significant Chi-square result ($p<0.05$) indicating an avoidance of older Heather moor by nesting Curlew. The avoidance of Heather moor should be treated with caution however since a marked selection of one habitat (in this case burns) can lead to an apparent avoidance of other habitats (Aebischer *et. al.* 1993).

Nest locations on Langlydale Common

Figure 4.4 shows the habitat map constructed for Langlydale Common with each nest found during the study period overlaid. Each point represents a nest, with the number representing the order in which it was found.

Figure 4.4. Langlydale Common nest location map.



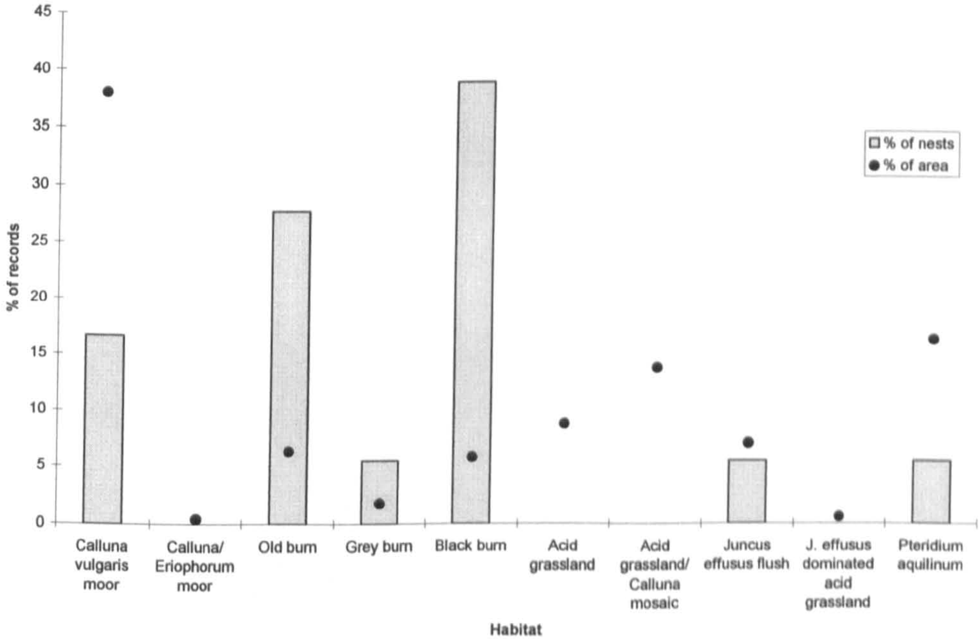
Nest habitat selection on Langlydale Common

The available area of each habitat on Langlydale Common and the number of nests found within each can be seen in table 4.4.

Table 4.4. Number of nests in each habitat.

Habitat	Number of nests	% of area
Calluna vulgaris moor	3	38.0
Calluna/ Eriophorum moor	0	0.5
Old burn	5	6.4
Grey burn	1	1.8
Black burn	7	5.8
Acid grassland	0	8.7
Acid grassland/ *Calluna* mosaic	0	13.7
Juncus effusus flush	1	7.1
J. effusus dominated acid grassland	0	0.6
Pteridium aquilinum	1	16.4
Bare earth	0	1.0

Figure 4.5. Comparison of the proportion of area each habitat contributes to Langlydale Common and the proportion of nests found within them.



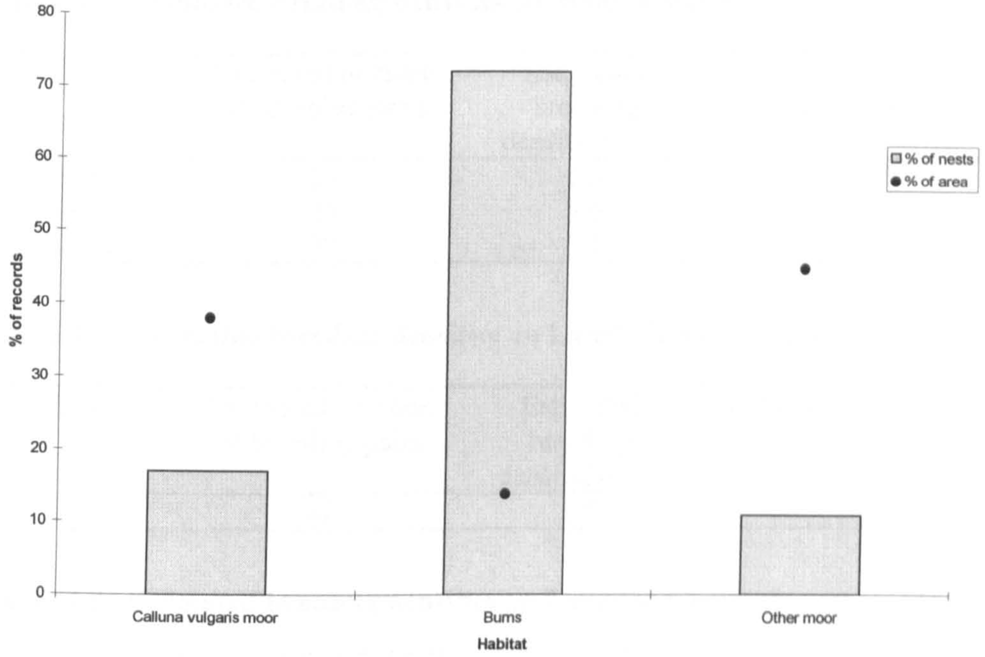
To satisfy the criteria for carrying out Chi-square analysis, similar habitats were pooled. These grouping are shown below in table 4.5.

Table 4.5. Habitat groupings for χ^2 analysis of Langlydale Common data.

Habitat Group	Component habitat(s)	No. of nests	% of nests	% area
Calluna vulgaris moor	*Calluna vulgaris* moor	3	17	38
Burns	Old, grey and black burns	13	72	14
Other moor	Acid grassland, acid grassland/*Calluna* mosaic, *Juncus effusus* and *Pteridium aquilinum*	2	11	45

Note that the grouping categories were kept the same as to those of Monk's Moor to allow comparisons to be made between the sites. Hence, rather than pool *Calluna/Eriophorum* moor and *Juncus effuses* dominated acid grassland with other groups, these habitats were not included in the analysis. Even if they were included, however, they would have made no difference to the outcome of the analysis as they made up only a very small proportion of the study site and contained no nests (see table 4.4).

Figure 4.6. Comparison of the proportion of nests in each habitat group and the proportion of area available.



Using Chi square analysis, the number of nests in each habitat group was compared to the expected number of nests, derived by taking the proportion of available area of each habitat into account.

A significant Chi-square result was obtained indicating that Curlew did not utilise habitats in the proportion that they were available ($\chi^2=50.5$, d.f.=2, $p<0.001$). Burns provided 43.6 of the Chi-square result (86%), which indicated a significant selection of burns as a nest site by Curlew (as on Monk's Moor).

Percentage of nests located and estimated breeding densities

On Monk's Moor and Langlydale Common the number of nests located as a percentage of the estimated total were high (table 4.6). These two Heather moorlands were found to have substantially higher estimated densities of breeding Curlew than the grass dominated Langdon Common, for which the estimated percentage of nests located was low. The following three tables (4.6-4.8) show the estimated breeding densities on each site and the estimated proportion of nests located.

Table 4.6. Estimated breeding densities on Monk's Moor

Year	Estimated number. of breeding pairs	Estimated breeding density(km^{-2})	Estimated percentage of nests located
1994	25	5.8	72
1995	24	5.6	79
1996	22	5.1	77

Table 4.7. Estimated breeding densities on Langlydale Common

Year	Estimated number. of breeding pairs	Estimated breeding density(km^{-2})	Estimated percentage of nests located
1996	21	8.9	86

Table 4.8. Estimated breeding densities on Langdon Common

Year	Estimated number. of breeding pairs	Estimated breeding density(km^{-2})	Estimated percentage of nests located
1994	8	1.5	37
1995	6	1.1	50

Since all of the nests were not located, the apparent avoidance of Heather on Monk's Moor should be treated with caution since all of the nests not located could conceivably have been in Heather. This would have resulted in the reduction of the Chi-square value that Heather contributed to the overall Chi-square value, taking the individual Heather value below that which was significant (though the overall Chi-square value would remain highly significant). However, the fact that all the nests may not have been located cannot alter the result of the highly significant selection of burns (by far the most significant influence on the overall Chi-square value).

Nest site selection within selected habitat type

A Wilcoxon test for matched pairs was carried out to determine whether Curlew select a specific nest site patch within a habitat on the basis of vegetation height (using data from Monk's Moor). Vegetation height (mean of 10 measurements) within the nest quadrat was compared to vegetation height (mean of 10 measurements) taken from outside the quadrat (within same habitat type).

No significant difference was found between the vegetation heights within the nest quadrat and outside it (Wilcoxon test for matched pairs, $z=-1.67$, $n=53$, $p=0.097$) indicating that Curlew did not select specific nest sites within a habitat patch on the basis of vegetation height.

Investigation into burn size as an influence on its selection as a nest site

The burns that were occupied by breeding Curlew covered a wide range of sizes and can be seen in table 4.9 below.

Table 4.9. Size range of occupied burns.

	Area (m^2)	Length (m)	Breadth (m)
Smallest	446	34	19
Median	2437	87	45
Largest	18548	231	146

Mann-Whitney U tests were carried out on the data obtained from occupied and un-occupied burns to determine whether the size variables associated with a burn influenced whether it was selected as a nest site. There was no significant difference between each of the variables measured in occupied and unoccupied burns (see table 4.10 for individual results).

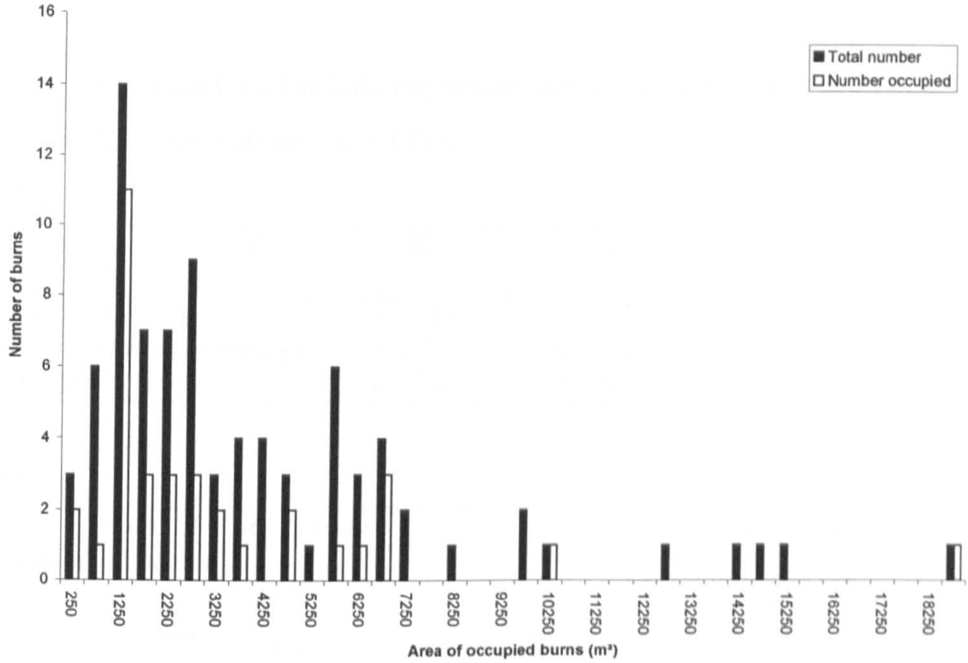
Table 4.10. Mann-Whitney U tests on burn size data. (Number of burns =79)

Variable	U	Significance (p)
Area (m^2)	634	0.3547
Length (m)	604	0.2202
Breadth (m)	661	0.5150
Perimeter length (m)	602	0.2109

A logistic regression analysis was also carried out to determine whether any of the burn variables measured (as above) could be used to predict whether a burn would be occupied or un-occupied. None of the variables measured had a significant effect on the likelihood that a burn was occupied by nesting Curlew.

Using occupied burns only, a histogram was constructed to examine the distribution of nests and the availability of burns within each size class (figure 4.7 below).

Figure 4.7. Number of burns occupied in each size class and the number of burns in each size class available. Note that the figure below each bar is the median of an arbitrarily chosen range of 500m (e.g. column 1 has a range from 1m² to 500m², therefore the figure below the bar is 250 m²).



A Chi-square analysis was carried out to determine whether the number of occupied burns in each size class was significantly different from what would be expected on the basis of their availability. There was no significant difference with burn classes being utilised in a similar proportion to their availability.

Distance of nests from burn edge

A Wilcoxon test for matched pairs was carried out to compare whether there was any significant difference between the distance of nests from burn edges and the distance of the nest from the burn centre. There was no significant difference (Wilcoxon test for matched pairs, z =-1.1724, df=29, p=0.2410).

Using habitat mosaic features to predict the presence/absence of Curlew

Logistic regression analysis was carried out to determine whether the presence of breeding Curlew could be predicted on the basis of the habitats within a mosaic, the results of which can be seen in table 4.11. The number of burns had a significant effect on the probability that an area of moorland would contain breeding Curlew. In addition, the number of habitat patches was included in the model as its inclusion gave a significant increase in the likelihood ratio.

Table 4.11 (a and b). Logistic regression model predicting the probability that Curlew will breed on an area of moor

Table a.

Variables in model	B	S.E	df	Significance (p-value)
Number of burns	0.3647	0.1562	1	0.0195
Number of habitat patches	0.1223	0.0754	1	0.1046
Constant	-2.7765	0.8694	1	0.0014

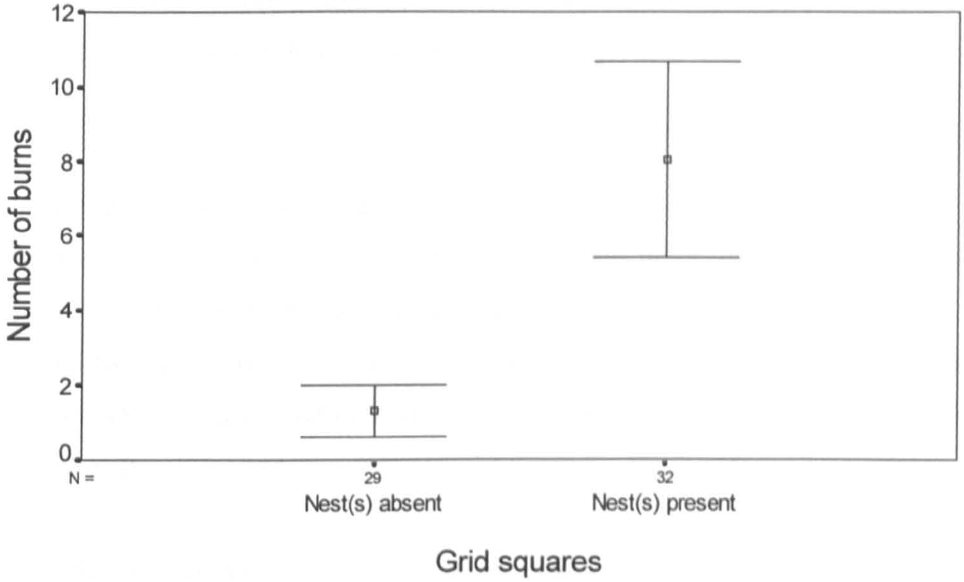
Table b.

Variables not in model	**Significance**
Number of habitat types	0.1231
Year	0.8086
Total area of burns	0.3281

The model gave a highly significant fit to the data (χ^2 goodness of fit test=35.75, df=2,p<0.001). Overall the model predicted the presence of breeding Curlew on an area of moorland in 82.0% of the cases, predicting occupied and un-occupied areas to similar accuracy (75.0% and 89.7% respectively).

Figure 4.8 illustrates the relationship between burn density and the presence/absence of Curlew in that area.

Figure 4.8. Error plot of nest presence/absence and number of burns (95% confidence limits).



Nest survival

The biggest cause of failure to produce hatchlings was predation (see table 4.12) followed by egg infertility (two nests only). Desertion of the nest was not encountered in this study. Table 4.12 contains a summary of nest predation from all three study sites.

Table 4.12. Nest predation. Note that the fate of nests on Langlydale Common was determined after the breeding season was finished since access to the site was limited. Nests were considered to have been predated if there was no evidence of egg shell fragments in the base of the nest (fragments of characteristic size and distribution were observed in all nests that produced hatchlings).

	Monk's Moor			Langdon Common		Langlydale Common
	1994	1995	1996	1994	1995	1996
No. of nests found	17	19	17	3	3	18
No. predated	3	6	11	3	2	6
% predated	18%	32%	65%	100%	66%	33%

The main point to note is that nest predation on Monk's Moor was highly variable between years, with a marked increase in the number of nests predated from 1994 to 1996. Nest survival was assessed using the data from Monk's Moor only, since the date of predation could not be assessed on Langlydale Common due to limited access.

The majority of the eggs predated disappeared from the nest and therefore the predator was not identified. Of the remaining eight nests, one was predated by a Crow (12%) and the remainder were predated by Stoats (87%). Predators were identified by characteristic hole sizes and teeth marks on the eggs, or by some eggs being found buried in vegetation near to the nest (characteristic of Stoats (L. Waddell pers. comm.)).

The results from the Cox regression analysis, using a time dependant co-variate, can be seen in table 4.13 below. Of the variables measured, only year had a significant influence on the likelihood of a nest being predated and was included in the model. The inclusion of the time dependant co-variate in the model indicated that nest survival varied through time.

Tables 4.13 a & b. Cox regression results from Monk's Moor

Table a.

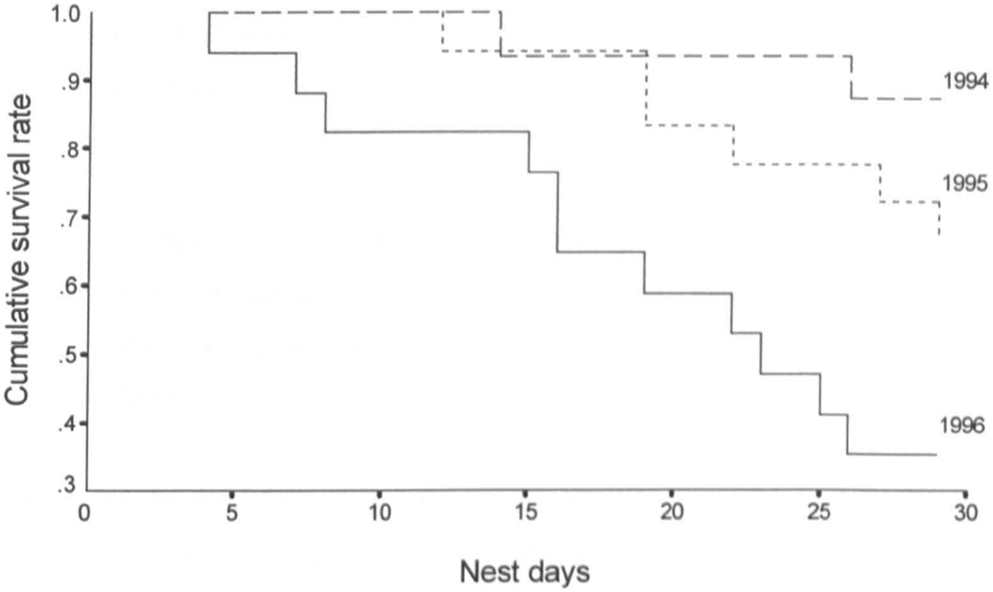
Variables in model	B	S.E	df	Significance (p-value)
Year			2	0.0102
Year (1)	-1.2582	0.5628	1	0.0254
Year (2)	-0.152	0.3995	1	0.9697
Time dependant co-variate	-0.1417	0.0674	1	0.356

Table b.

Variables not in model	**Significance**
Clutch size	0.4344
Nest site vegetation	0.4440
Nearest nest distance	0.8617
Distance to predator refuge	0.3433
Distance to habitat patch edge	0.2956
Nest vegetation height	0.7179
Slope	0.2438

The model gave a significant fit to the data ($\chi^2=10.75$, df=2, $p<0.05$). To investigate the relationship between predation and year, the survival rates of nests between years were compared using Kaplin-Meier survival analysis (figure 4.9).

Figure 4.9. Survival plots for each year of the study.



The mean survival time was significantly less in 1996 (21 days, 17-25 days 95% confidence limits) than in 1994 (28 days, 26-30 days 95% confidence limits). The mean survival time in 1995 (26 days, 24-29 days 95% confidence limits) was not significantly different to either of the other two years.

Discussion

Nest habitat selection

Each year of the study, breeding Curlew showed a significant preference for nesting in patches of recently burnt heather. On Monk's Moor 59%, 63% and 59% of nests located were located in recently burnt Heather in 1994, 1995 and 1996 respectively. In 1996 a further 12% of the nests were located in older burns resulting in a total of 71% of the nests being located in burnt patches.

In 1996 Langlydale Common was surveyed to determine whether a similar pattern of habitat preference would be found. This was the case, with 44% of nests being located in recent burns and a further 28% being located in older burns (72% of nests in burnt patches).

In both cases, the area of the study sites which constituted burns was relatively small (recent burns constituted approximately 5% of Monk's Moor and 8% of Langlydale Common). Why there was this marked preference for recently burnt patches is not clear, but there are several possibilities that will be considered.

Initially one may expect that incubating Curlew would be clearly visible in this relatively vegetation free habitat. However, Curlew were remarkably well camouflaged amongst the charred black and grey Heather branches of this otherwise relatively open habitat (pers. obs.). Larson *et. al.* (1996) found that open habitats hold a higher percentage of waders that demonstrate aggressive nest defence than habitats which provide concealment (possibly because areas of concealment by increased vegetation cover may prevent early detection of predators). Curlew demonstrate such aggressive nest defence (pers. obs.) and have been observed mobbing Raven *Corvus corax*, Lesser Black-backed Gull, Short-eared Owl, Stoat and myself *Homo sapiens*. Therefore, the fact that Curlew did prefer to nest in open burns would have been predicted from the work of Larson *et. al.* (1996).

Since the vegetation in burns was relatively sparse, incubating Curlew would have good visibility of the surrounding moorland through the burnt Heather branches, whilst remaining camouflaged themselves. A similar species, Long-billed Curlew, have also been found to select nest sites with good visibility and avoid patches of thick grasses and dense Big Sagebrush *Artemesia tridentata* (Campbell *et al* 1990). Long-billed Curlew have also been found to nest in new burns in areas where prescribed burning for game has taken place (Chatwin & Driessche 1996).

Götmark *et al* (1995) found that nest site selection was a trade off between concealment and a view of the surroundings in Song Thrush *Turdus philomelos*. Song Thrushes did not maximise nest concealment, but opted for intermediate concealment combined with good visibility. Curlew may therefore nest in burnt patches for similar reasons of good visibility, which allows them to cease incubation and mob predators some distance from the nest. This could also reduce the risk of the nest being discovered as the location from where a Curlew flew from (after walking from the nest) is less likely to have been noted by a predator (or a researcher trying to find nests - see nest finding in methods) some distance away.

Nesting in burns may also provide warning of more closely approaching predators (if they were not previously observed approaching at a distance). The brittle burnt heather branches snap readily under pressure and may therefore provide warning of an approaching predator on the ground by sound. The fact that the burnt material also produces a strong odour may also make it difficult for foraging ground predators to pick up the scent of the nest.

The possible explanations of why Curlew show a marked preference for nesting in burns mentioned are generally from the point of view of predator avoidance. However, this study found no evidence that nesting in burns reduced the probability of a nest being predated. Indeed, the only variable measured that had a significant influence on nest survival was the year of the study. All of the other variables measured, including whether the nest was in a burn or not, had no influence on nest survival. The reasons why there was such a marked increase in predation of nests over the three-year study period was unclear.

The main predator on the grouse moorland study sites were Stoats and to a lesser extent, Weasels (L. Waddell pers. comm.) as most Foxes, Corvids and Gulls were removed by keepering (L. Waddell pers. comm). The evidence of the presence of, and the predation by, Mustelids was also more common on the study sites than any other predator (pers. obs.). Though there is no conclusive evidence of a population cycle in Stoats and Weasels (R.A. McDonald pers. comm.), their numbers do fluctuate depending on prey availability (some of which have cyclic populations e.g. Voles) and weather conditions (mild, rainy winters and large amounts of snow over many years may have a negative impact on Stoats and Weasels (Eiberle and Matter 1985)). Both prey availability and weather conditions could have been one contributing factor behind the increased level of nest predation from 1994 to 1996.

Mustelids switch to alternative prey items if the density of their main prey (usually rabbits) decreases (e.g. Myberget 1985 & McDonald & Harris 1998). On Monk's Moor, the density of Rabbits, is relatively low and largely confined to a small area to the south-east of the moor. The abundance of other mammal prey was unknown, but since the populations of many, such as voles, cycle, it is possible that mammal prey was more abundant in 1994 and hence the predation of Curlew eggs infrequent. If in subsequent years the numbers of mammalian prey was reduced then this could have caused the increase in egg predation by Stoats.

During winter months, Stoats are trapped or shot around dry-stone walls of Monk's Moor (L. Waddell pers. comm.). However, snow-fall was heavy during the winter preceding the 1996 field season which caused a reduction in Mustelid predator control (L. Waddell pers. comm). The reduction in predator control could have resulted in an increased number of Mustelids during the Curlew breeding season, which could have been a cause of the particularly heavy nest predation in 1996.

The behaviour of Stoats themselves makes it difficult to predict their impact on wader populations. During the breeding season mature males roam over extensive areas seeking females (generally a few square kilometres, but up to an area of 26km^2) and then remain in a new location for up to eight days (Sandell 1986). Since a male Stoat can cover such a large area and remain within it for a few days, it is possible that just one individual on a moor could decimate a large number of nests. In addition to male Stoat, females have relatively large territories (about 50-100 ha in New Zealand forest (Murphy & Dowding 1994, 1995)) and have been found to kill at least eleven adult breeding New Zealand Dotterel *Charadrius obscurus* within two months (Dowding and Murphey 1996).

Since Stoats are relatively small and elusive, they can take advantage of dense moorland vegetation for cover while approaching an incubating Curlew. A Curlew may therefore not detect the presence of a Stoat until it is relatively close, therefore increasing the likelihood of a nest being located once the adult has flushed (pers. obs.).

Though there was no evidence of adult Curlew predation by Stoats in this study, the head of an adult was reportedly found in the den of a Stoat (L. Waddell pers. comm.) though the bird could have been carrion. There is, however, evidence that Stoats predate, or attempt to predate, adult waders from the nest (though smaller species than Curlew), for example Lapwing (D. Parish pers. comm.) and New Zealand Dotterel (Dowding and Murphey 1996)). Curlew may therefore prefer to nest in burns so that they can detect approaching Mustelids in the relatively open, vegetation free habitat, thus reducing the likelihood of adult mortality. Therefore, the main driving force of the preference of burns by Curlew may be a result of an instinct for self-preservation by adult Curlew, rather than for increased nest success.

Also from the point of view of adult Curlew, burning results in a clear, well-defined edge between two different habitat types. This may provide Curlew with well-defined territory boundaries that can be readily defended. Indeed, two rival Curlew have been observed in a territory dispute on Monk's Moor, pacing along the edge of a burn a few metres apart (pers.obs.)

Nest site selection within a selected habitat

On the basis of vegetation heights, Curlew did not show any within habitat selection of nest location. In general however, the habitats in which Curlew nested were relatively uniform. This was certainly true of the burns, which constituted the majority of the sample for analysis. Those nests that were located in Heather were also in uniform vegetation. Therefore this result was to be expected.

Burn size as an influence on its selection as a nest site

When occupied and unoccupied burns were compared to each other there was no significant difference between their size characteristics. When the distribution of nests between each size class was investigated, Curlew were found to utilise the burn sizes in a similar proportion as their availability.

Curlew nested in a range of burns of various sizes, from relatively small ($446m^2$) to relatively large ($18548m^2$). With the exception of one burn (the largest recorded), there was no more than one pair of Curlew per burn, even though the distance between some nests was often less than the length of many burnt patches. The minimum distance between any two nests was 53m, each of these nests being in an individual burn.

Using habitat mosaic features to predict the presence/absence of Curlew

The number of burns on an area of moorland had a significant influence on whether breeding Curlew would be present. The likelihood of finding breeding Curlew increased with increasing number of burns.

Breeding densities and broad-scale land type preferences

The breeding densities of Curlew found on the two grouse moorlands (Monk's Moor and Langlydale Common) were both substantially higher than was found on the grass dominated moorland (Langdon Common). Haworth and Thompson (1990) found similar results, with the distribution of Curlew being positively associated with game keeping, an activity not carried out to any major degree on Langdon Common. Stillman and Brown (1994) also found that Curlew were positively associated with tall heather, a feature absent from Langdon Common.

Compared to a number of other studies, the densities of Curlew found on Monk's Moor and Langlydale Common were relatively high (5.5 pairs km^{-2} and 8.9 pairs km^{-2} respectively). Brown and Sheperd (1993) found average densities of 4.0 pairs km^{-2} in surveyed marginal farmland fields in Teesdale and 3.75 pairs km^{-2} on surveyed moorland on the North York moors. Stillman and Brown (1994) found a maximum of 5 pairs km^{-2} in the South Pennines with regional breeding densities ranging from 0.19-2.76 pairs km^{-2} (from JNCC unpublished data (Stillman and Brown (1994)).

Higher densities have been found in other studies areas such as in Orkney (Grant in Gibbons *et al* (1993)) where they averaged 12 pairs km^{-2} (with peaks of 55 pairs km^{-2} on fragments of moorland and wetland below 100m). In Northumberland Philipson (1954) found up to 12.5 pairs km^{-2} in high density areas and Williamson (1968) found densities of between 14 and 18.5 pairs km^{-2} on Calcareous moorland in Teesdale. However, such high densities appear atypical and the habitats on which they were found are not widespread.

On the basis of the findings of Haworth and Thompson (1990), Stillman and Brown (1994) and the results of this thesis, the implications are that grouse moorlands support higher densities of Curlew than grass dominated moorlands. The preference for grouse moorlands is likely to be attributable to the presence of burnt Heather patches.

The other major upland habitat type, which provides important breeding habitat for Curlew, is marginal farmland below the moorland edge (Baines 1988). However, establishing whether moorland or marginal farmland is the most important habitat type for Curlew breeding in Britain is difficult to achieve, as is the determination of which of the two is the sink or source population. The determination of whether Curlew breeding on moorland in this study were a source or a sink population to Curlew breeding on the surrounding marginal farmland was beyond the scope of this research.

To determine whether Curlew breeding on moorland are a source or sink population would have required full Curlew population models on the moorland study sites and on additional marginal farmland breeding sites. Other aspects of population dynamics such as adult mortality and return rates should also have been investigated and a much higher number of colour-ringed individuals would have been essential.

There is anecdotal evidence, based upon nest densities, which suggests that Curlew prefer to breed on Grouse moorland rather than the surrounding marginal farmland. However, this evidence is far from conclusive and should be treated with caution accordingly.

Though clearly not directly comparable with intensive nest searches on moorland, marginal farmland fields surrounding the study sites were surveyed weekly for feeding Curlew, and though some fields were unsuitable for breeding Curlew, only a maximum of three breeding pairs were observed in any year. In addition, the breeding densities found on the two Grouse moorlands of this study (5.5 pairs km^{-2} and 8.9 pairs km^{-2}), were also higher than the estimated breeding densities of Curlew found during intensive studies within marginal farmland in Teesdale (4.0km^{-2}) (Brown and Shepherd 1993).

Higher breeding densities than those found on moorland in this study have been found on marginal farmland in the North Pennines (Lunedale and Baldersdale – NY9220) (12-15 pairs km^{-2} M. Grant pers. comm.). However, breeding densities varied widely within the total c10km^2 survey area and the estimated densities were calculated from areas of suitable habitat where there was a relatively continuous distribution of pairs (generally areas of between 0.5-1km^2) (M. Grant pers. comm.).

If the Monk's Moor nest distribution map in chapter 4 (figure 4.1) is consulted, it can be seen that there are high and low density areas on this site also. In particular, there is a large area of the moor to the north-east of the site where densities are very low due to the dominance of rank Heather, which was generally avoided as a nest habitat.

If breeding densities were calculated for areas of only suitable habitat on Monk's Moor then the north-east section of this site would be omitted and the breeding densities would be correspondingly higher. Clearly, calculating densities is strongly influenced by the area of the study site. If the surveyed area is divided on the basis of suitable and unsuitable habitat (which may be useful for identifying "hot-spots" of bird activity for example) then these results are not directly comparable with other studies that calculate density estimates on the basis of the total area surveyed.

To illustrate this point, if the breeding density of Curlew on marginal farmland from M. Grants study is calculated from the total surveyed area an estimate of 6 pairs km^{-2} is obtained, a figure comparable to that of Monk's Moor (5.5 pairs km^{-2}) and substantially lower than that of Langlydale Common (8.9 pairs km^{-2}).

It should also be noted that, in this case, it is not practical to compare two studies in an attempt to gain an insight into overall land type preferences based on breeding densities. For example, M. Grant's research makes no mention of the availability of suitable moorland nesting habitat above the marginal farmland. It is possible that breeding densities are so high on the marginal farmland because there is little suitable moorland nesting habitat available in that area resulting in farmland utilisation being the only viable option. It is also possible that any moorland in the area has even higher breeding densities than the marginal farmland, but there was no data available to assess this as it was outside the scope of the research.

During this research, Curlew breeding densities appeared to be much higher around Monk's Moor and Langlydale Common than in the surrounding marginal farmland, some of which was rough grassland, rich in *Juncus* species and hence suitable for nesting. However, the majority of the fields surrounding these study sites were pastures, probably resulting in much less continuous suitable nesting habitat than Grant found in his study area. Clearly, the problem encountered is that for both studies, there is a lack of information on the availability of other suitable nesting habitats in the area (because this was outside the scope of each study), making direct comparisons between them difficult.

Therefore, as an area of future research it would be valuable to carry out intensive long-term Curlew surveys in a location where there is suitable moorland breeding habitat immediately surrounded by marginal farmland containing suitable breeding habitat. In this way the determination of whether moorland or marginal farmland is the preferred breeding habitat and which of the two land types provides a source population and which is the sink population could be achieved.

Implications of results

This chapter has quantitatively demonstrated that Curlew show a significant preference for nesting within burnt patches of Heather on grouse moorlands. This has been suggested in other studies (e.g. Baxter and Rintoul (1953), Blair (1961) and Reed (1985), but not quantitatively, and for other species such as Golden Plover (Ratcliffe (1976), Reed (1985) and Whittingham 1996)). However no other published study has looked at the factors which affect the choice of a burn as a nest site or the implication of such factors.

The results obtained by examining the physical attributes of the burns have important implications from a management perspective as they can be readily controlled during burning. This chapter found that burns were a preferred nesting site and that as the number of burns increases so does the likelihood of finding breeding Curlew. The size of the burn had no significant effect on whether it was selected as a nest site. Burns of various size classes were utilised, according to their availability.

Therefore to benefit breeding Curlew an area of moorland should have many small burns rather than few large burns (maximising availability of patches of preferred nesting habitat). The minimum recommended size would be 446m^2 (smallest occupied burn), with a maximum of around 2500m^2 (The median size of occupied burns). The closest distance between two nests in line of sight was 53m and therefore, the distance between burns should be no less than this. The proposed management prescriptions to benefit nesting Curlew will be discussed in greater detail in chapter 7.

CHAPTER 5.

CHICK HABITAT SELECTION

Aims of Chapter

The main aim of this chapter was to determine which habitats Curlew chicks preferred. Invertebrate prey availability in each of the major habitats described in chapter 2 was also investigated to determine whether chicks selected habitats on the basis of food availability. In addition, chick survival in different habitats was investigated to determine whether this could account for habitat selection. The timing of hatch was also investigated to determine whether it coincided with the period of peak prey availability.

Introduction

Since Curlew chicks are precocial and nidifugous (i.e. they are capable of feeding themselves from hatching and leave the nest almost immediately) they must have suitable habitat to provide food and cover relatively close to the nest site. If one were to manage an area of moorland to benefit breeding Curlew, it would be essential to provide suitable habitat for foraging chicks.

Habitat use can be assessed by direct observations of broods, but locating and observing chicks can prove very time-consuming (Grant *et al* 1992c and pers. obs.). Locating chicks can be very difficult since they conceal themselves in vegetation almost instantaneously once the adults begin calling in alarm (Philipson 1954 and pers. obs). Once located, observations of broods remains difficult as chicks tend to be obscured from view by dense vegetation while foraging (pers. obs.).

A more rapid method to collect data on chick habitat use is by radio-telemetry. Radio-telemetry involves attaching a small tag, which emits a radio signal (a pulse).

The chick can be relocated at a later date with the aid of a receiver that picks up the radio-tag signal, the volume of which becomes louder as the tag is approached.

This method has been used successfully on a number of animals to investigate the habitat use and growth rates. Species studied include Stoat (Sandell 1986, Erlinge & Sandell 1986), Sparrowhawk *Accipiter nisus* (Kenward 1978), Willow Grouse *Lagopus l. lagopus* chicks (Erikstad 1985), Pheasant *Phasianus colchicus* chicks (Kenward *et al* 1993) and Golden Plover adults (Percival & Smith 1992, Whittingham 1996) and chicks (Yalden 1981, Percival & Smith 1992, Whittingham 1996).

Studies of Golden Plover by Yalden (1981), Percival & Smith (1992) and Whittingham (1996) demonstrated the usefulness of radio-telemetry on a species whose chicks use moorland and have a similar life-style to Curlew chicks (i.e. precocial and nidifugous). Whittingham (1996) also investigated the validity of using radio-telemetry to measure habitat use and found that chicks very rarely switched habitat when approached by an observer. Radio-telemetry has also been used successfully to assess Curlew chick habitat preferences on marginal farmland (M. Grant pers. comm.).

Since chicks are difficult to locate once they have left the nest, nests were visited on the day that they hatched in order to radio-tag them. This was achieved by predicting the hatch date of eggs. Since egg density decreases as the chick develops, this can be used as a predictor of the age of the egg (Hoyt 1976, 1979). Using density data for eggs of known hatching date, a plot of egg density against hatching date was constructed. The equation obtained from the regression line was then used to predict when eggs would hatch and to estimate hatching dates for nests which did not survive (due to predation for example).

Since a number of studies have shown that hatching is timed to coincide with the period of peak prey availability (Lack 1954, Perrins 1970 and Perrins & Birkhead 1983), the timing of hatching in relation to invertebrate prey abundance (using data from chapter 2) was investigated. In addition, habitat selection by chicks has been shown to be linked to prey abundance in a number of species. For example adult Red

Grouse have been found to lead their broods to areas rich in arthropods (Redpath and Thirgood 1997), and Erikstad (1985) found that Willow Grouse broods selected habitats with the largest number of insects. Galbraith *et al* (1993) found similar results with Dotterel. Therefore the invertebrate data from chapter 2 were used to investigate whether they could explain chick habitat selection.

In chapter 4, the impact of predators on Curlew nests was investigated and nest predation was found to be high. A number of studies have investigated the role of chick predation on productivity. For example, in a recent study of grouse predation on moorland, up to 37% of grouse chicks were predated by raptors (mainly Hen Harrier and Peregrine *Falco peregrinus*) (Redpath and Thirgood 1997). In a study of Curlew breeding on marginal farmland in Teesdale, Grant (pers. comm.) found that predation (mainly by Stoats) accounted for virtually all chick mortality.

Since one of the major aims of this thesis was to produce management prescriptions to benefit Curlew, the consequences of habitat selection on chick survival rates could have important implications. For example, if predation rates were significantly higher in a particular habitat, appropriate management may reduce the area of that habitat. If a significant reduction in area was not possible (which would be likely if the area of the habitat in question were large) then preferred nesting habitat (i.e. new burns) could be created in areas where predation rates were lowest. This could therefore encourage Curlew to nest in areas where chicks were more likely to survive. Therefore, it was also important to determine whether survival rates varied between habitats.

Methods

Due to the complete predation of eggs from nests found on Langdon Common and the lack of regular access onto Langlydale Common (due to its sensitivity as a grouse shoot), all of the data regarding chicks in this chapter were collected from Monk's Moor.

The use of egg density to predict hatch dates

In order to construct a standard plot of egg density index against hatching, actual hatch dates must be known. Therefore, during the first field season (1994) the estimated number of days until hatching were calculated using Grant's formula from his County Antrim study of Curlew (M. Grant pers. comm.);

$$\text{Days until hatch} = 287000\,(\text{mean egg density index}) - 117.688$$

Where, after Hoyt (1979);

$$\text{Egg density index} = \frac{\text{weight}}{\text{length} \times (\text{breadth})^2}$$

In subsequent field seasons, estimated hatching dates were derived using data from eggs located during this study. The equation generated from 1994 data was used to to predict the hatch date of all eggs in the field in 1995 and the equation generated from the combined 1994 and 1995 data was used to predict hatch dates in 1996. Each formula was very similar and generally accurate to within two or three days of hatching. The nests were checked daily from a few days before the predicted hatch date to look for signs of hatching, which normally occurred between 48-72 hours after the initial cracking of eggs.

Timing of hatch was compared with invertebrate prey availability to determine whether hatching was timed to coincide with peak prey availability (see discussion). The methods and results of measuring prey availability can be seen in chapter 3.

Locating chicks

Every effort was made to visit nests on the day the eggs were due to hatch, before the chicks had time to leave. However, due to adverse weather conditions, it was not always possible to visit the nest on the expected hatch day and on several occasions, the brood had already left the nest when it was visited. Chicks that had left the nest were, if possible, located by using one of two methods:

1) Chicks were observed from a hidden position and then searched for at their last observed location. Even then, locating their position after the adults had begun alarming was difficult since they concealed themselves in dense vegetation where possible. The success rate of this method was low (12% of attempts), with only one chick being captured over the three year period.

2) This method involved listening for audible clues to a chick's location by sitting motionless and silent in an area where they were suspected to be. Some young chicks quietly call to alarming adults (L. Waddell pers. comm. and pers. obs.) and were located by carefully and silently following the direction of their calls. This technique proved more dependent on the age and individual behaviour of a chick, therefore making success more variable between broods. The success rate using this method was relatively high (54% of attempts) with six chicks being located over the three year period.

Processing Curlew chicks

When located, all chicks were weighed and measured to provide information on body size at hatching. The measurements taken were bill length, right tarsus to toe length and back of head to bill-tip length, all of which could be measured rapidly in the field (therefore keeping handling time to a minimum). Chicks were then individually marked with a colour ring combination and a BTO metal ring. At least one chick was radio-tagged from each brood, with two being tagged in broods of four. Since the habitat selection data obtained from siblings would not be independent, data from one chick only was used (from the sibling with the most radio-tag locations). The second chick was tagged for "insurance" purposes only, so that it could continue to be monitored if the first chick were predated.

Superglue was used to attach a radio-tag onto a bare patch of skin on the back of each chick, as this had proved successful with Golden Plover (Percival & Smith 1992). A bare patch of skin was located by gently blowing the area and parting the down between thumb and forefinger. The down surrounding the tag was also superglued onto it to achieve a firm hold. Each time a chick was relocated the attachment of the tag was checked and a small amount of Superglue re-applied when necessary.

During the first field season, two different types of radio-tags were used; 1) Biotrack 0.8g SS-2 button cell transmitters and 2) Holohil 1.7g BD-2G transmitters. Both transmitter types worked well, but the Holohil tags had the advantage since removing a magnet activated them. The Biotrack transmitters needed soldering and sealing before being activated.

Depending on topography, the transmitted pulses from Biotrack radio-tags could be received from between 50m to 250m away. The larger (3.5% of mean chick hatching weight, but below the recommended <5% of body weight (Kenward 1987)), more powerful Holohil transmitters could be picked up from up to 600m away. On one occasion a pulse was picked up when a Holohil tag was 400m away and 30cm underground in a Stoat run. On the basis of these results and the ease at which the tags were prepared for use (i.e. removal of magnet), only Holohil radio-tags were used in subsequent years.

Data recorded on chick re-location by radio-telemetry

The most accurate method of investigating habitat use by chicks would be to observe them all day, every-day throughout the pre-fledging period to determine the amount of time each habitat was used. Clearly this is not possible, due to the amount of time this would involve and the practical difficulty of observing chicks in dense vegetation. Therefore when possible, habitat use was sampled once per day using radio-telemetry. However, sampling every day was sometimes prevented by adverse weather conditions. No visits were made to the moor during periods of strong winds and heavy rainfall to avoid any chance of deleterious effects on grouse or wader chicks.

Chicks were generally located by approaching them directly, the received pulse getting louder as the radio-tagged chick was approached. The ability to locate the tag directly without having to carry out triangulation (see methods, chapter 6) was attributable to the performance of the high quality radio-tags and the receiver (TRX 1000).

When a chick was located the following were recorded.

1) Habitat type – identified on the basis of vegetation composition and cover as one of the nine habitats defined in chapter 2. The habitat type was recorded to determine which were used and which were avoided within the home ranges of chicks (see chick habitat preferences).

2) Biometric measurements – These were recorded every three days where possible to allow growth curves to be determined. The equations of the growth curves could then be used to estimate the age of any chicks from unidentified broods located opportunistically. The weight/age growth curve could also used to determine an index of body condition for each chick, which was included in survival analyses. Chicks were measured every three days (where possible) to minimise the potential trauma caused by handling, while still allowing the development of the chick to be monitored. It was not always possible to measure chicks every three days, as handling them during very cold, damp conditions was avoided to prevent them from chilling. On days when chicks were not measured, their locations were determined by visual contact but they were not handled.

3) The location of the radio-tagged chick within the study site – this was plotted onto a habitat map, using features such as burns, grouse butts and walls as reference points. These locations were then transferred on to the computer habitat map (see chapter 2), to allow measurements to be taken.

Once processed, the chick was returned to the exact location where it was found.

Determination of whether handling chicks affected their behaviour

Handling chicks may have influenced their behaviour. If the experience was too traumatic, chicks may travel further than usual after being handled, for example.

To assess this possible effect, the distances chicks moved between being handled and the following day were compared to distances moved between non-handling location days and the following day. Chick locations were overlaid onto the computer habitat maps, allowing distances travelled to be measured using *PC Image*.

A Mann-Whitney U test was carried out on the data to determine whether there was any significant difference between the distances moved following handling and non-handling days.

Home range of chicks

In order to assess the habitat preferences of any animal, the amount of each habitat that was available to it and the amount of times each habitat was used must be determined and compared. The rationale behind this can be demonstrated by the following example; if an animal spent 90% of its time in habitat x, and habitat x contributed only 1% of the area available to the animal, then this could be indicative of a preference that habitat. The amount of each habitat that is available to an animal can be assessed by determining its home range.

The area within which an animal moves while performing its normal activities can be described as its home range (Harris *et al* 1990). However, there are various methods to determine the home range of an animal (Harris *et al* 1990). Dry-stone walls form the outer boundaries of Monk's Moor, with no other boundaries within the site. Therefore, the potential home range could be considered to be the whole site. However, this is not very realistic since young chicks are not likely to travel several kilometres to access the whole site. In fact a number of studies have shown that wader chicks remain within a few hundred metres of the nest (Grant *et al* 1992, Percival & Smith 1992, Whittingham 1996) though they can travel further (>1km for one Curlew brood in this study for example).

A more appropriate means of identifying the home range of a chick would be to define the outer limits of that range by using either; a) some measure of the distance a chick actually travels or b) some measure of the distance a chick could potentially travel. There are several methods of determining home ranges available (see Harris *et al* 1990 for a review), one from each of the two categories mentioned above being outlined below.

a) Minimum Convex Polygon (MCP) method

This is one of the most commonly used methods of determining home ranges (Harris *et al* 1990). This method involves constructing a convex polygon around the outer-most locations of a chick. The home range is considered to comprise of the total area within the polygon and is a measure of the area actually utilised.

Chick MCP home range areas were determined using the computer generated habitat map and *PC Image* (an example of an MCP home range seen below in figure 5.1). The area of each habitat within the polygon was also measured using *PC Image*.

Figure 5.1. Home range area (MCP method). Note this was the actual home range area of a chick from nest 9 (1994) and each black dot was a chick location and the white dot was the nest. The habitat types are the same as in chapter 2.

b) Potential home range method.

This method involves determining home ranges based upon the area that is potentially available to chicks (rather than the area that is actually used, as in the method above). This method determines the home range on the basis of the area that could be utilised if a chick chose to. Therefore potential home range area is always larger than that of MCP home range area.

Potential home range area was measured by constructing a circle around each nest, with the nest at its centre, the radius of which was a measure of the distance a chick could potentially travel. This was taken as the maximum distance, within the moor, that any brood moved from its nest (690m). These broods all displayed the general behaviour of travelling multi-directionally around the nest area. However, one brood did not behave in this manner and essentially travelled in a single direction from the nest, leaving the moor, until it was approximately 1.5km away. This brood was not included in the habitat preference analysis due to the difficulty in assessing its home range.

Home ranges were calculated for those broods for which at least six locations were recorded. All other chicks had between nought and four locations recorded, due to mortality, and defining habitat preferences based upon so few records was inappropriate.

An initial examination of the data by eye revealed that the percentage of each habitat within the home range of each chick was similar when using the MCP home range method and the potential home range method. To test for differences, Wilcoxon matched pairs tests were carried out, comparing the percentage of each habitat found using the MCP method to the percentage of each habitat found using the potential home range method (a test was carried out separately for each chick). For every chick, no significant difference was found between the percentage cover of habitat that each method estimated to be within the home range. Since the proportions of the habitats within home ranges using either method were not significantly different, the data from either could be used for the habitat selection analysis. Therefore the data obtained from the MCP method was used for the subsequent analysis since this is one of the most commonly used methods of determining home ranges and is the only one that is strictly comparable between studies (Harris *et al* 1990).

Chick habitat preferences within their home range

A chart was constructed for each chick (Appendix 2) to examine potential habitat preferences by comparing the proportion of times each habitat was used to the proportion of the area of that habitat within the home-range. Initially, no statistical analysis was carried out at this stage since all that was being sought was an indication of potential habitat preferences.

It was initially intended that chick habitat use would be explored using compositional analysis (Aebischer *et al* 1993). This technique utilises data on the proportional use of habitats by individual chicks to explore the relationship between habitat availability and use (Aebischer *et al* 1993). Compositional analysis has several advantages over some other habitat use analysis methods, a comprehensive break-down of which can be found in Aebischer *et al* (1993).

However, to carry out compositional analysis certain criteria have to be met. For example, a sample size of six radio-tagged animals is the absolute minimum that can be used to carry out the analysis, though sample sizes above ten and preferably above thirty are recommended (Aebischer *et al* 1993). It is also preferable that the sampling of each animal should take place throughout the same time period, otherwise year effects must be incorporated into the model (Aebischer *et al* 1993).

The same habitats must also be available to all animals (Aebischer *et al* 1993), but this was not the case in this study. To meet this criteria an attempt was made to pool some habitats so that every habitat group was available to each chick (for example Acid grassland and *Calluna*/acid grassland mosaic were pooled). However, to have the same habitat group available to every chick could only have been achieved by reducing the number of habitats to two pooled groups (which was also inappropriate since vastly different habitats had to be pooled). The combined effect of these criteria was that compositional analysis could not be carried out on the Curlew chick data.

Therefore, as with nest habitat preferences, Chi-square analyses were used to investigate chick habitat preferences (see methods, chapter 4). Habitat preferences were compared with invertebrate prey availability to determine whether habitats were used on the basis of prey availability. Methods for measuring prey availability can be seen in chapter 3.

Chick survival

The fate of each chick was recorded and the overall percentage that died was calculated. Productivity (number of fledglings per breeding pair) was calculated using the following two methods;

a) by dividing the number of fledged radio-tagged chicks by the number of nests which had radio-tagged chicks (i.e. the productivity of a sample of Curlew).

b) by dividing the total number of fledglings observed on the study site by the estimated number of breeding pairs on the site (i.e. an estimate of total site productivity).

To determine whether productivity was high enough to maintain the viability of the Curlew population on the study sites, productivity, in terms of recruitment into the breeding population per adult per year, was calculated. The formula used to calculate productivity was (after Berg 1994);

Recruitment into the breeding population per adult per year = 0.5 × productivity per pair × proportion of birds surviving first year × proportion of adults surviving per year.

Curlew probably start to breed at two years (Glutz von Blotzheim *et al* 1977), and while first year mortality was taken as 53% (Bainbridge and Minton 1978), second year survival was assumed to be the same as adult survival (Berg 1994). Since adult mortality rates were not investigated in this study, mortality rates from other studies were used in the formula above. Adult mortality was taken as 15.4% (the mean of figures from three other studies - 17.9% (Berg 1994), 16.8% (Evans 1991) and 11.5% (Kipp 1982)).

Factors affecting chick survival

In chapter 4 Cox regression was used to determine whether any of a series of variables had an influence nest survival. Eight variables were recorded for use in the Cox regression analysis, and only one (year) was included as a statistically significant predictor in the model.

The intuitive approach to chick survival analysis, therefore, was to use Cox regression analysis once again. However, many of the variables recorded for use in the nest survival analysis could only be measured accurately because of a particular characteristic of nests, a characteristic not shared by chicks. That characteristic was that nests were stationary in a fixed position. Chicks however, were not stationary and therefore it was not possible to measure most of the variables that could be measured for nests. Problems with measuring those variables that could potentially have an effect on chick survival are discussed below.

1) Habitat – the habitat that a nest was located in can be readily determined. However, a chick is capable of moving hundreds of metres from the nest and therefore assigning it to a habitat is largely a subjective decision. For example, a dead chick could be assigned to being in a habitat category based upon its last (alive) recorded location, but since the chick could have moved a few hundred metres from its last recorded location, it could have been in a different habitat when it died. Alternatively, the chick could be assigned to being in the habitat where its carcass was found, but the predator could have carried it there from another habitat. A chick could also be assigned to a habitat based upon the dominant habitat within its home range but again, it could have died in any habitat within its home range.

2) Distance to predator refuge - There may be an increased likelihood of a chick being predated if it is close to a predator refuge (dry-stone walls and rocky-outcrops in this case (L. Waddell pers. comm. and pers. obs.). Again this is measurable from a nest at a fixed location, but where should the distance to a predator refuge be measured from for chicks? The problem was that the chicks location at the time of its death was unknown.

3) Vegetation height – a chick may have a reduced chance of being predated if it is in tall vegetation (providing concealment). However, the location of a chick when it was predated is once again unknown.

Clearly, the problem was that the last location of a chick when it died was unknown and therefore, it was not sensible to measure many of the variables used in the nest survival analysis.

Intuitively, body condition could also have had important implications for chick survival. Chicks in poor condition may have less chance of escaping predators or have an increased chance of succumbing to disease or adverse weather conditions. For each chick, body condition index could be taken as the residual of its last weight measurement from the curve of the weight growth chart (see results). Body condition index would therefore either have a positive or negative sign depending on whether the chicks weight was above or below the average growth rate curve respectively. However, to reduce the possibility of causing stress on tagged chicks, they were only weighed every three days (at most) and therefore body condition index on the day of predation would be unknown. Since chicks can increase their weight by 50g in three days and in one case loose 44g in three days (pers. obs), the body condition index at time of death was likely to be inaccurate.

Due to the problems with accurately and objectively measuring the characteristics of chicks and their surroundings it was deemed inappropriate to carry out a Cox regression survival analysis for chicks. Therefore, only the survival rates of chicks between years were compared (using Kaplan-Meier survival analyses) since this variable was an objective measure that was also found to influence nest survival rates.

Comparison of survival rates of chicks which preferred *Juncus effusus* flushes and those which did not have access to them

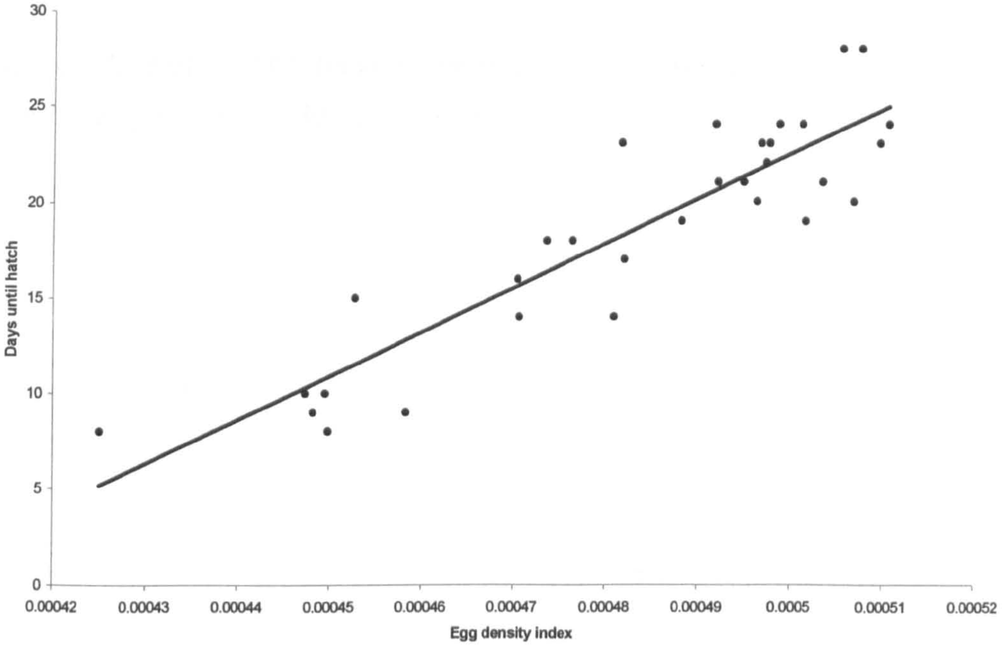
A Kaplan-Meier survival analysis was also carried out on the two groups of chicks included in the habitat selection section. This was carried out to determine whether the preference of *Juncus effusus* flushes (the only preference encountered – see habitat selection results) could be explained in terms of higher survival rates. Predation rates may be expected to be lower for chicks in the tall vegetation of *Juncus effuses* flushes since they would be less visible to predators. Of course, the preference for a particular habitat does not necessarily mean that a chick used it exclusively (for example a chick may move between adjacent flushes via acid grassland) and it could have been predated while being within a habitat other than a flush (acid grassland in the previous example). Therefore, caution should be taken when interpreting the results of this analysis.

Results

Predicting hatch date from egg density

Egg density was used to predict hatch date so that nests could be visited before the chicks had left. Using data from 31 nests on Monk's Moor (combined over three years) for which the date of hatch was known from direct observation, Figure 5.2 was constructed.

Figure 5.2. Egg density index plot for use in predicting the hatch date of Curlew clutches



There was a significant correlation between egg density index and the number of days until hatch (Spearman's r=0.95, n=31, p<0.001). A linear regression was carried out on the data to give the formula;

$$\textbf{Days to hatch} = \textbf{231144} \times \textbf{mean egg density} - \textbf{93.1}$$

This formula was also used to predict the hatch dates of all nests that were predated so that they could be included in the timing of hatch section.

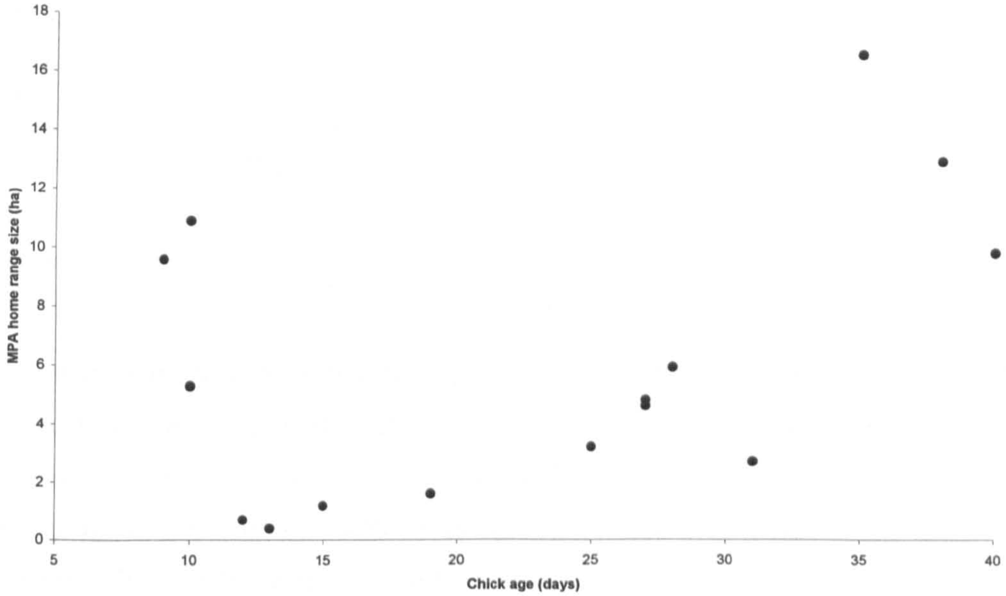
Determination of whether handling chicks affects their behaviour

A Mann-Whitney U test was carried out on distances moved by chicks following handling days (median =117m, range = 4m-504m) and non-handling days (median =110m, range = 5m-711m). No significant difference was found (Mann-Whitney U=1159.5, n=100, p=0.54) demonstrating that handling did not influence the distance travelled by chicks, which was taken as an indicator of behaviour.

Chick home range sizes

The home ranges of chicks varied between 0.7ha-16.5ha (median = 4.8ha). Figure 5.3 below shows the distribution of home range sizes with regards to chick age.

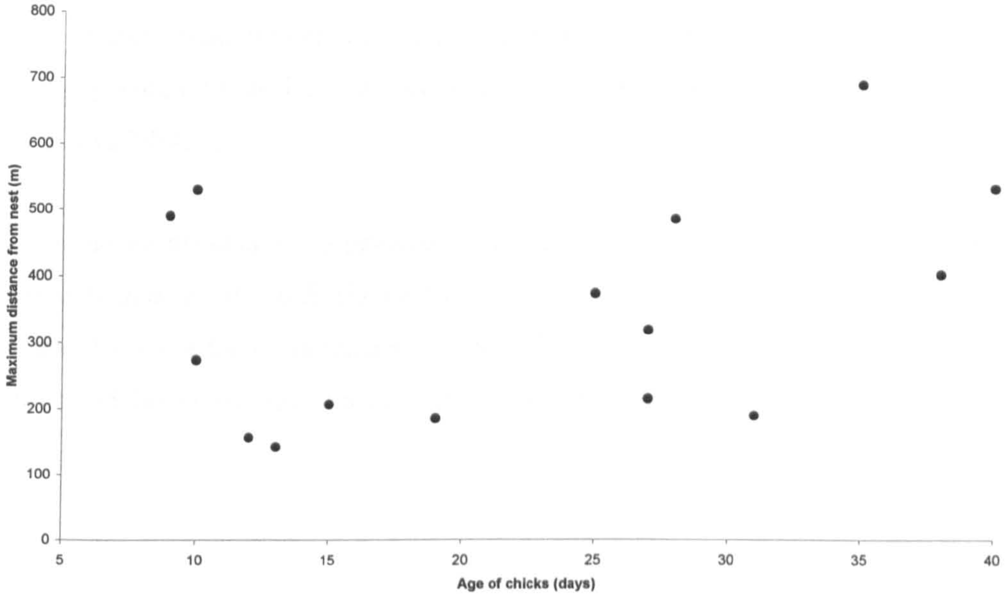
Figure 5.3. Plot of MCP home range size against chick age (age at time of death or at fledging for chicks with six or more radio-locations).



The main point to note is that there was a wide degree of variation in home range sizes and the oldest chicks did not necessarily have the largest home ranges (e.g. the home range of one 10 day old chick was larger than that of a 40 day old chick). There was no significant correlation between chick age and home range area (Spearman's r=0.3041, n=15, p=0.270).

The maximum distance that those chicks that remained on the moor moved from the nest varied between 140m-690m (median = 318m). In addition, one brood that left the moor moved 1.5km from the nest within fourteen days from hatch. Figure 5.4 below shows the distribution of maximum distances moved from nest with regards to chick age.

Figure 5.4. Plot of maximum distance moved from nest against chick age (age at time of death or at fledging for chicks with six or more radio-locations)



The main point to note is that there was a wide degree of variation in maximum distances moved from nests and the oldest chicks did not necessarily move the furthest from the nest (consider the brood that left the moor for example). There was no significant correlation between chick age and maximum distance moved from nest (Spearman's r=0.3453, n=15, p=0.208).

Also note that the maximum-recorded distance from a nest, which was used as the radius of the potential home range area for each brood, was 690m. This distance was similar to those of 740m and 600m found for Golden Plover chicks (Percival and Smith 1992 and Whittingham 1996 respectively).

Radio-tagged chick habitat selection

Before any analysis was carried out, the charts in Appendix 2 were constructed to provide an indication of any potential habitat preference/avoidance. The main points to note from the charts in Appendix 2 were:

1) Those chicks that had *Juncus effusus* flushes within their home range appeared to utilise them to a greater extent than may have been expected from the available area.

2) Those chicks that did not have *Juncus effusus* flushes within their home range appeared to utilise the available habitats in a similar proportion to their availability.

To summarise the charts in Appendix 2, chicks were pooled into two separate groups, those with *Juncus effusus* flushes within their home range and those without. Figures 5.5 and 5.6 were then constructed to show the percentages of observations in each habitat and the percentage of area available within their home range.

Figure 5.5. Available habitat area and chick locations for those broods with *Juncus effusus* flushes within their home range. Note n=6 chicks and the % of records represents the combined total for the pooled chicks.

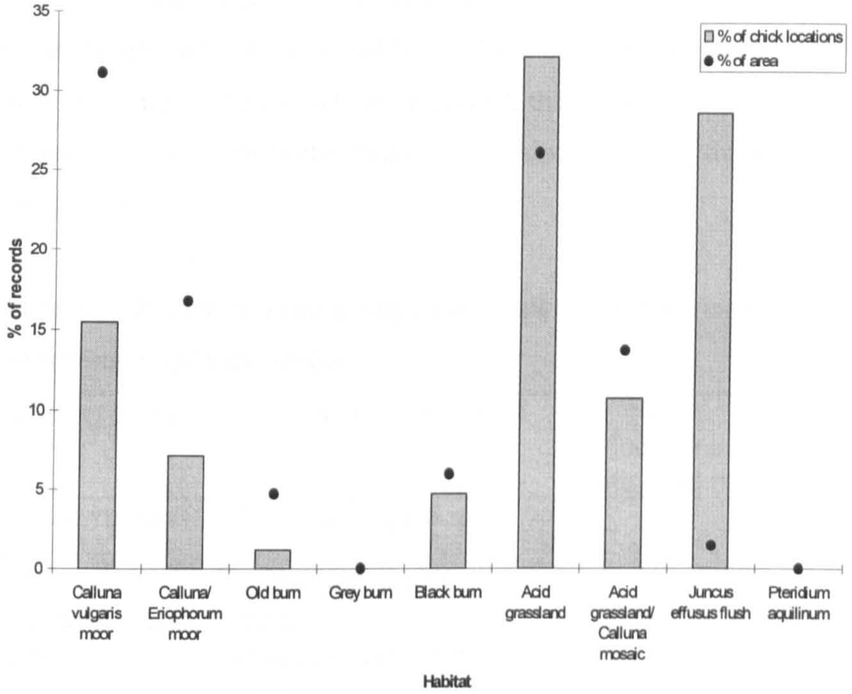
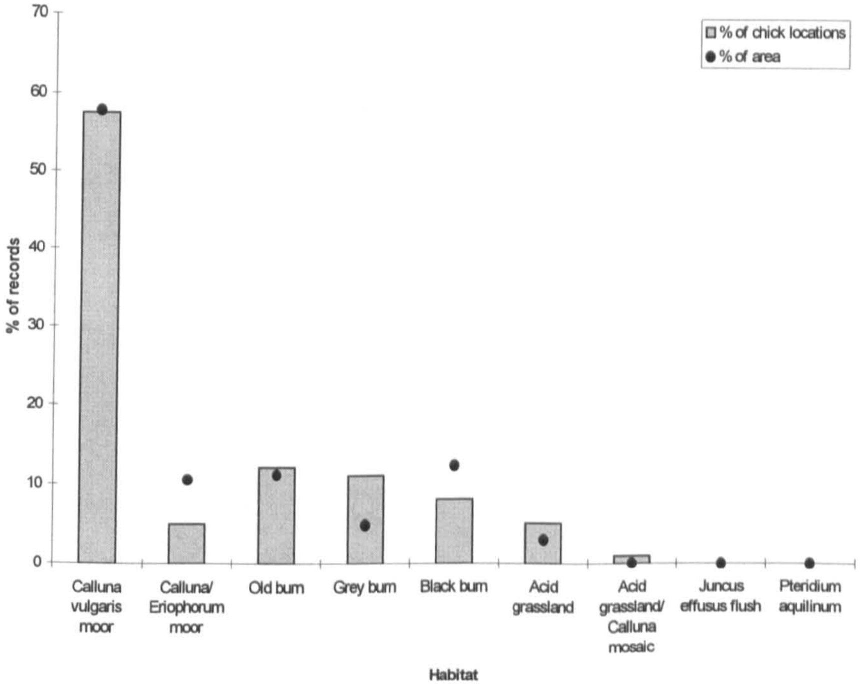


Figure 5.6. Available habitat area and chick locations for those broods without flushes within their home range. Note n=9 chicks.

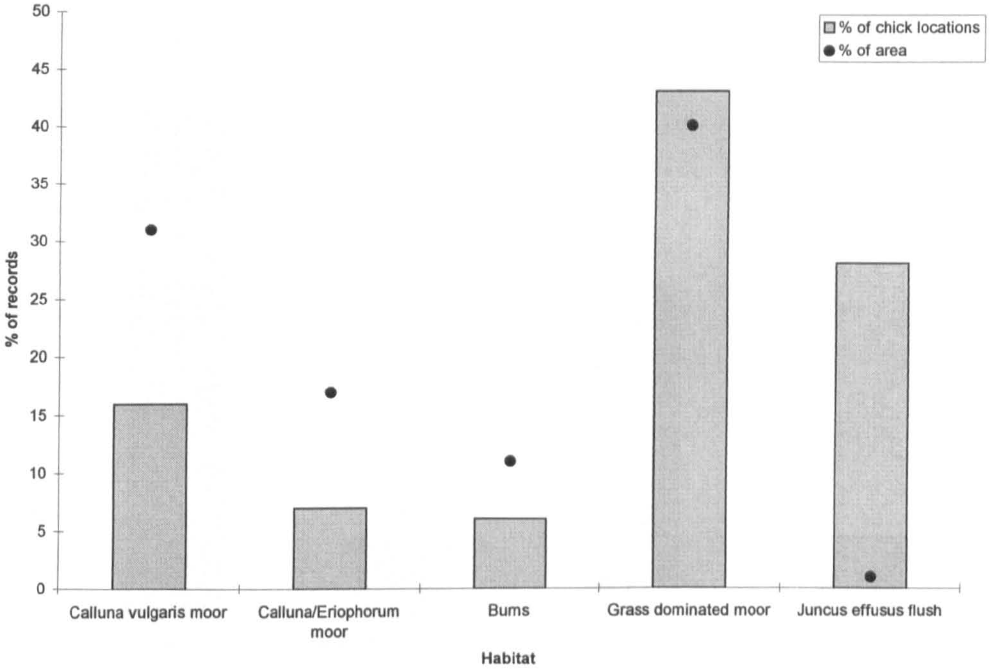


Chi-square analysis was used to determine any habitat preferences/avoidances. As with the Chi-square analysis of nest habitat data (chapter 4), the number of chick records in each habitat was compared to the number of records expected in each habitat on the basis of its availability. However, to satisfy the criteria for Chi-square analysis, some of the habitats were pooled, the results of which can be seen in table 5.1 and 5.2 for those home ranges with *Juncus effusus* flushes and those without respectively.

Table 5.1. Pooled habitat groups for chick Chi-square analyses of home ranges containing *J. effusus* flushes.

Habitat group	Component habitat(s)	No. of locations within habitat	% locations within habitat	% area
Calluna vulgaris moor	*Calluna vulgaris* moor	13	16	31
Calluna/ Eriophorum moor	*Calluna/ Eriophorum* moor	6	7	17
Burns	Old, grey and black burns	5	6	11
Juncus effusus flush	*Juncus effusus* flush	24	28	1
Grass dominated moor	Acid grassland, acid grassland/Calluna mosaic	36	43	40

Figure 5.7. Comparison of the proportion of area each habitat group contributes to the home ranges containing *Juncus effusus* flush and the proportion of chick locations within each habitat.

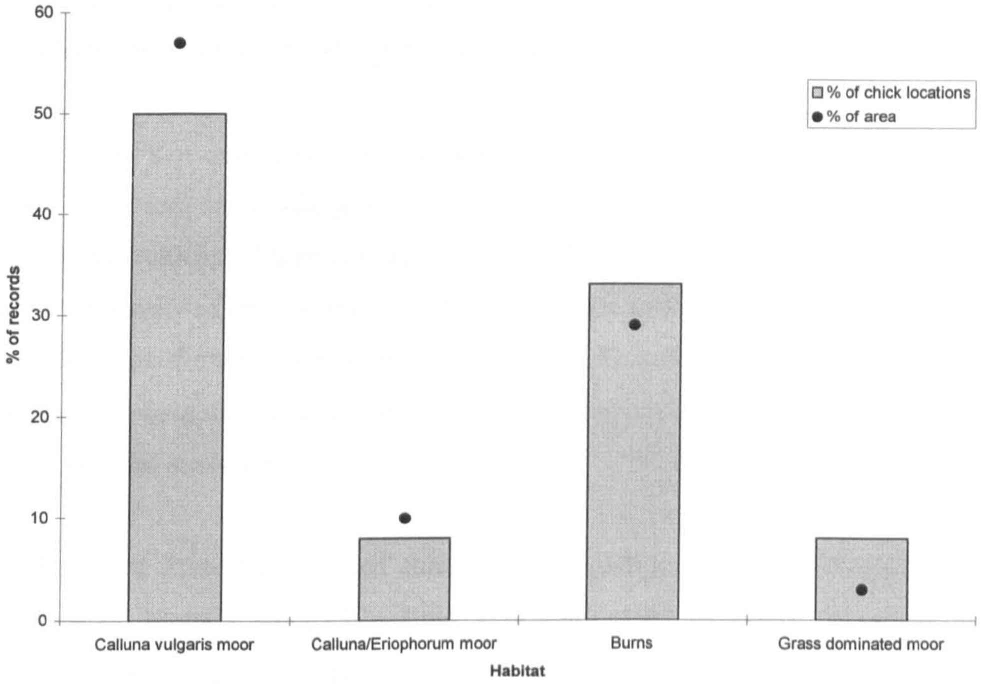


A significant Chi-square result was obtained, demonstrating that chicks were not utilising habitats in the same proportion as their availability (χ^2=439, df=4, p<0.001). *Juncus effusus* flushes were utilised to a higher proportion than they were available and contributed 97% of the Chi-square result indicating a significant preference of that habitat by chicks.

Table 5.2. Pooled habitat groups for chick Chi-square analyses of home ranges without the presence of *J. effusus* flushes.

Habitat group	Component habitat(s)	No. of locations within habitat	% locations within habitat	% area
Calluna vulgaris moor	*Calluna vulgaris* moor	30	50	57
Calluna/ Eriophorum moor	*Calluna/ Eriophorum* moor	5	8	10
Burns	Old, grey and black burns	20	34	30
Grass dominated moor	Acid grassland, acid grassland/Calluna mosaic	5	8	3

Figure 5.8. Comparison of the proportion of area each habitat group contributes to the home ranges not containing *Juncus effusus* flush and the proportion of chick locations within each habitat.



A non-significant Chi-square result was obtained indicating that habitats were used in a similar proportion as their availability (χ^2=5.9, df=3, p>0.05). Chicks demonstrated no preference or avoidance of any habitat.

Chick survival

Chick mortality was high during each year of the study, the main cause generally being predation. Table 5.3 shows a summary of the fate of radio-tagged chicks, a more detailed version of which is given in Appendix 3.

Table 5.3. Fate of radio-tagged chicks

Year	No. radio-tagged	No. fledged	% mortality	% predated	% disappeared	Other % died (weather/disease)
1994	11	0	100	27	27	46
1995	19	1	95	68	16	11
1996	9	2	78	56	11	11
Mean	13	1	92	50	18	23

Note that chicks in table 5.3 were only recorded as being predated when there was proof (i.e. the carcass was found). In each case Mustelids were identified as being the predators (determined by characteristic jaw marks on the back of the neck (Thorburn 1984 and L. Waddell pers. comm.).

It was likely that those chicks that disappeared were predated, as extensive searches of the moor and surrounding areas were carried out, and there was no sign of the radio-tagged chicks. There was also no sign of the adults within the area, and since the vast majority of broods remained relatively close to the nest, this provided further evidence that the chicks had been predated. Therefore, those chicks that had disappeared were also considered to have been predated for the subsequent Kaplan-Meier survival analyses

In addition to those radio-tagged chicks that fledged, six additional fledglings were observed on Monk's Moor (3 in 1994, 2 in 1995 and 1 in 1996). However, since each of these fledglings were observed flying, they may have come onto Monk's Moor from the surrounding moorland, rather than being resident there.

From these results the mean productivity of Curlew was calculated, the results of which can be seen in table 5.4 below (including the results of estimated number of fledglings per pair from the other two study sites).

Table 5.4. Curlew productivity during the study period. Note that productivity in b) was the best case scenario, since the total number of fledglings included those which may not have been resident on the site.

	Monk's Moor	Langlydale Common	Langdon Common
a) mean productivity for tagged broods (fledglings/ pair)	0.14	Non-tagged	Non-tagged
b) mean productivity for estimated total population (fledglings/ pair)	0.13	0.39	0

The main point to note is that Curlew productivity was very low on all study sites which leads to the question - is productivity too low to maintain viable populations?

Is productivity high enough to maintain population?

Using mortality figures from other studies, 0.154 adults need to be replaced by first-time breeders each year to maintain the population level. Following the method of Berg (1994), the estimated number of first-time breeders that would actually be produced on Monk's Moor using the equation;

Recruitment into the breeding population per adult per year = 0.5 × productivity per pair (0.14) × proportion of birds surviving first year (0.47) × proportion of adults surviving per year (0.85)

was 0.028, which was far lower than that required to maintain the population (0.154).

To determine the productivity (number of fledglings per pair) that would be required to maintain the population the following equation was used (following Berg 1994);

(Adult mortality (0.154) ÷ number of first year breeders produced (0.028)) × existing productivity per pair (0.14)

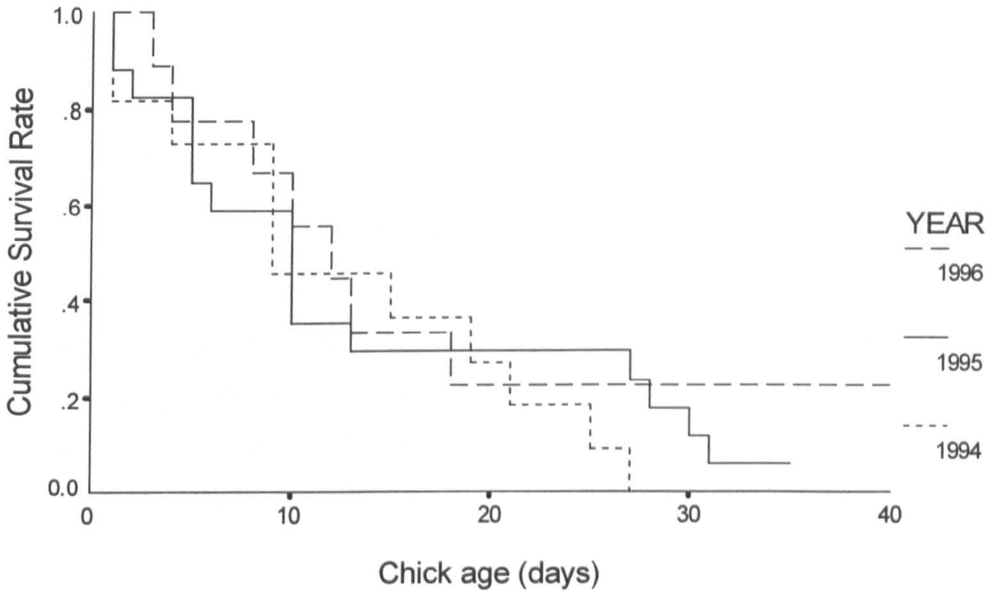
To maintain the Curlew population, a productivity of 0.77 fledglings per breeding pair is required. Therefore the observed productivity of 0.14 fledglings per pair is too low to maintain the Curlew population at Monk's Moor.

Using the estimate of number of fledglings produced per pair (0.39) gives a production of 0.078 first year breeders per individual at Langlydale Common. The observed productivity of 0.39 fledglings per pair is too low to maintain the Curlew population at Langlydale Common (productivity (fledglings/pair) needs to be approximately doubled to maintain the population). Since Curlew productivity was zero at Langdon Common, the productivity at this site was also too low to maintain the population.

Survival analysis

Unlike nest survival, there was no significant difference between the survival rates of chicks in each year (median survival time for chicks in – a) 1994=9 days (0-18 days 95% confidence limits), b) 1995=10 days (7-13 days 95% confidence limits) and c) 1996=12 days (6-18 days 95% confidence limits). The survival rate plots of chicks each year can be seen in figure 5.9 below.

Figure 5.9. Chick survival plot for year.

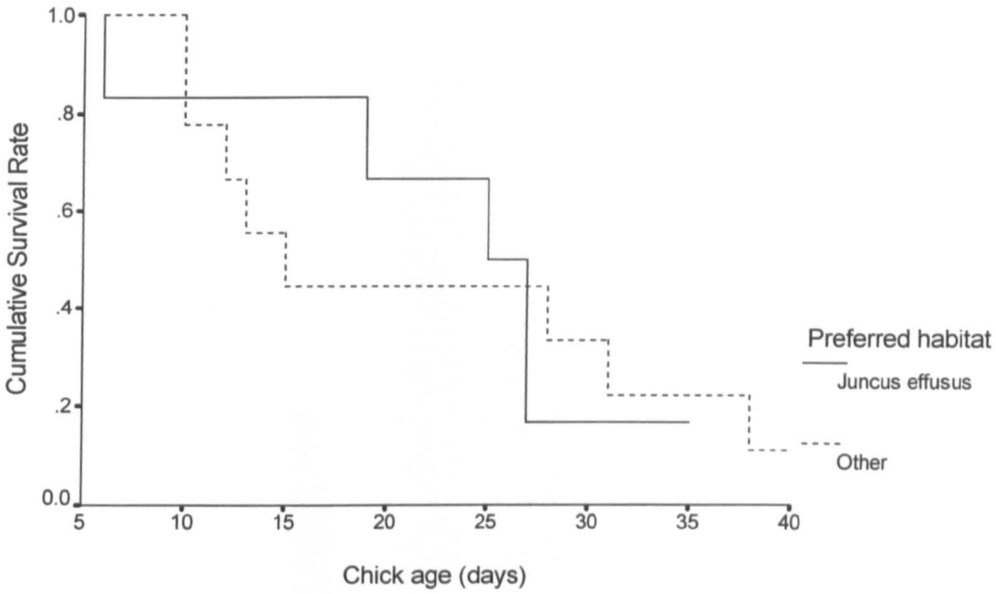


The main point to note is that within the pre-fledging period a similar rate of mortality was recorded throughout each year of the study. Generally the highest mortality rate occurred within the first two weeks, but also occurred only a few days prior to fledging.

<u>Comparison of survival rates of chicks which preferred *Juncus effusus* flushes and those which did not have access to them</u>

The survival rate of those chicks which preferred *Juncus effusus* flushes was compared to the survival rate of those chicks which did not have *Juncus effusus* flushes within their home range. The survival plots can be seen in figure 5.10 below.

Figure 5.10. Survival plots for chicks which preferred *Juncus effusus* flushes and for those which did not have them within their home range.

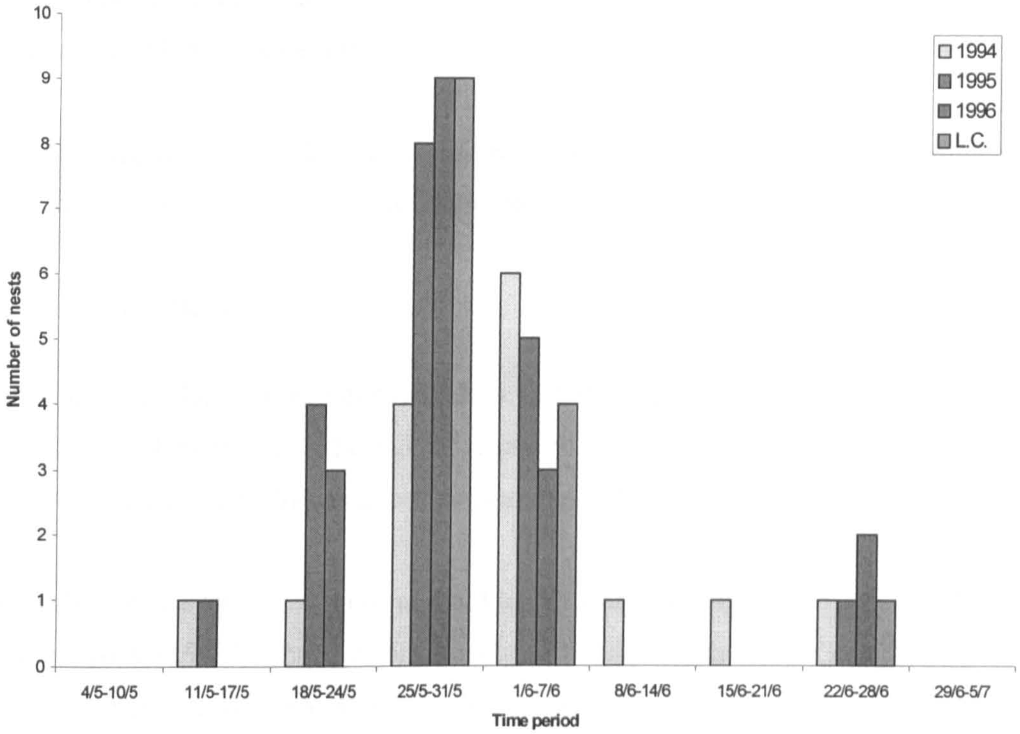


There was no significant difference between the survival rates of chicks that demonstrated a preference for *Juncus effusus* flushes (median survival time=25 days (19-31 days 95% confidence limits), and those that did not have access to them flushes (median survival time=15 days (9-21 days 95% confidence limits).

Timing of hatch

For clarity of information, the hatch dates of nests were pooled into weekly totals and can be seen in figure 5.11 below.

Figure 5.11. Timing of hatch. Note data labelled 1994,1995 and 1996 was from Monk's Moor and data labelled L.C. was from Langlydale Common in 1996.



A Kruskal-Wallis test was carried out on the weekly hatch date of nests from Monk's Moor. There were no significant differences in hatch date between each year (Kruskal-Wallis, H=2.84, N=51, p=0.2411).

To ensure that the action of pooling the data to weekly counts had not caused "artificial" differences in hatching period between years another Kruskal-Wallis test was carried out on the daily hatch counts, a chart of which can be seen in appendix 4. There was no significant differences between years (Kruskal-Wallis, H=3.18, N=51, p=0.2040).

Mann-Whitney U tests were carried out to compare the 1996 hatch dates of Monk's Moor and Langlydale common. There was no significant difference between hatch dates at the two sites (Mann-Whitney U=120.5, N=34, p=0.3512 for weekly hatch dates and Mann-Whitney U=111.5, N=34, p=0.2537 for daily hatch dates)

The main point to note from figure 5.11 is that the peak hatching period was the last week in May, with substantial hatching taking place one week to either side of it. The clutches hatching in the fourth week of June could be re-lays but no quantitative data were available to assess this.

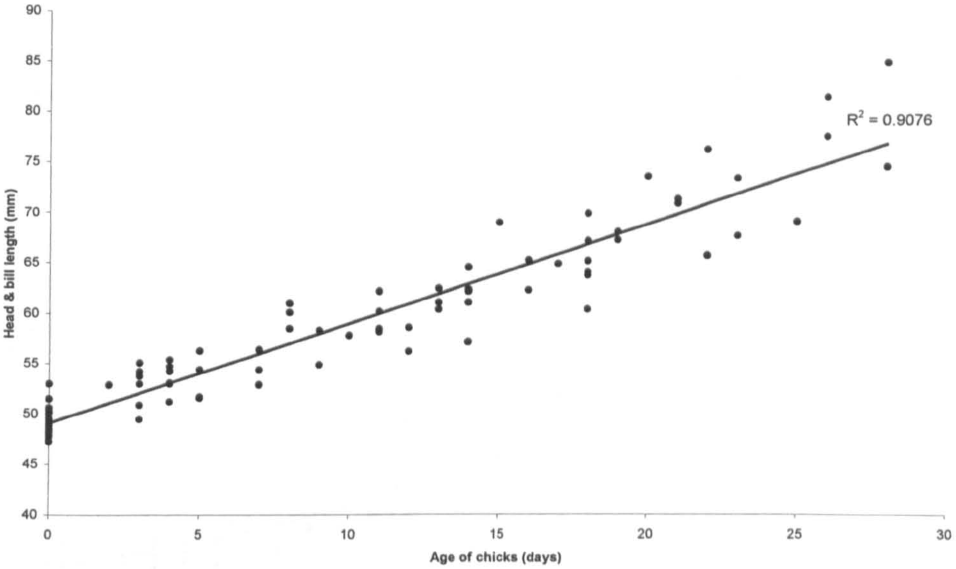
The consequences of the timing of the breeding season with regards to invertebrate prey availability (chapter 3) will be addressed in the discussion.

Chick growth rates

Chick growth charts were constructed so that the equation of the regression line could be used to estimate the age of captured chicks from previously un-located nests. These chicks could be radio-tagged and monitored to increase the sample size.

Of the biometrics measured, head and bill length was most highly correlated with age (age of chick=0.9872 × head & bill length + 49.108). It should be noted however, that there is a lack of independence in the growth data sets because individual chicks were measured several times over the sampling period since so few chicks survived for any great length of time. However, since the regression equation was only intended to be used in the field to give an estimate of the age of opportunistically located chicks, this was not considered to be a major problem. The growth chart of head and bill length against age can be seen in figure 5.12.

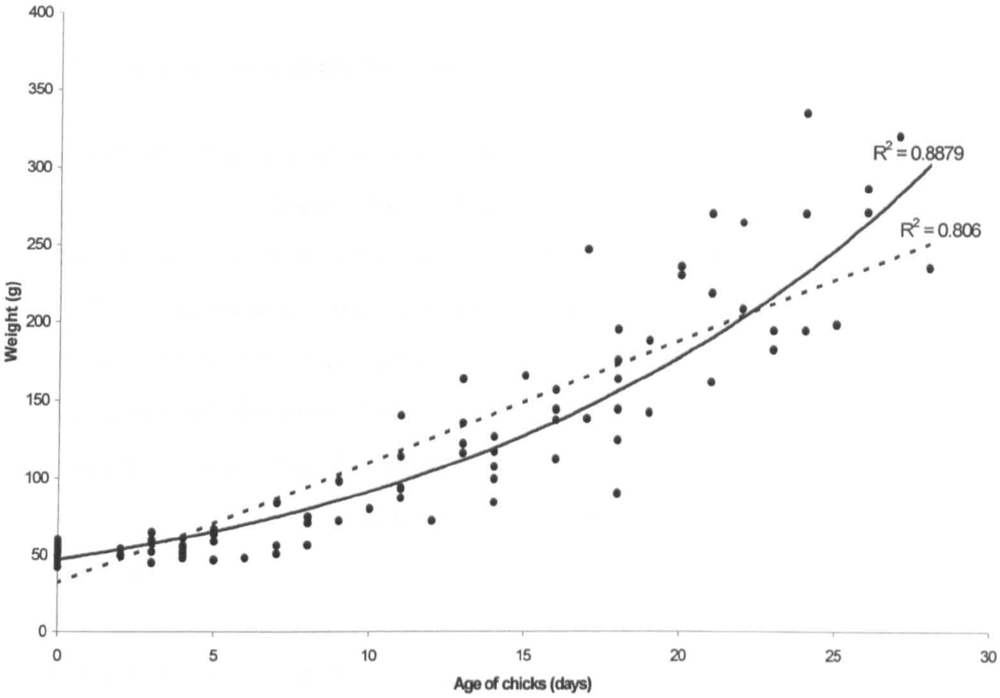
Figure 5.12. Chick growth rate (head & bill length against age)



The biometrics charts for bill length against age and tarsus and toe length against age, which are very similar to figure 5.12 (but have lower R^2 values – 0.86 and 0.82 respectively), can be seen in Appendix 5.

However, whereas a linear regression line fitted the biometric charts mentioned above the most accurately, an exponential curve described the relationship between age of chicks and their weight more accurately (see R^2 on figure 5.13 below).

Figure 5.13. Chick growth rate (weight against age)



The equations for the lines were; age of chick=47.052e$^{0.0664 \text{ x weight}}$ for the exponential curve and age of chick=7.8286 × weight + 31.6, for the linear regression line respectively.

The main point to note from figure 5.13 was that up till about one week in age there was little increase in chick weight. During the period following the first week there was a much more rapid growth rate in chicks.

Discussion

Problems in analysing habitat use data

The availability of each habitat was measured and converted to a proportion of the total area within the home range of a chick. Therefore, when combined, the proportion of each habitat adds up to one (unit-sum constraint) (Aebischer *et al* 1993). As a consequence, the avoidance of one habitat can result in an apparent preference of another habitat (Aebischer *et al* 1993). Since compositional analysis tests for an overall departure from random habitat use (Aebischer *et al* 1993), this problem is not encountered. However, since sample sizes were too small to carry out compositional analysis, Chi-square tests were carried out, which suffer from the unit-sum constraint.

However, in this study the unit-sum constraint had no influence on the outcome of the analysis. This can be demonstrated by viewing the habitat use charts in figures 5.5 and 5.6. Those chicks that had *Juncus effusus* flushes within their home ranges (figure 5.5), which consisted of only one percent of the available area, showed a significant preference of that habitat. However, if another habitat was being avoided, chicks would be more likely to use the substantially more widespread habitats than the least widespread habitat. In the case of those chicks that did not have *Juncus effusus* flushes within their home ranges (figure 5.6) there was no significant preference or avoidance of any habitat. This added to the evidence that chicks with access to them, were selecting *Juncus effusus* flushes since chicks without access to it did not demonstrate any habitat avoidance.

Aebischer *et al* (1993) also commented that there could be a lack of independence if the radio-location is taken as the sample unit and the number of radio-locations, which are pooled over several individuals, is the sample size. The first possible cause of lack of independence is that the location of the chick could be influenced by its previous location (Swihart and Slade 1985). However, in this study, chick locations were not recorded more than once in 24 hours, within which time chicks have been found to travel up to 711m (see determination of whether handling influences behaviour), allowing them access to each habitat within the home range. Even day old chicks have been observed moving up to 200m in one day (pers. obs.) and a recently hatched Golden Plover chick of 25g has been observed moving 400m within 3 hours (Whittingham 1996).

Aebischer *et al* (1993) also go on to comment that pooling animals can lead to a lack of independence in the data, due to variation in the behaviour of individuals. However, Aebischer *et al* (1993) state that pooling is justifiable if individuals do not differ in behaviour. In this study behaviour of individual chicks did not appear to differ, with chicks foraging multi-directionally around the nest site. In addition, for the Chi-square analysis, those chicks with and without *Juncus effusus* flushes within their home ranges were pooled separately as this appeared to cause the only observed difference in behaviour (i.e. the preference of *Juncus effusus* flushes if they were available).

Chick habitat preferences

This chapter has demonstrated that there was some degree of variation in habitat selection by broods on Monk's Moor, reflecting differences in habitat availability within the home range. Those chicks that had *Juncus effusus* flushes within their home range showed a significant preference for that habitat. However, those chicks that did not have *Juncus effusus* flushes within their home range used the habitats available to them, in a similar proportion as their availability.

There is evidence that there is a link between the habitat preferences of some precocial chicks and invertebrate prey availability. For example, Erikstad (1985) found that Willow Grouse broods selected habitats with the largest number of insects and Dotterel have also been found to show a preference for feeding in habitats with the highest invertebrate abundances (Galbraith *et al* 1993). Southwood and Cross (1969) found that the distance travelled by Partridge *Perdix perdix* broods was proportional to insect availability (those broods in areas of high insect availability moved least distance). Black Grouse broods have also been shown to use habitats that had the most invertebrates (Baines *et al* 1996).

However, other studies have found no indication of a link between habitat preference and invertebrate prey abundance. For example, Grant (1989) found that Whimbrel broods showed no evidence of an association between habitat use and invertebrate biomass. Whittingham (1996) found no clear pattern between invertebrate biomass distribution and selected and avoided habitats.

The preference for *Juncus effusus* flushes when they were available cannot be explained by overall invertebrate abundance, since the abundance of invertebrates sampled by pit-fall trapping was relatively low compared to the other habitats. However, the abundance of Tipulids, an important prey item of chicks (chapter 2), was highest in *Juncus effusus* flushes and this may be the cause of the preference for that habitat. Tipulids are relatively easy to capture since they can be grounded by light wind and rain and have a high nutritional content (Galbraith *et al* 1993).

It has been suggested that Red Grouse lead their broods to areas of high invertebrate abundance (Redpath and Thirgood 1997), but there was no evidence of Curlew chicks being led to any habitat in this study. From observations of feeding broods, it appeared that adults followed foraging chicks rather than the other way around. Therefore, this would suggest that chicks select the habitat they feed in rather than being led there by an adult. Since Curlew chicks are largely visual hunters moving from one prey item that catches their attention to another (pers. obs.), it would appear that chicks would be more likely to remain in a habitat where there is more food.

However, the chicks which did not have *Juncus effusus* flushes available to them demonstrated no significant preference or avoidance of any habitat even though invertebrate abundance varied between them. However, it is possible that invertebrate abundance is sufficiently high in all of the habitats available to chicks and even those habitats for which invertebrate abundance was the least may have had sufficient prey availability to support chicks. That possibility could account for the lack of preference or avoidance of the habitats available.

Timing of breeding

The peak hatching period in 1995 and 1996 coincided with the period of peak Tipulid abundance (chapter 2, figure 3.10), an important prey of Curlew chicks. In 1996 there was also a significant increase in the abundance of other invertebrates (captured in pit-fall traps) coinciding with peak hatch period (chapter 2, figure 3.8). There was also a significant difference in invertebrate abundance in each sampling period in 1995. However, in 1995 the greatest increase in invertebrate abundance occurred in the sampling period following peak hatch (though it should be noted that abundance was also relatively high (and similar to 1996) during the peak hatch period (chapter 2, figure 3.8)).

Green *et al* (1977) also found that the under-lying factor that determined laying date in many arctic breeding waders appeared to be the abundance of insect food at hatch time. Baines *et al* (1996) found that the main hatch of Black Grouse eggs was timed to coincide with the peak availability of the moth caterpillars preferred by chicks. A similar degree of synchronisation was also found between peak hatch of Capercaillie eggs and moth caterpillar availability (Baines *et al* 1996).

However, it should be noted that factors affecting timing of breeding are likely to be more complex than just food availability (Thompson *et. al.* 1986) and factors such as climatic and female specific factors have been shown to be influential (Green *et al* 1977 and Thompson *et. al.* 1986).

Chick survival

Curlew productivity on each study site was low, resulting in mean productivity's of 0.14, 0.39 and 0.0 fledglings per pair on Monk's Moor, Langlydale common and Langdon Common respectively. Of the two heather moorlands studied, productivity appeared to be higher on Langlydale Common than on Monk's Moor. However, this should be treated with caution since productivity on Langlydale Common was an estimate, rather than being based on quantitative data, and could have included Curlew from outside the study sites. It is possible that there was a "real" difference in productivity between the two sites, and this could possibly be explained in terms of the main predators on the two study sites. The main predator on Monk's Moor was Stoats, which are likely to be more efficient Curlew chick predators than Corvids, which were the main predators at Langlydale Common (M. Gibbs pers. comm.).

Other studies have also found Curlew productivity to be low. For example, Berg (1994) found that only 20% of chicks survived until fledging, resulting in a mean productivity of 0.25 fledglings per pair, Glutz *et al.* (1975) found a mean productivity of 1.33 fledglings per pair and Boschert and Rupp (1993) found a mean productivity of 0.32 fledglings per pair. The latter study also highlighted high between year variation, with productivity varying between 0-1.6 fledglings per pair per year. Though no figures were given, Whittingham (1996) also commented that Golden Plover chick survival was low.

Curlew are relatively long-lived birds (oldest recorded ringed bird 31 years six months (Rydzeweki 1978 in Cramp *et al* 1983) and mortality rates after fledging are relatively low (see productivity section in methods). Therefore, putting the high mortality rate into perspective, for Curlew numbers to remain stable or even increase, few chicks need to fledge as few adults will need "replacing".

However, the productivity required to maintain the Curlew population on Monk's Moor for example (following the method of Berg 1994) was 0.77 chicks per pair. Therefore the productivity of 0.14 fledglings per pair on Monk's Moor is too low to maintain the population. The decrease in the estimated number of breeding pairs from 25 to 22 over the three-year study (see chapter 4) could be a reflection of this. Since productivity is variable between years (see Boschert and Rupp 1993), it is possible that productivity may increase in future years. However, it is also possible that productivity will remain low. In fact the latter may be the most likely scenario in the long-term as a number of local farmers and residents throughout Teesdale have commented that Curlew numbers have been declining in recent years (though there is no data to support this). It has been suggested that low reproductive success is a major factor in the decline of Curlew populations on Swedish farmland (Berg 1994), but more extensive, longer-term studies would need to be carried out to determine population trends and the causes of them in Britain.

There were a number of causes of chick mortality identified, including predation, bad weather and possibly disease in one case. However, the major cause of chick mortality by far was predation by Mustelids. Predation definitely accounted for a mean of fifty percent of radio-tagged chick deaths. This was confirmed by jaw marks, most commonly on the head or neck, on the carcasses, many of which were buried, attributes characteristic of stoat attacks (Lindsay Waddell, pers. comm.). It is likely that a further eighteen percent (mean) of chicks that disappeared were also predated (see results), possibly by avian predators (hence the loss of radio-contact if the tag was removed from the moor).

Avian predators are known to take precocial chicks (see Parish and Coulson (in prep) and Redpath and Thirgood 1997 for example) and there was evidence of this on Monk's Moor. For example, a radio-tag from a Curlew chick was found surrounded by plucked down, most likely the victim of a raptor (L. Waddell pers. comm.). In addition, while investigating the feeding site of a Short-eared Owl on Monk's Moor, a blue colour ring was found. On further investigation the complete set of colour rings and metal ring from a chick ringed in the previous year were found within a pellet. Short-eared Owl have also been found to take Red Grouse chicks (Redpath and Thirgood 1997).

Bad weather has a direct effect on Curlew chicks, particularly the very young. In bad weather (cold and wet) the chicks need to be incubated by the adult Curlew (and can be regularly incubated until they are around ten days old (Nethersole-Thompson and Nethersole-Thompson (1986)) and therefore cannot feed. If there is an extended period of such weather, particularly around hatching, the chicks cannot feed without risking exposure. This appeared to be the cause of death of several broods that hatched at the beginning of bad weather spells. These chicks had no visible signs of injury, each carcass being found crouched upright in thick vegetation. Elkins (1988) also found that weather affected survival rates of a number of nidifugous chicks (e.g. Willow Grouse and Ptarmigan *Lagopus mutus).*

Disease could also have been responsible for the death of at least one chick during the study. Up until twenty-two days old one particular chick was steadily increasing in weight but three days later it had lost forty-four grams in weight and was very inactive. Two days later it was found dead in the same location and on examination there was no signs of injury.

When the survival rate of chicks that preferred *Juncus effusus* flushes was compared to the survival rate of chicks which did not select *Juncus effusus* flushes, again, there was no significant difference. Therefore, the preference for *Juncus effusus* flushes when they were available did not appear to be a result of predator avoidance, but more likely as a result of the high abundance of Tipulids.

Implications of results

Chicks utilised all of the moorland habitats that were available to them, but preferentially chose *Juncus effusus* flushes when available. This preference could be accounted for by the high abundance of Tipulids in these wet flushes. The Kaplin-Meier survival analysis for chicks that preferred *Juncus effusus* flushes and those that did not select them (figure 5.10) indicated that having access to flushes did not result in an increased survival rate. However, this could be a result of the subjectivity in assigning chicks to a habitat type (see methods). It is possible that those chicks that preferred *Juncus effusus* flushes were predated while they were moving between flush patches and that while within the tall vegetation the risk of predation could be reduced. Though it could not be assessed in this study due to poor chick survival, it is also possible that the growth rates of chicks that preferred *Juncus effusus* flushes was better in this Tipulid rich habitat, leading to fledglings in better condition giving them a better chance of long-term survival.

Therefore, since wet flushes are beneficial to a number of other species as foraging areas (Red Grouse (Redpath and Thirgood 1997) and Golden Plover (Whittingham 1996) for example), it is recommended that flushes be created within moorland, particularly near to areas with nesting habitat preferred by Curlew (burns).

Since productivity was low, predator control could also be another important aspect of a management program designed to benefit breeding Curlew. This will be addressed in more detail in chapter 7.

CHAPTER 6.

Use of marginal farmland fields by adult Curlew

Aims of Chapter

The aim of this chapter was to characterise habitats used by adult Curlew as feeding areas, and to determine what factors influenced their choice. Information on the incubation duties of breeding Curlew was also collected as an incidental product of the study.

Introduction

County Durham, like many areas of upland Britain, is dominated by large expanses of open moorland (see chapter 2). Below these moorlands, fields managed for sheep dominate the landscape (Parker and Tallentire 1990). These areas are referred to throughout as marginal farmland. Though there is currently no published quantitative data demonstrating that moorland breeding Curlew use marginal farmland as feeding areas, casual observations suggest that fields are important feeding areas for this species. In addition, Curlew breeding on semi-natural habitats in Orkney have been found to be largely dependant on improved grasslands as feeding sites (M. Grant pers. comm.) and Golden Plover use fields surrounding their moorland breeding grounds as feeding areas (Ratcliffe 1976, Parr 1980 and Whittingham, 1996).

Previous chapters have considered the nesting habitat preferences of Curlew (chapter 4), the habitat preferences of chicks (chapter 5) and the implications of those preferences for habitat management. If marginal farmland is an important feeding area for Curlew, it may not be sufficient to provide suitable nesting and chick rearing habitats alone in order to maintain a viable population. Rather, it may be that an integrated management scheme is required, providing both suitable breeding habitats on moorland and suitable feeding habitat in adjacent fields.

The Pennine Dales Environmentally Sensitive Areas guidelines for farmers (MAFF 1994) and English Nature's Wildlife enhancement Scheme (1996) and land management for upland birds (1996) outline a number of management practices that can be carried out (or avoided) in fields to potentially benefit upland birds. These publications contain management recommendations, but whether farmers follow them is entirely voluntary (though incentive payments are made to farmers who enter the ESA and Wildlife enhancement Schemes). Habitat management recommendations within these publications include; avoiding the use of insecticides (maintaining invertebrate prey), maintaining meadows by avoiding re-seeding or ploughing (to maintain seed availability for Twite and nesting habitat for waders), maintaining areas of rushes (as wader nesting habitat), though not allowing them to overrun fields and avoiding practices such as rolling and cutting when birds (e.g. Lapwing) are nesting. This study aimed to determine which characteristics determined whether fields were used by moorland breeding Curlew so that management recommendations aimed specifically at this species could be formulated.

Fields used by Curlew can be readily identified by standardised observations, a method that has been used in many studies (see Davis 1967, O'Brien and Smith 1992 and Robson 1993 for example). Survey data can be complemented with data obtained by radio-telemetry, an approach that has been demonstrated to be effective in other studies. Radio-telemetry has been used effectively to determine the night-time location and behaviour of several species of birds (Wood 1986, Thibault and McNeil 1994 and Whittingham 1996) and mammals (Beyer and Haufler 1994). With the use of radio-telemetry, collection of such data becomes relatively rapid, as visual contact is not essential (see results). Birds can be located by triangulation of radio-tag signal source (see Wood 1986 for example) and, by using tags with position-sensitive switches, an indication of their activity can be determined (Whittingham 1996).

Radio-telemetry has also been demonstrated to be an effective method to gather data on incubation duties. Whittingham (1997), for example, showed that breeding Golden Plover show gender-defined incubation duties with females generally on-duty during the day and males generally on-duty at night. Radio-telemetry was therefore also used to gain knowledge on Curlew incubation duties.

Methods

Standardised field surveys

Before the 1995 field season began, a route that could be followed in a vehicle (for speed and convenience) was established around 166 fields. The route was approximately 25 miles in length and consisted of fields immediately surrounding the Langdon Common (figure 6.1) and Monk's Moor (figure 6.2) study areas. The field surveys were carried out once weekly from early April to mid July.

The 1995 field survey was essentially a pilot study of field usage by adult Curlew and in 1996 the survey was adapted and improved following the acquisition of additional information. The survey was increased in size because it was discovered (by radio-telemetry) that the fields most often used by Curlew from Monk's Moor were not on the original survey route. Since this discovery was made several weeks after initiation of the 1995 survey, the route was not altered that year. The number of fields surveyed in the Monk's Moor area was increased by 46 in 1996. These fields were not accessible by road, which was initially considered a key criterion for the road survey and had therefore not been included in the original survey route. The survey route in 1996 therefore had a component section that comprised fields that could only be accessed on foot. It should be noted that the foot route consisted of the majority of the fields within the maximum recorded flight distance by Curlew from Monk's Moor and not only those discovered to be used by radio-telemetry.

Since the number of fields surveyed differed between years, the data analysis was carried out separately for each year. The routine field surveys were carried out around two geographically distinct locations (i.e. fields around the Langdon Common area and those around the Monk's Moor area), approximately 16 km apart. Since the distance between the two areas was considerably greater than the maximum-recorded distance travelled by a radio-tagged adult (3km), Curlew from one site were not likely to use fields adjacent to the other site. Therefore the data from the two sites were also analysed separately.

For each field that was included in the standardised surveys, a series of variables were recorded. The variables recorded were those which were considered to have a possible influence on whether a field would be used by Curlew. The influence that the majority of the variables could have on field usage, was from the point of view of prey availability and disturbance (from potential predators or Human activity). The variables recorded were:

1) Field type – prey availability could differ in different field types. Fields were categorised as either:
1) Pasture (short sward (<10cm) due to grazing)
2) Meadow (sward >10cm)
3) Rough grazing (unimproved fields characterised by high proportions (>40%) of tussock forming grasses and rushes)

2) % Cover of rushes – this was taken as an indicator of the wetness of the soil which could again influence food availability. Also, visibility of approaching predators (e.g. foxes or stoats) could be reduced as the amount of rush increases.

3) % Cover of tussock forming vegetation – prey availability could differ between fields with a short uniform sward and those with taller, tussock forming vegetation.

4) Presence/absence of livestock – livestock could cause a disturbance to feeding Curlew. The dung of livestock could also provide a food resource for invertebrates, which could attract Curlew.

5) Presence/absence of mole hills - used as an indicator of earthworm abundance (Micol, Doncaster and Mackinlay 1994), which are a prey item of Curlew (*Cramp et al* 1983 and pers. obs.).

6) Hummocks - % of the field which was raised above the general level of the field which was taken as an indication of visibility of approaching ground level predators.

7) Slope of the field – this could effect the ease of walking within a field while searching for prey (e.g. it is more energetically expensive to walk uphill while searching for food). Slope could also effect the view of approaching predators (see chapter 4). Slope was categorised as either:

1) Flat (all less than 5°)
2) Varied (25 % greater than 5°)
3) Sloped (80% above 10°)

Several other variables were also recorded for each field, but these were taken directly from computer generated field route maps (Results-figure 6.1 & 6.2) which were constructed following the same procedure as described in the methods of chapter 2. The variables recorded from the computerised maps by direct measurement using *PC Image* were:

1) Field size – approaching predators would be less visible from small fields than large fields. Curlew would have a greater chance of escape if they could see a predator come over a wall that was some distance from them. Field area, length and breadth were measured. Since field length and breadth are directly linked to field area (larger fields have either larger length, breadth or both than smaller fields), length was divided by breadth to give an alternative variable, index of field shape. For example a perfectly square field would have a shape index=1, and the index would increase as the length increased with respect to breadth.

2) Field distance from nearest moorland – less energy would be used by foraging Curlew if they could use fields close to the moor, rather than having to fly a great distance. Field distance was taken as the shortest distance between moorland edge and field edge.

3) Field distance from road - This was taken as a measure of disturbance from human activity (vehicles and walkers). Field distance from nearest road was measured as the shortest distance between a road edge and field edge.

Since total field use over the whole field-season was being investigated, weekly field use was pooled into one data set. It was therefore necessary to redefine some of the field variables. This was the case for field type for example, since over the course of the sampling period of thirteen weeks some fields that were initially pastures became meadows. Therefore fields were defined as being in one of three categories for the data analysis;

1) **Pasture** - which were short sward pastures throughout the sampling period

2) **Pasture/meadow** - which were grazed pastures at the beginning of the sampling period, but had livestock removed to become hay-meadows.

3) **Rough grazing** - as explained previously.

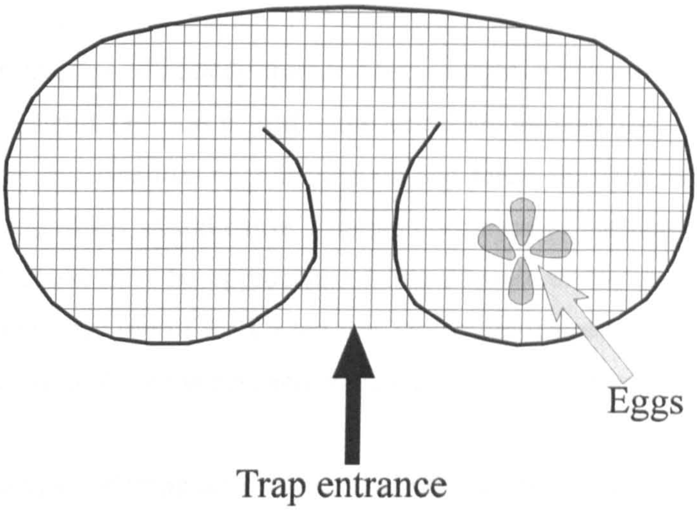
The proportion of visits that a field had livestock present was also calculated from the data collected in the field used in this analysis. This variable was referred to as livestock in the analyses.

Radio-telemetry of adult Curlew

Capturing adult Curlew for radio-tagging

As part of the 1994 field season, an attempt was made to see how readily adult Curlew could be caught on the nest. Curlew were captured using a wire mesh trap, following the method of Percival and Smith (1992). The trap used to capture Curlew was constructed from mesh of size 1 inch by 0.5 inch with the dimensions: height, 70cm; width, 90cm; breadth 60cm. Looking from above the trap consisted of a small entrance at the front leading to two large cups (Figure 6.1).

Figure 6.1. Aerial view of walk-in trap



The eggs were removed from the nest and placed in cotton wool in an insulated container to avoid the possibility of damage or chilling. "False" eggs (predated curlew eggs that had previously been filled with "Polyfilla") were used to replace the real eggs in the nest. One of the cups of the trap was then placed over the nest and secured to the ground using tent pegs, making sure that the trap entrance was facing the observer. The trap was then withdrawn from and observed (where possible) from a distant hidden position to allow the incubating adult to return.

Once the Curlew had returned to the nest and resumed incubation, the observer rapidly approached the trap entrance, causing the incubating Curlew to attempt to flee the nest. However, rather than walk towards the trap entrance and hence towards the approaching observer, the Curlew would attempt to get out the back of the trap which had no exit. The trapped Curlew could then be carefully removed from the trap and processed.

However, this trapping method was not without its problems. For example, on a number of occasions the incubating adult could not be observed returning to the nest due to the lack of suitable places to remain unobserved by the Curlew. On such occasions, after waiting for a suitable period (around 30-60 minutes, depending on weather conditions), a number of attempts at catching adult Curlew failed because the bird was not in the trap when the nest was approached.

In 1996, in an attempt to remedy this problem, a light-sensitive radio-tag (LS tag) from Holohil Systems Ltd. was placed in the nest when the trap had been set up. The rationale behind this was that once incubation had resumed, light would be cut off from the LS tag, which would cause a marked decrease in the pulse rate. At that point the nest could then be approached in an attempt to capture the incubating Curlew. However, the use of the LS tag was largely unsuccessful and in most cases it was found removed from the nest and no change in pulse rate had been detected.

The overall success of trapping Curlew was 50% (n=24), a figure similar to that found in a study of Curlew breeding on marginal farmland (M. Grant pers. comm.). The earliest a Curlew was captured was 13 days before eggs were due to hatch. However the proportion of successfully trapped Curlew rose to 59% when the trap was set within one week of hatching and to 79% if the trap was set while eggs were chipping. Setting traps near to the hatching of eggs, as well as being the most efficient time to catch Curlew, also reduces the risk of desertion (M. Grant pers. comm). No instances of desertion following the setting of a trap were recorded.

Alternative techniques for catching adult Curlew

Lamping was another technique used to catch adult Curlew and was employed during the 1995 field season. The equipment used was a powerful narrow-beamed light attached to a car battery strapped to a rucksack frame. The rationale behind this technique was that animals caught in an intense light beam become dazzled and remain motionless as they are approached (seen with rabbits caught in car headlights for example). Therefore, dazzled birds could be approached and scooped up in a long poled landing net used for fishing (S. Percival pers. comm.).

Lamping was usually only conducted on cloudy moonless nights away from any lighting, so that stalked birds could not see the stalker. Wind and rain were also favourable to mask any sound made when a bird was approached.

In conditions where there was no wind or rain, the sound of a tractor played through loud speakers was used to mask the sound of the approaching stalker. The stalked birds appeared to be less concerned about common place agricultural machinery sounds than approaching footsteps (L. Waddell pers. comm.).

However, initial trials of this technique proved unsuccessful, largely due to the infrequency of locating Curlew due to their low density.

Processing captured Curlew

Since sexes are similar in appearance, all captured Curlew were weighed and had their bill length measured to aid sexing (in general males are smaller and have shorter bills than females). Since sexes are best distinguished by bill-length (Cramp *et al* 1983), this measurement was used to sex Curlew in this study. The bill length of males is generally below 130.5mm and female bill length is generally above this (Cramp *et al* 1983). Since there is some degree of over-lap between sexes, Cramp *et al* (1983) estimate that 5% of Curlew could be wrongly sexed. However, none of the Curlew captured during this study had bill lengths within 10mm of 130.5mm and many were up to 20mm above or below this length (therefore reducing the number that could have been wrongly sexed).

Each Curlew was individually marked using a colour and metal ring combination obtained from the Wader Study Group and each was radio-tagged. The radio-tags used were Holohil 3.6g PD2 position sensitive radio-tags. These contained mercury-tilt switches that were sensitive to the position of the tag, the pulse rate doubling if the tag was tilted from horizontal to vertical. If a radio-tag was attached to the upper back of a Curlew, it would be almost horizontal when the bird was incubating or standing upright. However, if the Curlew was feeding, it's body and hence the tag, would be tilted towards the ground and the pulse rate would change. Hence, pulse-rate provided an indication of the birds' activity. Radio-tags represented less than 1% of the body-weight of adult Curlew.

Since Curlew could not be recaptured once released, a very firm radio-tag attachment was required (loose radio-tags on re-captured chicks could be re-attached if required).

To achieve a firm attachment, each radio-tag was first Superglued to a piece of cloth that was larger than each tag (following the method of Kenward (1987)). This increased the surface area that could be attached onto the Curlew. The tags were attached to bare skin below the Curlews neck, again using Superglue. Feathers surrounding the tag were also Superglued over it to increase the firmness of the attachment.

Data collection from radio-tagged Curlew

When weather conditions permitted, radio-tagged Curlew were located at least once per 24hr cycle and at every other available opportunity. All periods of the 24 hour cycle were monitored, but the majority of the records were taken from the period around dusk and early evening when the highest densities of feeding Curlew occurred on marginal farmland (L. Waddell pers. comm. and pers. obs.).

Once a radio-tagged bird had been contacted, two major questions had to be addressed; a) where was it? and b) what was it doing?

- **Where was it?**

The location of a Curlew was determined by visual sighting where possible. If visual location was not possible (generally at night or in poor weather conditions) the location of a Curlew was determined by triangulation, which involved determining the pulse direction from three locations. The observer's location was put on a map and a line drawn from it in the direction of the tagged Curlew. Lines were drawn from each observation location and the point at which the three lines crossed was taken as the location of the Curlew.

The methods detailed so far were used to address the major question in the aims of this chapter which was - which fields were used by Curlew? The methods outlined below were used to address questions regarding the behaviour of Curlew: The second question that needed to be addressed once a radio-tagged Curlew was located was;

- **What was it doing?**

The activity of a Curlew was determined by visual observation where possible. Where observation was not possible, the activity of a Curlew was determined by interpretation of the pulse rate of the radio-tag. The activity of Curlew was assessed by;

a) Pulse rate action - a note was made for each of five consecutive one minute samples as to whether the pulse rate of a radio-tag was constant or variable (indicating the bird was motionless or in motion respectively). A constant pulse rate action was recorded when a pulse was emitted at equal intervals throughout the sampling period. A variable pulse rate action was recorded when the intervals between the pulses were erratic and uneven (for example, during the sample period there could have been two periods of rapid pulse rate with a period of slow pulse rate in between). The rationale behind recording pulse rate action was that it was not temperature dependant, unlike pulse rate itself (Holohil Systems Ltd.). Therefore pulse rate action was used as the indicator of Curlew activity in this thesis. Since the samples were taken over consecutive one minute periods, each cumulative five minute sample was treated as an independent data point since the activity during a minute sample was likely to influence the activity during the next sample (resulting in a lack of independence).

b) Activity by observation - where possible visual observations of feeding tagged birds were made to assess their activity. The activity of individual birds was compared to their pulse rate action to calibrate the activity of un-observed birds by their pulse rate action.

Does radio tagging have an effect on adult Curlew feeding rates?

Though other studies have reported no effects of radio-tags on Curlew (Grant and Smith 1996) and Golden Plover (Whittingham 1997), the possibility remained. Therefore a comparison was made between the peck rate of foraging radio-tagged and non-tagged (control) Curlew.

The numbers of pecks per minute were recorded by visual observation of tagged birds and control birds. The data were analysed using a Mann-Whitney U test.

Assessment of incubation duties by radio-telemetry

The incubation duties of Curlew were investigated using radio-tagged birds. The locations of radio-tagged Curlew and their pulse rate action were used to determine whether Curlew were incubating or not.

However, radio-telemetry allowed only a tentative look at the incubation duties of Curlew. The problem encountered was that the sample of individuals that could be used to determine incubation duties was small. This was mainly due to the fact that the majority of the Curlew were captured close to the hatch date of chicks. Therefore there was not a long enough sampling period to gather information.

Another cause of the low sample size was that a constant pulse rate action did not necessarily mean that a Curlew was incubating (see table 6.9). On a number of occasions, radio-tagged Curlew were observed loafing (giving a constant pulse rate action) near to the nest while its partner was incubating. Therefore a constant pulse rate action from the vicinity of the nest did not necessarily mean that the tagged Curlew was incubating. Therefore only the Curlew that were confirmed to be incubating by visual confirmation and those feeding in fields (i.e. their partner was assumed to be incubating) were used to determine incubation duties (figure 6.12).

How important are fields to Curlew?

Observations carried out during this study and the comments of farmers and game-keepers suggested that fields were important feeding areas for Curlew, particularly in the evening. To obtain an indication of the importance of the fields, the proportion of the records of individual radio-tagged curlew that were on fields was calculated. Only records from evenings were used since this was the most regularly surveyed time-period since most days were used to locate nests and/or chicks.

Results

Standardised field surveys

The location of the fields surveyed in relation to the moorland study sites can be seen in figures 6.1 and 6.2. The key for the maps can be seen below figure 6.2.

Fig 6.1. Road survey fields around Langdon Common region

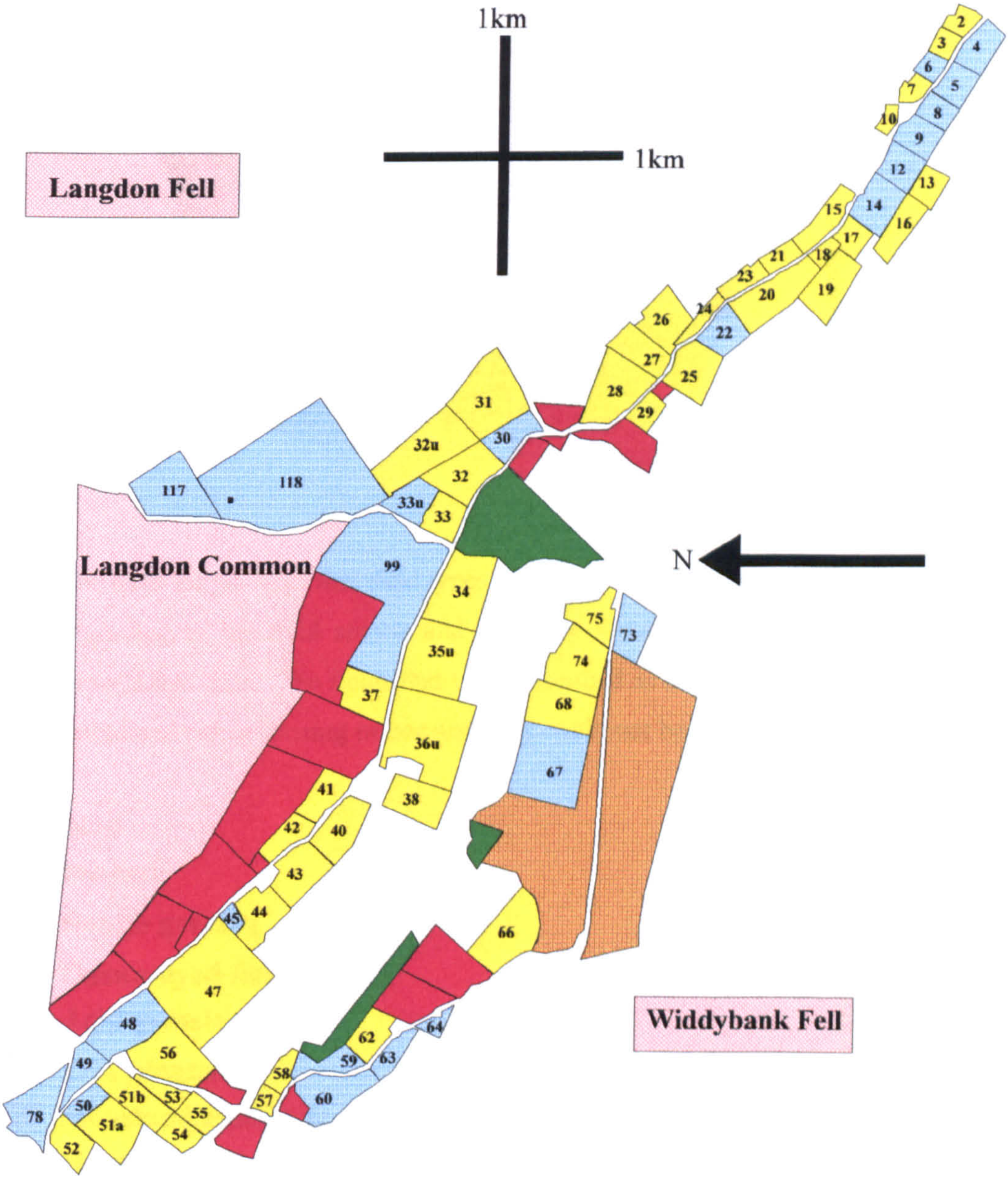
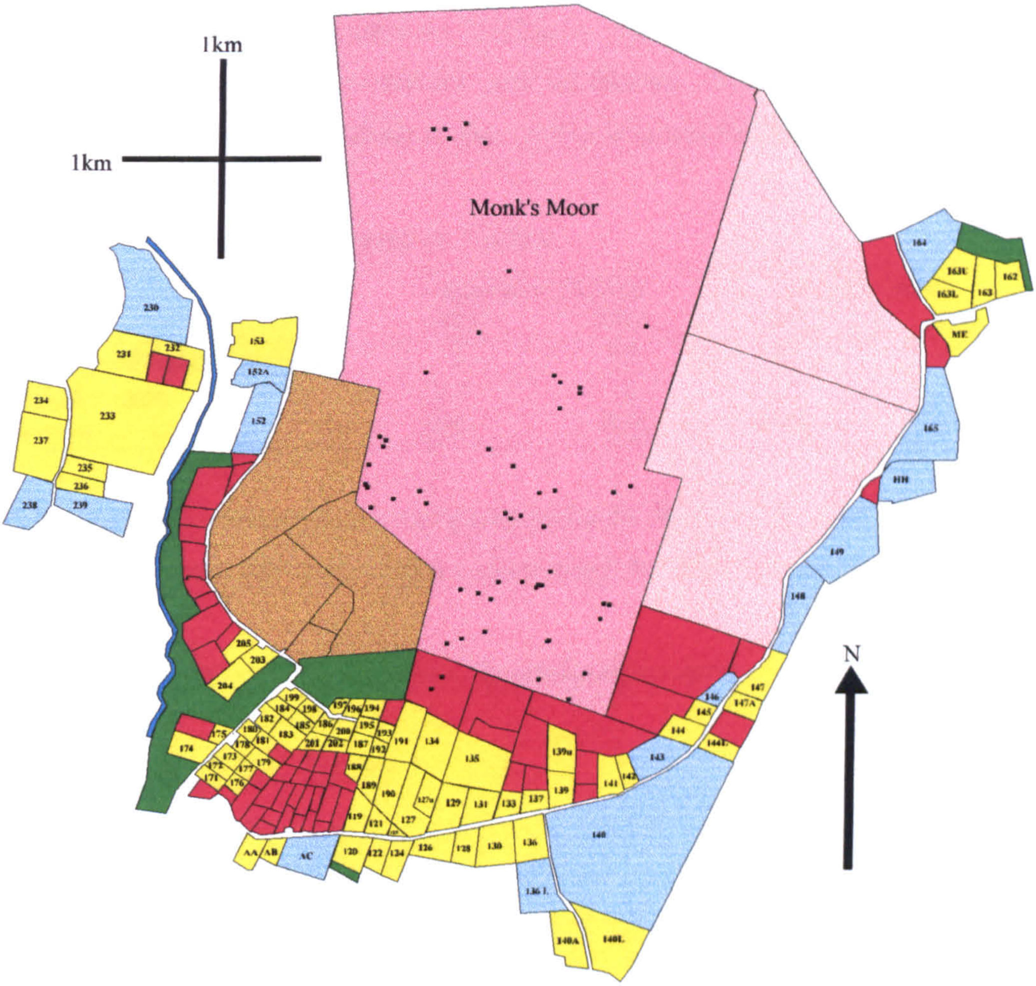


Fig 6.2. Road survey fields around Monk's Moor region



Key for field maps. Note that field types are described on these maps as they were at the beginning of the field season and therefore none of the pastures had become meadows at that time. The fields that were described as unsurveyed were so, because they contained either housing or because they could not be clearly observed.

▪ **Nest**
🟨 **Pasture**
🟦 **Rough grazing**
🟥 **Unsurveyed fields**
🟫 **Acid grassland moor**
🟩 **Tree plantation**
🟪 **Moorland study site**
⬜ **Heather dominated allotment**
🟦 **River**

The activities of Curlew were recorded while carrying out the field surveys. Each field visited by Curlew was used for feeding in. Therefore, throughout this Chapter, the term "used" was taken to indicate used for feeding. Table 6.1 below provides a summary of the numbers of fields in each survey area and the number of fields used.

Table 6.1. Surveyed fields used by Curlew

	Langdon Common		Monk's Moor	
	1995	1996	1995	1996
Number of fields surveyed	71	71	49	95
Number used	14	15	15	29
% used	20%	21%	21%	31%

Table 6.2 and 6.3 below show contingency tables for the numbers of used and unused fields in 1995 and 1996 for Langdon Common and Monk's Moor respectively.

Table 6.2. Langdon Common field use contingency table

		1996	
		Used	Unused
1995	Used	9	5
	Unused	6	51

Table 6.3. Monk's Moor field use contingency table. Note that table includes only those fields common to survey route in both years.

		1996	
		Used	Unused
1995	Used	9	6
	Unused	10	24

The main points to note from the three tables above is that relatively few of the fields that were available were used by Curlew and many of the used fields of one year were not used in the other.

Field usage by adult Curlew

Logistic regression analysis was used to analyse the field-usage data from both study areas to determine whether it was possible to predict if a field would be used by adult Curlew from its habitat management and physical characteristics.

Langdon Common study area

The results of the analysis from the Langdon Common study site data can be seen in tables 6.4 and 6.5 for 1995 and 1996 respectively. In both years, field area had a significant influence on the probability of a field being used by Curlew. In 1996, in addition to area, the presence of molehills and field shape were included in the model as their inclusion gave a significant increase in the likelihood ratio.

Tables 6.4a and b. Logistic regression model of the 1995 Langdon Common field usage data, predicting the probability that Curlew will use a field.

Table 6.4 a. Variables included in model

Variables in model	Logistic coefficient (B)	S.E.	d.f.	Significance (p-value)
Field area	3.46E-05	1.299E-05	1	0.0078
Constant	-2.8076	0.6151	1	0.0000

Table 6.4 b. Variables not included in model

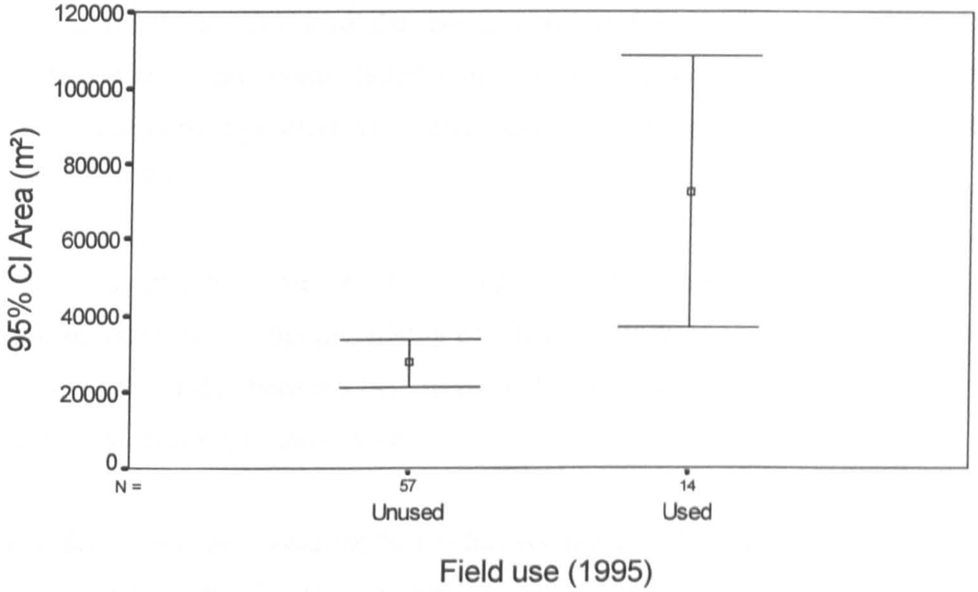
Variables not in model	Significance
Field type	0.7612
Hummock cover	0.9737
Rush cover	0.5882
Mole-hills	0.6390
Distance to moor	0.3450
Distance to road	0.3473
Field shape	0.3211
Slope	0.3531
Livestock	0.5001
Tussock cover	0.7362

The model for 1995 field usage gave a highly significant fit to the data (χ^2 goodness of fit test=13.89, df=1, p<0.001). Overall the model predicted the use of fields by

Curlew correctly in 81.69% of the cases, though the predicting of used fields was poor compared to predicting unused fields (21.4% and 96.5% respectively).

Field area had a significant influence on the probability of a field being used by Curlew. Figure 6.3 shows the relationship between field usage and field area. Curlew preferred to feed in large fields.

Figure 6.3. Error plot (95% confidence limits) of Curlew field usage and field area at Langdon Common in 1995



Tables 6.5a and b. Logistic regression model of the 1996 Langdon Common field usage data, predicting the probability that Curlew will use a field.

Table 6.5 a. Variables included in model

Variables in model	Logistic coefficient (B)	S.E.	d.f.	Significance (p-value)
Field area	7.40E-05	2.319E-05	1	0.0014
Field shape	-3.3070	1.9538	1	0.0905
Livestock	-4.2682	2.4940	1	0.8070
Mole-hills	1.3076	0.8064	1	0.1049
Constant	-0.0127	2.6742	1	0.9962

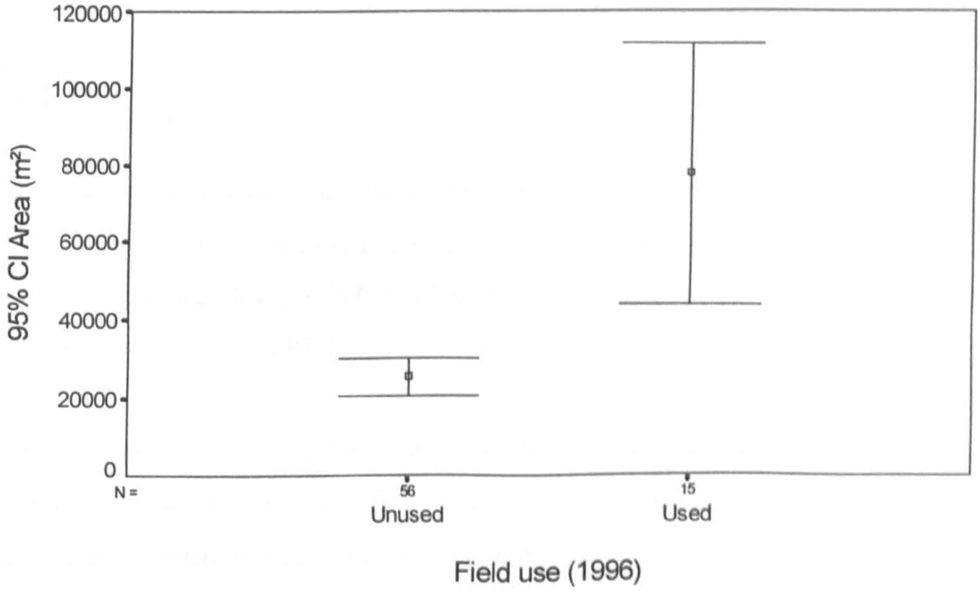
Table 6.5 b. Variables not included in model

Variables not in model	Significance
Field type	0.2200
Hummock cover	0.9893
Rush cover	0.2940
Distance to moor	0.1298
Distance to road	0.5641
Slope	0.3853
Tussock cover	0.4906

The model for 1996 field usage gave a highly significant fit to the data (χ^2 goodness of fit test=39.30, df=4, p<0.001). Overall the model predicted the use of fields by Curlew correctly in 88.7% of the cases, again predicting of unused fields more accurately than used fields (94.6% and 66.7% respectively). However, the percentage of correct predictions of used fields was a marked improvement on that obtained in 1995.

The results from 1996 confirmed the findings of 1995, indicating that field area had a significant influence on the probability of a field being used by Curlew. Figure 6.4 shows the relationship between field usage and field area in 1996. Curlew showed a preference for feeding in large fields.

Figure 6.4. Error plot area (95% confidence limits) of Curlew field usage and field area at Langdon Common in 1996



Monk's Moor study area

During both years of the Monk's Moor field survey, field area once again had a significant influence on the probability of a field being used by Curlew. In 1996, in addition to field area, distance to nearest moor also had a significant influence on the probability of a field being used by Curlew.

Tables 6.6 a & b. Logistic regression model of 1995 Monk's Moor field survey data, predicting the probability that Curlew will use a field.

Table 6.6a. Variables included in model

Variable in model	Logistic coefficient (B)	S.E.	d.f.	Significance (p-value)
Field area	3.41E05	1.594E-05	1	0.0322
Constant	-2.0774	0.667	1	0.0018

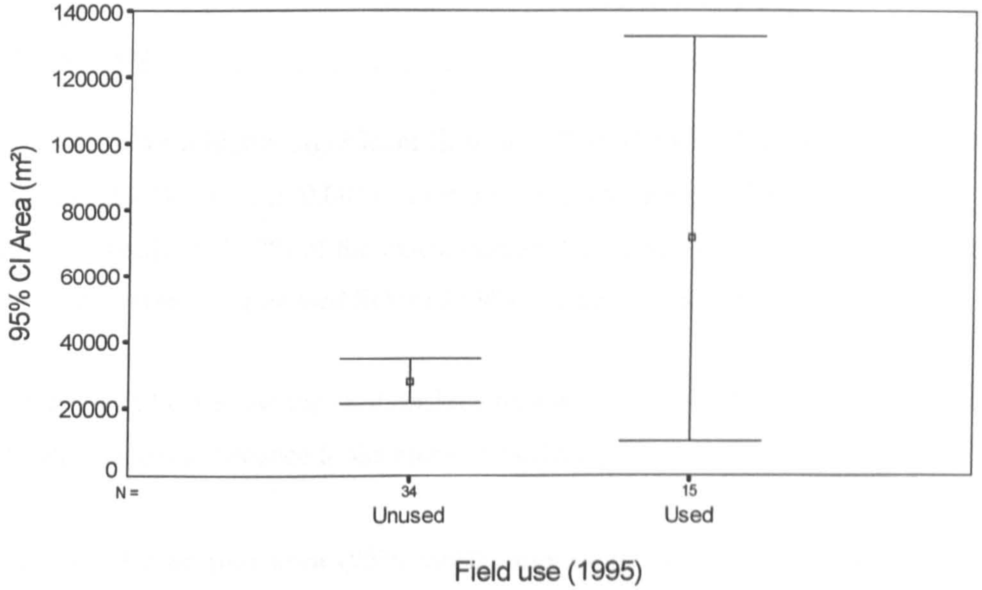
Table 6.6 b. Variables not included in model

Variables not in model	Significance
Field type	0.6261
Hummock cover	0.1400
Rush cover	0.6920
Mole-hills	0.2576
Distance to moor	0.5134
Distance to road	0.8770
Field shape	0.6729
Slope	0.7288
Livestock	0.7156
Tussock cover	0.5657

The model gave a significant fit to the data (χ^2 goodness of fit test=7.50, df=1, $p<0.01$). Overall the model predicted the use of fields by Curlew correctly in 71.43% of the cases, though the predicting of used fields was poor compared to predicting unused fields (26.7% and 91.2% respectively).

As with Curlew at the Langdon Common site, in 1995 Curlew from Monk's Moor showed a preference for larger fields. Figure 6.5 shows the relationship between field usage and field area around Monk's Moor in 1995. However, a larger range of field sizes were used at Monk's Moor in 1995 than in either year at Langdon Common causing the overlap of the 95% Confidence Interval error bars of used and unused fields.

Figure 6.5. Error plot area (95% confidence limits) of Curlew field usage and field area at Monk's Moor in 1995



Tables 6.7 a & b. Logistic regression model of 1996 Monk's Moor field survey data, predicting the probability that Curlew will use a field.

Table 6.7a. Variables included in model

Variable in model	Logistic coefficient (B)	S.E.	d.f.	Significance (p-value)
Field area	3.15E-05	1.170-05	1	0.0072
Distance to moor	-0.0022	0.0008	1	0.0038
Constant	-0.5380	0.5886	1	0.3607

Table 6.7 b. Variables not included in model

Variables not in model	Significance
Field type	0.7530
Hummock cover	0.1991
Rush cover	0.5933
Mole-hills	0.5261
Distance to road	0.8701
Field shape	0.5992
Slope	0.2738
Livestock	0.3680
Tussock cover	0.9658

The model gave a highly significant fit to the 1996 Monk's Moor data (χ^2 goodness of fit test=26.74, df=2, p<0.001). Overall the model predicted the use of fields by Curlew correctly in 73.7% of the cases, though the predicting of used fields was poor compared to predicting unused fields (37.9% and 89.4% respectively).

Figures 6.6 and 6.7 show the relationships between Curlew field usage and field area and field usage and distance to the moor respectively.

Figure 6.6. Error plot area (95% confidence limits) of Curlew field usage and field area at Monk's Moor in 1996

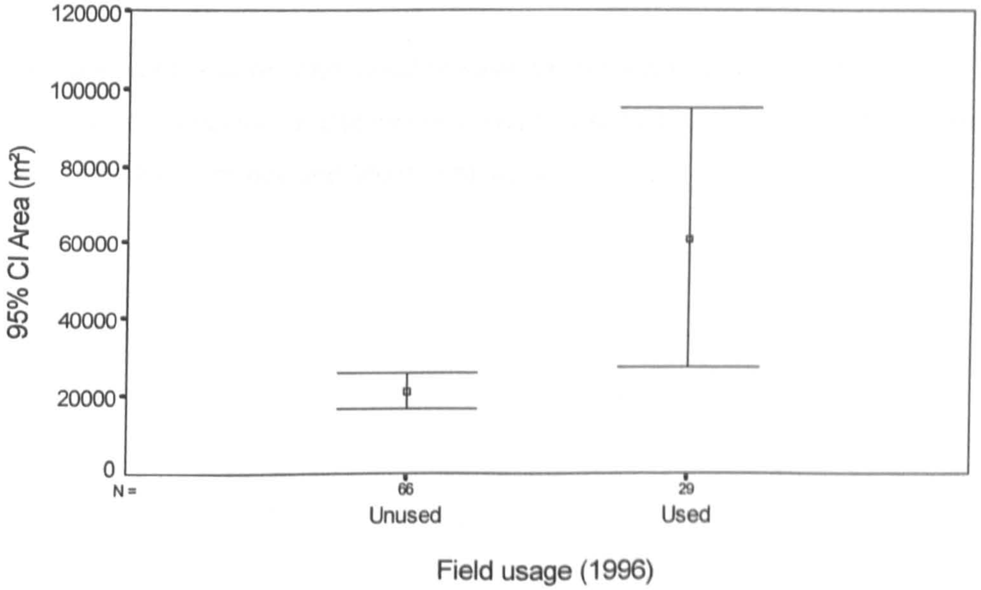
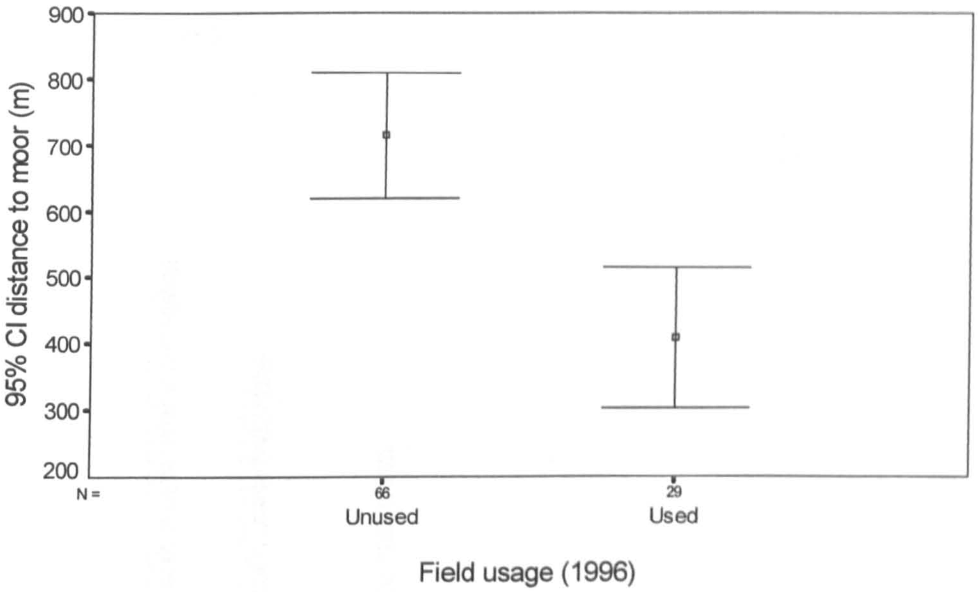


Figure 6.7. Error plot of Curlew field usage and field distance from moor (95% confidence limits).



Field area and distance to the nearest moor had a significant effect on the probability of a field being used by Curlew. Figure 6.6 demonstrated that Curlew again showed a preference for larger fields and figure 6.7 demonstrated that there was a preference of fields close to the moor.

Relative use of used fields

Figures 6.8 and 6.9 were constructed to show the weekly use of fields (for used fields only) and the numbers of Curlew that were observed during the survey periods around Langdon Common and Monk's Moor respectively.

Figure 6.8. Field usage around Langdon Common. (Note that surveys were carried out for thirteen weeks and the y axis shows the field number – see figures 6.1 and 6.2 for location)

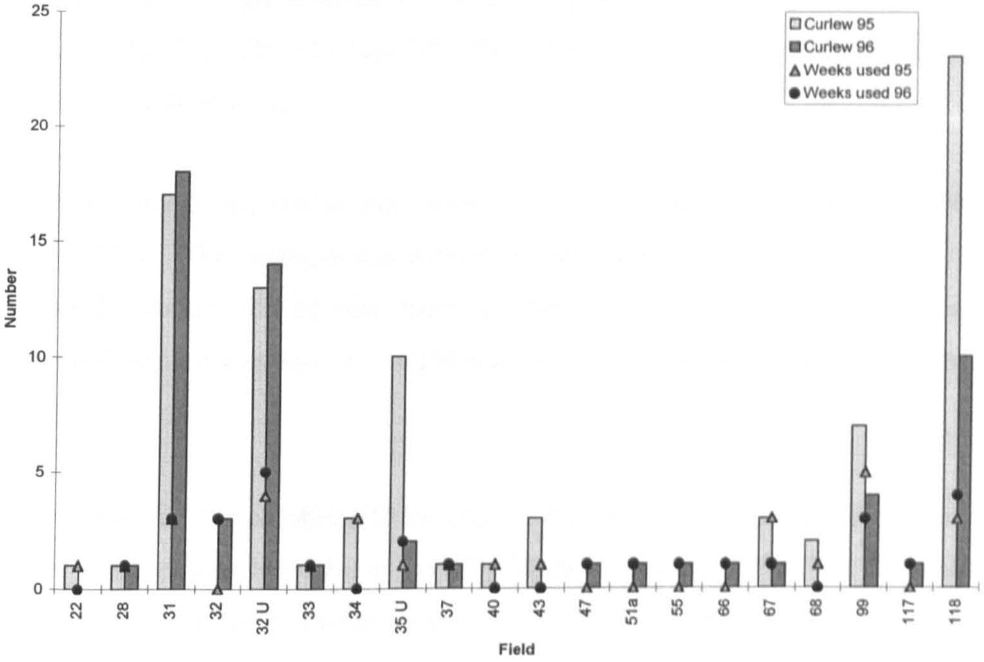
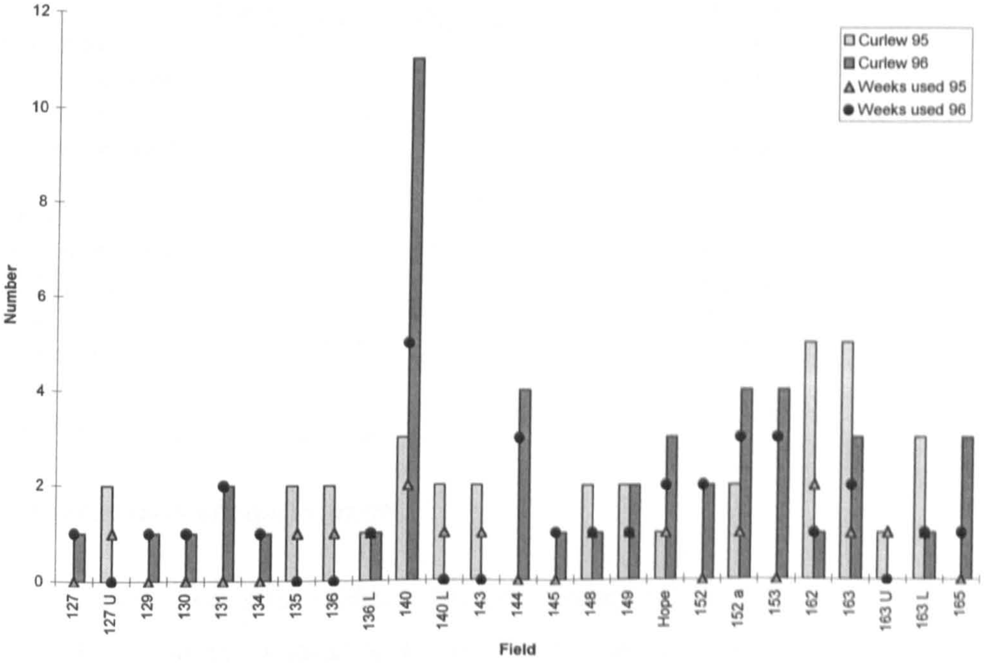


Figure 6.9. Field usage around Monk's Moor.



The main point to note from the charts is that of those fields used, a minority were used relatively regularly by a number of Curlew, while the majority were used infrequently by few Curlew. Eighteen fields were used both years and these included the fields with the highest number of weekly visits and highest numbers of recorded Curlew (fields 31, 32U, 118 and 140, the former two being pastures and the latter two being rough grazing).

A stepwise linear regression was carried out on the used field data from Monk's Moor in 1996. This analysis was carried out on the 1996 Monk's Moor data alone, because the sample size of used fields at Monk's Moor in 1995 and both years at Langdon Common was low (14 or 15) and most were used infrequently (figures 6.8 and 6.9).

The influence of the variables (those used in the logistic regression analysis) on the number of weeks each field was used at Monk's Moor in 1996 was investigated. However, none of the variables were found to have a significant influence on the number of weeks that a field was used (see table 6.8 below).

Table 6.8. Stepwise linear regression results

Variable	Significance
Field area	0.7548
Distance to moor	0.7528
Field type	0.7669
Hummock cover	0.6728
Rush cover	0.4527
Mole-hills	0.3640
Distance to road	0.3146
Field shape	0.7926
Slope	0.3690
Livestock	0.4022
Tussock cover	0.7607
Constant	0.7232

Radio-telemetry of adult Curlew

Radio-telemetry was used to address the question of what Curlew were doing as well as where they were. In order to assess what Curlew were doing, pulse rate action was calibrated to activity, which was assessed by visual observations.

Calibrating pulse rate action to activity

The activities corresponding to the two pulse rate action categories are shown below in table 6.9.

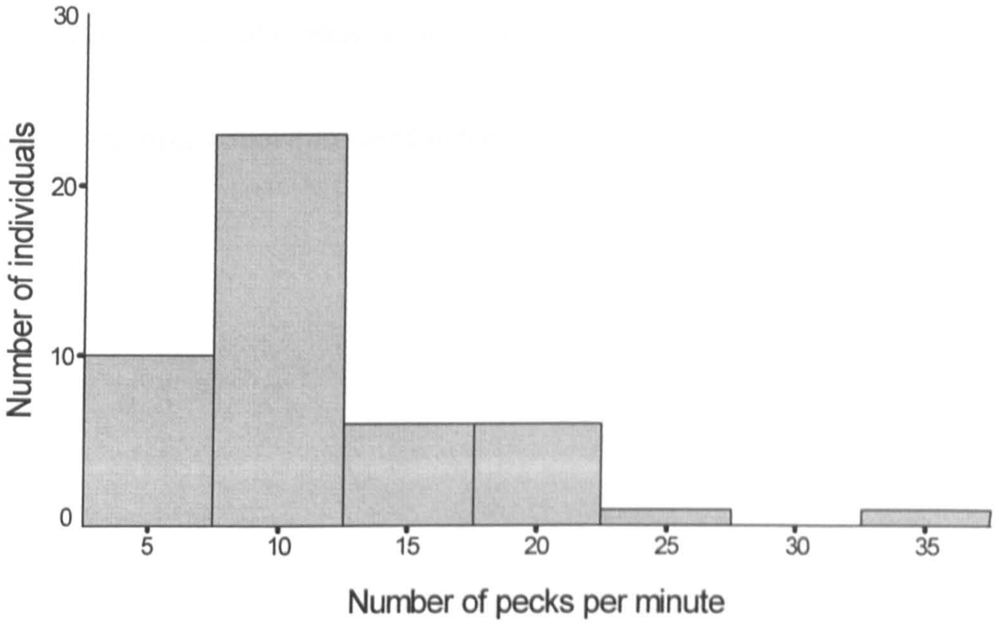
Table 6.9. Radio tagged Curlew activities. Note that the samples were taken over a one-minute period.

Pulse rate action	Activity		
	Feeding	Incubating	Other
Variable	445	0	25
Constant	0	95	135

In 94.7% of the cases a variable pulse rate action corresponded to feeding. The remaining 5.3% was taken up by either flying (<1%) or a mixture of feeding and chick guarding. Since there were no broods in the fields and pulse strength of flying birds was erratic and weak, the activity of Curlew with variable pulse rate action when in a field was taken to indicate feeding.

Whittingham (1997) described a method for using the "pulse pattern" emitted from radio-tags used on Golden Plover to estimate feeding rate. This method was inappropriate for Curlew due to differences in feeding technique between the two species. Golden Plover tend to feed in a systematic manner (bending down and then alert in a regular fashion) (Whittingham 1997). Observations of feeding Curlew have shown that this species feeds more erratically than Golden Plover, with a wide range of feeding rates demonstrated by individuals. A histogram can be seen in figure 6.10, demonstrating the range of peck rates observed in this study. Therefore, pulse rate action was used as the indicator of feeding rather than pulse pattern.

Figure 6.10. Peck rate histogram



Does radio-tagging affect feeding activity?

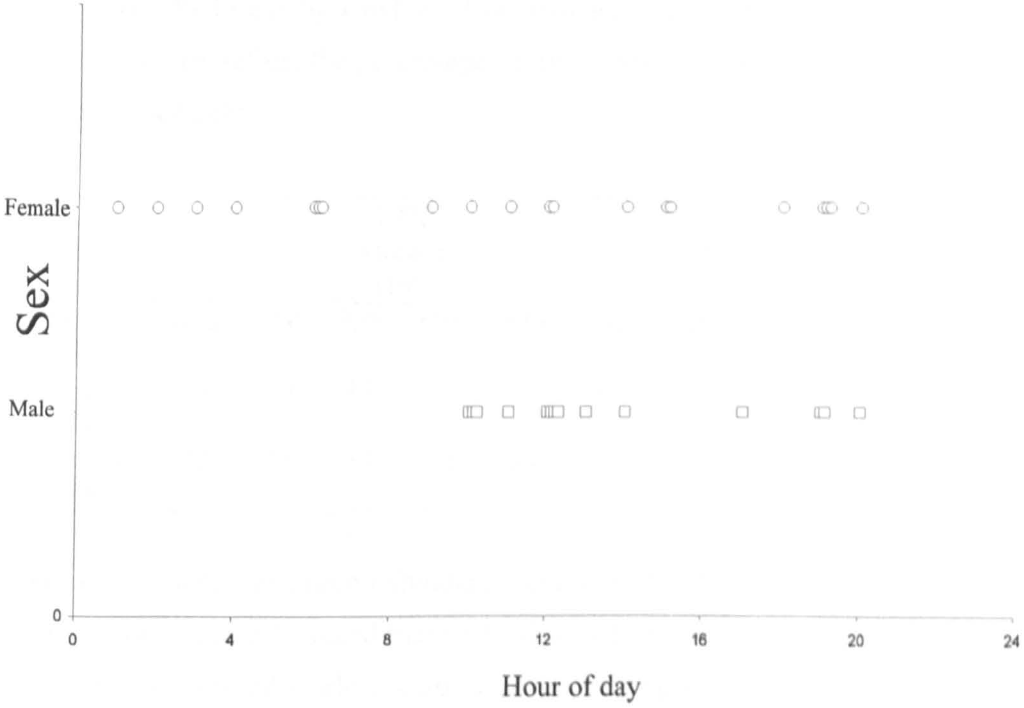
A Mann-Whitney U test was carried out on feeding rates of radio-tagged and control Curlew. There was no significant difference between the peck rates of radio-tagged birds and control birds (Mann-Whitney U=203.5, n=47, p=0.1257).

Radio-tagged Curlew were observed on several occasions feeding on marginal farmland fields in flocks (up to 50 birds on one occasion). Though no quantitative data was collected from these flocks, both radio-tagged birds and non-tagged birds fed almost continuously when in the fields. These observations, along with the quantitative data above, suggest that radio tagging had no effect on the feeding activity of Curlew.

Incubation duties of Curlew

The incubation duties of Curlew can be seen in figure 6.11.

Figure 6.11. Incubation duties of Curlew



The main point to note was that there was no pattern in incubation duty periods for each sex. This was observed within pairs (i.e. the times that each individual of a pair was incubating differed from day to day) and between different pairs (i.e. males from some pairs were incubating while females from other pairs were also incubating).

How important are fields to Curlew?

Table 6.10 shows the proportion of evening records of each of eleven radio-tagged Curlew from two years and two sites.

Table 6.10. Field use by Curlew. Note that adults were recorded on moor as well as on fields. Therefore, the percentage of times each adult was recorded in a field is also expressed below.

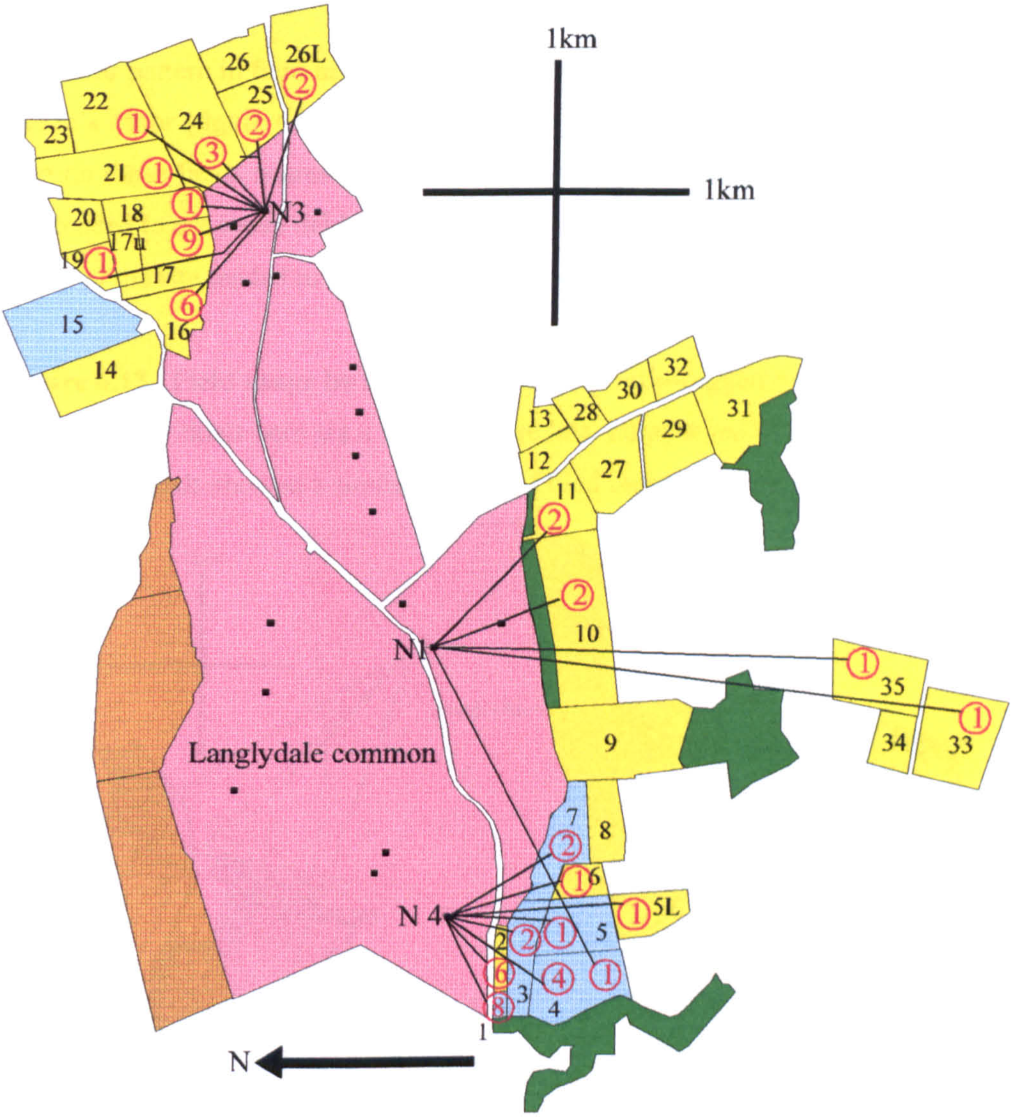
	1995 Monk's Moor						1996 Monk's Moor		1996 Langlydale Common		
Bird i.d. (tag freq.)	650	710	858	601	879	735	789	910	648	959	703
Number of records	21	19	15	15	10	11	10	13	15	17	13
% records on fields	90	58	67	13	60	55	70	69	73	71	31

Apart from two Curlew, each individual spent at least 55% of its evenings feeding in fields. It should also be noted that no Curlew without chicks was observed feeding on moorland. Several Curlew were observed feeding on the moor while guarding chicks, but this appeared secondary to guarding as peck rates were very low. These facts demonstrate that fields are very important feeding areas for Curlew.

Field usage by individual birds

Field selection at the individual level was investigated using data obtained from radio-tagged Curlew. Figures 6.12 and 6.13-6.14 show which fields were used by individuals on Langlydale Common and Monk's Moor respectively. Most of the fields visited by radio-tagged Curlew were also used regularly by small flocks of Curlew, particularly from early to late evening, with fewer fields being used by fewer birds during the day.

Figure 6.12. Field usage by individual Curlew radio-tagged on Langlydale Common. Note that those fields containing a red circle are those used by the individual curlew from the nest connected to them by a black line. The number within the red circle indicates the number of recorded visits to the field.

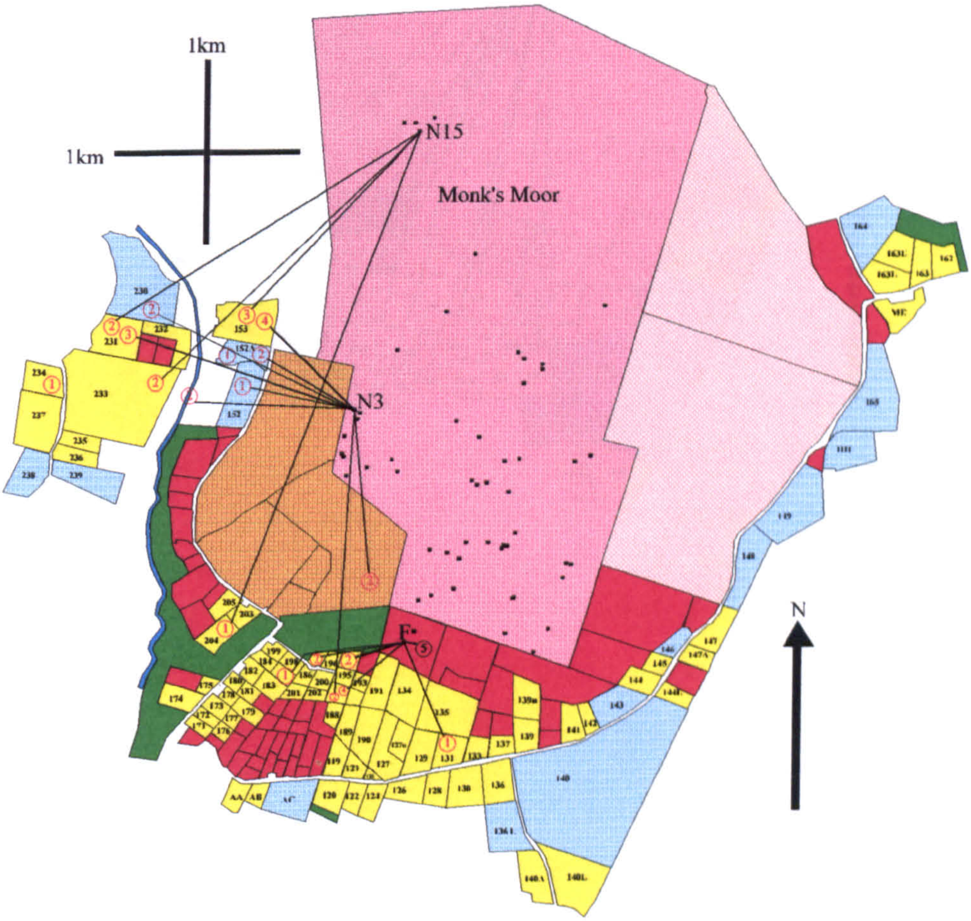


The main point to note from the distribution map is that individual Curlew tended to use those fields that are closest to them. This takes the logistic regression result one step further, since the distance of the fields were measured from the moorland edge. In the case of individual birds the distance from the nest appears to be important in determining whether or not a field was used. The distance from the nests of used and unused fields was found to be significantly different (Mann-Whitney U=244.5, n=109, p=0.000).

Individuals from nest 3 and 4 used a completely different set of fields with no overlaps. The map indicates that field type (when rough grazing or pasture) appeared to be unimportant when considering feeding site. The tagged Curlew from nest 3 was only recorded on pasture whereas the Curlew from nest 4 used a mixture of pasture and rough grazing (NB field type was not included in the logistic regression model).

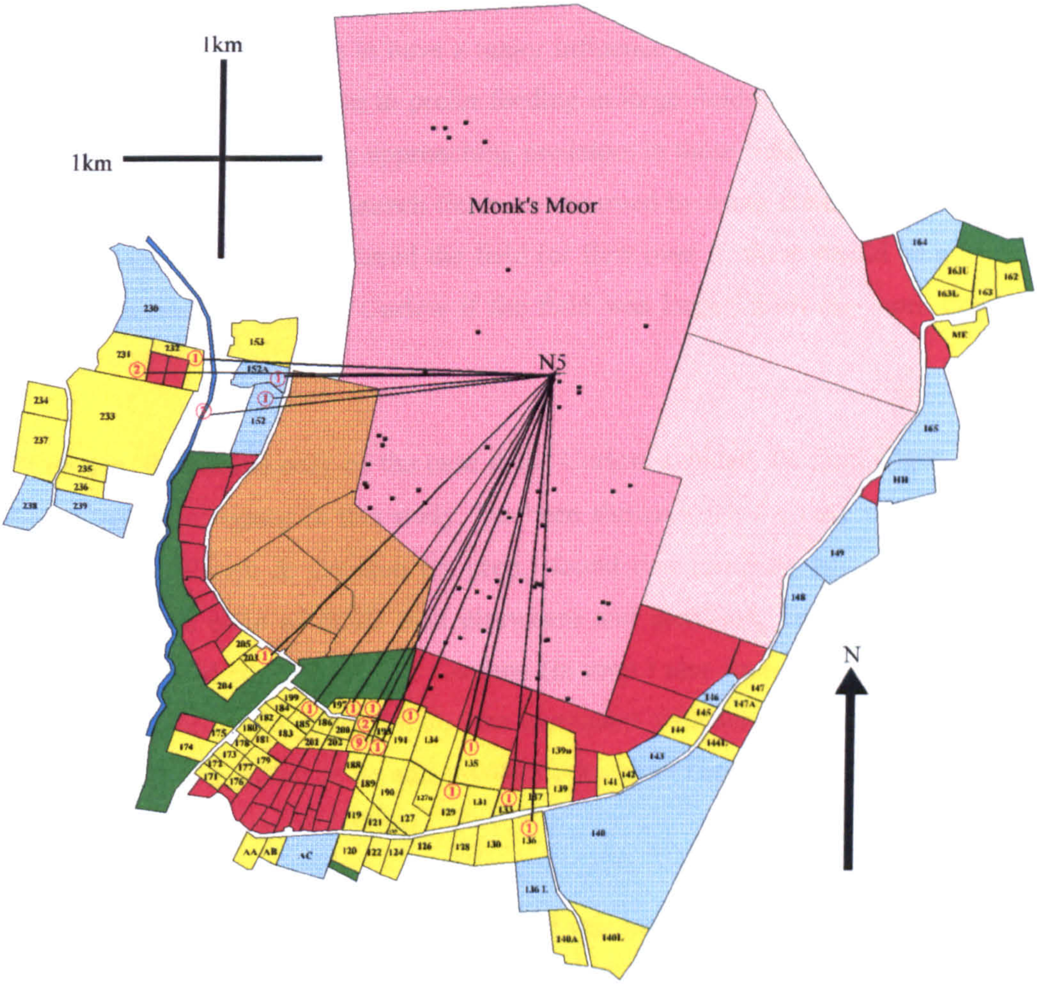
A similar pattern in field usage was observed in individually radio-tagged Curlew on Monk's Moor (figure 6.13). The majority of the records of individual Curlew were also on those fields nearest to their nest. The tagged Curlew from the North of the site tended to use those fields to the North of the area and the tagged Curlew from the South of the site tended to use those fields to the South of the area.

Figure 6.13. Field usage by individual Curlew radio-tagged on Monk's Moor. Note the individuals here are a sample of the total number radio-tagged. All the other individuals showed a similar pattern of field usage.



The nest of the individual Curlew in figure 6.14 was situated relatively centrally. Again the majority of the records from this individual were on fields closest to the moor (but this individual had to travel further to get there).

Figure 6.14. Field usage by individual Curlew radio-tagged on Monk's Moor.



Discussion

Field usage by adult Curlew

The major aim of this chapter was to determine the characteristics of fields used by feeding Curlew. Within the fields surveyed, at both sites and during both years of the study, only area was shown to have a major influence on whether they were used by Curlew. Curlew were shown to prefer feeding in large fields which may be because of better visibility to observe approaching predators in these fields. It is possible that potential predators could approach fields un-observed by using the dry-stone walls as cover. Once the predator entered the field (or flew over it) there would be a greater distance between it and the Curlew if the field was larger, allowing more time for escape.

Of course, this would only be the case if the Curlew avoided the field edges, which, though not investigated in this study, has been shown to be the case with Lapwing. For example, Parish & Coulson (in prep.) found that Lapwing egg predation was higher near the edge of fields than elsewhere and therefore, they tended to avoid nesting near field edges. Parish & Coulson (in prep.) also found that non-incubating Lapwing avoided field edges which was consistent with winter foraging behaviour which was also regarded as an anti-predator response (Thompson & Barnard (1983) and Barnard & Thompson (1985)).

When the number of fields that were sampled was increased around Monk's Moor in 1996, in addition to field area, distance of a field from the moor was also found to be a major influence on whether it was used. The 1996 field survey around Monk's Moor was the most definitive investigation of field use around that site as it included the vast majority of the fields available within the maximum recorded flight distance from the moor. The 1995 survey did not cover many of the fields that were used by foraging Curlew, the majority of which were close to the moor. At Langdon Common in both years, and Monk's Moor in 1995, there was much less variation in distance of field from the moor, hence this variable did not make a significant contribution to the logistic regression models.

The diagrams of field usage by individual Curlew provided further evidence to back up the findings that, given the choice, Curlew show a preference for feeding in fields near to the moor. Individual Curlew were generally found to use fields nearest to their nest.

However, the fact that Curlew show a preference for using fields closest to them is not surprising, since it is more energetically efficient to fly a short distance to feed, rather than flying a long distance. If food is available close-by there is little point in travelling further away to feed.

Field type and the variables associated with them (e.g. % rushes and % tussock forming grasses) had no influence on whether a field was used in the logistic regression analysis and no influence on the number of times each of the used fields was visited in the stepwise regression analysis. However, Curlew are able to exploit different field types by using their versatile bill to either probe into the soil for invertebrates such as worms (Cramp *et al* 1983 and pers. obs.) or probe within vegetation for surface dwelling invertebrates (pers. obs.). Therefore the utilisation of a variety of field types was expected.

Curlew were observed leaving the moor most evenings to feed in fields, often in small groups of between 5 to 20 individuals (up to 50 on one occasion). In addition, radio-tagged Curlew were observed feeding on moorland very infrequently (most individuals were not observed feeding on moorland at all), while all were frequently observed feeding on marginal farmland fields. Only Curlew guarding chicks were observed feeding on the moor, but this appeared to be opportunistic feeding rather than being a concerted effort. Therefore, marginal farmland fields were clearly important foraging areas for Curlew and were preferred over moorland for feeding.

There are several possible reasons for the use of fields as feeding areas. Food availability may be greater in fields than on moorland. This may be the case with improved pastures as improved fertility (by sheep droppings and applied fertiliser) may lead to greater invertebrate abundance (Hudson 1988). It may also be easier for Curlew to probe for earthworms (which are also likely to be at higher densities in the more fertile soil) in such areas due to the more uniform, shorter, vegetation than is generally found on moorland. Feeding in fields could also be carried out to reduce the chances of predation of both the eggs and the adult Curlew. If a non-incubating bird fed on the moor it would presumably have to do so within it's own territory if Curlew density was high (as it would be chased from the territory of other pairs). This could draw attention to the nest if a predator attempted to approach the feeding Curlew. The fact that Curlew were often observed feeding in fields in groups could also be anti-predator behaviour as there is less chance of an individual being predated if it is amongst a flock (i.e. safety in numbers) with more chance of an approaching predator being detected (Hassell and May 1985). This could increase the time available for feeding due to a reduction in the level of vigilance required by an individual (Goss-Custard 1985).

Incubation duties

Though limited data were obtained, incubation duties of male and female Curlew appeared to be variable with regards the timing of this activity. Male Curlew and female Curlew were found incubating at variable times throughout the day and night, with no definitive trend in duty. From observations of nests and data gathered from radio-tagged birds it appeared that Curlew did not demonstrate the gender defined incubation duty periods as observed in Golden Plover (Whittingham 1997).

This has been observed in other studies, for example, Spillner (1971) (in Cramp *et al* 1983) found that both Curlew sexes share incubation equally with a mean period of about 3.6 hours. D. Nethersole-Thompson (in Cramp *et al* 1983) found that in most cases both sexes share incubation in periods of 2.5-4.5 hours (though some males were found to take little part in incubation).

Change over of incubation has been observed to be influenced by disturbance. On several occasions a Curlew was flushed from its nest at which point it began alarming. This alarming has alerted the other Curlew of the pair to return to the nest area and once the disturbance has passed, resume incubation. This would be less likely to occur if a species showed such specific gender defined incubation duties as demonstrated by Golden Plover.

Implications of results

This chapter provided no evidence to warrant any change in current marginal farmland management practices as recommended in the Pennine Dales ESA guidelines for farmers (MAFF 1994) and land management for upland birds (English Nature 1996) to aid feeding Curlew. The current management of marginal farmland has produced a range of field types, all of which were used by feeding Curlew. Such fields are clearly important feeding areas for Curlew and other waders such as Golden Plover (Whittingham 1996), Whimbrel (Grant 1992b) and Lapwing (Baines 1988) and therefore management practices that reduce invertebrate availability may well reduce their value and should be avoided.

This chapter dealt with the use of marginal farmland fields as foraging areas, but they are also important nest sites for a number of waders including Curlew (M. Grant pers. comm.), Lapwing and Snipe (Baines 1988) and the management of fields can have a direct impact on nesting birds. For example, Baines (1988) found that the improvement of fields (by drainage or fertilising for example) caused a marked reduction in the breeding densities of several waders such as Curlew and Redshank (by reducing the amount of Rush cover with regards to these two species). Therefore, although the management of marginal farmland fields, with respect to foraging Curlew, requires no change, the habitat requirements of nesting waders may require specific management practices to be carried out or avoided. The implications of these results will be discussed further in chapter 7.

CHAPTER 7

Management prescriptions to benefit Curlew

Were questions to be addressed answered?

Several questions were posed in chapter 1. This chapter provides a brief summary of the answers to each of those questions (which are re-iterated below), then continues with a more detailed discussion of recommended management strategies.

Question 1 Do breeding Curlew select particular habitat types to nest in?

Nest habitat selection was investigated in chapter 4 of this thesis. It was quantitatively demonstrated that Curlew breeding on Heather moorland preferred to nest in patches of recently burnt Heather. The range of burn sizes that were used varied from 0.045ha –1.85ha and as the number of burns within an area increased, so did the likelihood of finding nesting Curlew.

Question 2 Do Curlew broods show a preference for particular habitat types and if so can prey abundance account for this preference?

Chapter 5 quantitatively demonstrated that those chicks which had *Juncus effusus* flushes within their home-range selected them, whereas those without them showed no marked preference or avoidance of any habitat, but merely used what was available to them. Invertebrate abundance was investigated in chapter 2 and it was concluded that the preference for *Juncus effusus* flushes could be accounted for by the abundance of Tipulid prey, but not by the availability of other invertebrate prey. With regards to the availability of non-Tipulid prey, it was possible that even the habitats with the poorest invertebrate abundances had sufficient to sustain chicks.

Question 3 Do adult Curlew show a preference for particular areas as feeding sites when they are not incubating?

Chapter 6 of this thesis has provided quantitative evidence that marginal farmland fields are important foraging areas for adult Curlew, with very little foraging taking place on moorland. Curlew foraged in all of the field types that were available (permanent pastures, hay meadows and rough grazings), but preferred large fields close to the moor.

Question 4 Which factors influence the productivity of Curlew on their upland breeding grounds?

The major influence on productivity was high mortality of eggs (chapter 4) and chicks (chapter 5) caused by predation. The main predators were Stoats, though Short-eared Owl, large Gulls and Corvids were also likely to have been responsible (or probably responsible) for some egg and chick predation. Infertility and damage (cause unknown) of some eggs was encountered, as was chick mortality caused by adverse weather conditions.

Question 5 Can data obtained in this study be put into use in the implementation of management plans which will be beneficial for Curlew populations?

All of questions one to four were answered successfully by this study, each of which has important management implications. Those habitats preferred by Curlew were identified, each of which can be maintained or encouraged by appropriate management. Predation was identified as the main influence on Curlew productivity and predator control could be maintained or increased in certain areas. Therefore, the information obtained by this research could be used as the basis of a habitat management plan to benefit Curlew.

Management prescriptions

1 to maintain/increase nesting Curlew numbers

Burning of Heather dominated moorland

Burning is essential if the open and varied nature of heather moorlands is to be maintained (SNH 1995) since it is this practice (and grazing) that prevents these areas from reverting to scrub and woodland (in areas below the tree-line). However, careful consideration should be given to the length of burning rotation since too frequent burning can result in invasion by grasses like Purple-moor grass and infrequent burning can result in rank Heather which has poor vegetative regeneration abilities (Mowforth and Sydes 1989).

Since the local productivity of Heather varies, it has been recommended that it should be burnt when it is between 20cm-30cm tall (Grant & Milne 1981 and Miller *et al* 1984), rather than the burning rotation being a set number of years. This would produce an optimum burning regime which would allow Heather to regain dominance, while not allowing it to accumulate too much woody material (reducing productivity) (Mowforth and Sydes 1989). Older stands of Heather also burn at higher temperatures than younger stands, which causes a reduction in vegetative and seedling regeneration (Grant 1968).

Where possible burning steep slopes and blanket bog should be avoided as there is the danger of soil erosion and controlled burning in such areas is difficult (Philips *et al* 1993). Slopes with old Heather growth also provide nesting areas for Hen Harrier (Watson 1977) and are home to some rare liverworts and mosses (Philips *et al* 1993). Some areas of longer Heather should also be maintained to provide suitable nesting habitat for Short-eared Owl (Cramp *et al* 1983). A well managed moor should therefore provide a mosaic of different aged Heather stands and other habitats resulting in an area of structural diversity.

Burning some part of a moorland should be carried out every two years, as it is these recent burns that are favoured by Curlew. In order to benefit Curlew, there should be many small burns rather than few large ones. In general, only one pair of Curlew nested in each burn and the median size of the occupied burns was 0.25ha. Therefore it is recommend that burns be no larger than 0.25ha to maximise the total number of available burns within an area of moorland. It is also recommended that the minimum distance between burns should be 50m as no pairs were found nesting any closer than this.

Creating small burns every two years will allow a suitable rotation period between burning, even on relatively small areas on moorland. For example, on a site with 45ha of Heather, 12 burns of 0.25ha could be created every two years giving a rotation period of 15 years. Of course this is a very simplistic view and site characteristics such as topography and availability of non-heather habitats needs to be taken into account for each individual site.

Burning is also beneficial to other birds. Most obviously is Red Grouse, for which burning is an integral part of the management. Therefore burning on moorland, which is not currently managed for grouse, will benefit this species as well as Curlew.

High densities of Golden Plover have also been found to be associated with rotationally burnt moorland (Thompson *et al* 1995) and other studies such as Haworth and Thompson (1990) and Reed (1985) have found a positive association with Golden Plover and rotational burning. Whittingham (1996) found that Golden Plover breeding on Widdybank Fell in Upper Teesdale showed a preference for nesting in recently burnt (<2 years old) Heather. Golden Plover have also been observed nesting in recently burnt patches of Heather while carrying out this study. Though Lapwing generally avoid higher moor with tall vegetation (Reed 1985), burning provides suitable nesting habitat, particularly on the lower edges of moorland (pers. obs.).

Grazing

When burning is carried out, the density of sheep also needs to be taken into account as heavy grazing following burning can lead to the invasion of grasses (Anderson and Radford 1994) or an increase in bare ground (Lance 1983). To prevent the invasion of grasses, the recommended grazing level on Heather moorland is 1 ewe ha^{-1} (Philips *et al* 1981), but this can be variable depending on Heather condition. For example, in areas where Heather condition is poor, NCC (1990) has recommended that ewe density should be between 0.5 and 0.75 ha^{-1} and no sheep should be allowed to feed on the moor over-winter for at least five years.

Burning few large areas of moor can exacerbate the problem of heavy grazing since sheep tend to be attracted to burns for feeding (Mowforth and Sydes 1989). Therefore, the burning recommendations to benefit Curlew (many small burns) will help to alleviate this problem as sheep will be spread their grazing over a wider area of moor (Mowforth and Sydes 1989).

Where heavy grazing has reduced Heather cover to the advantage of grasses, it is recommended that Sheep densities be reduced to very low levels, varying between several blocks of years (see NCC 1990) to help Heather recovery. In experiments carried out in the Peak District, Anderson and Radford (1994) found that reducing sheep grazing intensity resulted in a significant increase in Heather cover. They also found that the majority of the bare and eroding ground became re-vegetated. It is therefore possible to increase the quality of a moor (in terms of vegetation diversity), and to re-create an area consisting of a mosaic of different habitats of higher conservation value than the original grass-dominated moor (which was found to be relatively poor for nesting Curlew (chapter 4)).

In summary, to benefit Curlew (and other species), a number of relatively small burns should be created, avoiding steep slopes and blanket bog. Sheep grazing should be monitored and densities adjusted as appropriate, depending on their impact on Heather regeneration. As a financial incentive to reduce grazing densities, farmers may be eligible to enter the Moorland Scheme, which was introduced by MAFF. At least 20 hectares of land, containing at least 25% Heather, must be entered into the scheme (the moorland must be outside Environmentally Sensitive Areas). Providing that at least 10 ewes are removed, farmers will receive a payment of £30 for each and additional money is available for fencing.

2 to provide suitable foraging habitat for Curlew chicks

During this study chicks demonstrated their ability to use all of the habitats that were available to them. Curlew chicks used relatively dense Heather, even though other studies have reported an avoidance of this habitat by wader broods (e.g. Golden Plover (Whittingham 1996)). Although chicks used all of the habitats available to them, *Juncus effusus* flushes were used preferentially when available.

A number of studies have found that flushes have high invertebrate abundances (e.g. Galbraith *et al* 1993) and this was true of Tipulid abundance in this study, an important prey item of the chicks of several bird species (e.g. Golden Plover (Whittingham 1996), Red Grouse (L. Waddell pers. comm.) and Curlew (pers. obs.). Coulson & Butterfield (1985) commented that wet areas produce the spring peak in invertebrates and that a mosaic of wet and dry areas possess the most diverse invertebrate fauna. Gardner (1991) also commented on the importance of *Juncus/Sphagnum* dominated bogs for their distinct Carabid community, which adds to the overall diversity of Carabids on moorlands. There are also many general references to damper marsh/flush areas being rich in invertebrates (e.g. EN 1996, Watson and Miller 1973) (though the information upon which this was based is unknown).

Wet flushes are important foraging areas for Red Grouse (Redpath and Thirgood (1997) and as long ago as 1911, the importance of these areas for providing nutrition for Grouse chicks has been acknowledged (Grimshaw in Lovat 1911). The creation of flushes to benefit Golden Plover chicks was also a major recommendation by Whittingham (1996).

Therefore, it is recommended that the creation of flushes should be carried out, since Curlew chicks preferred them when available and they are beneficial to other species. The creation of flushes will increase the overall abundance and diversity of moorland invertebrates (Coulson & Butterfield 1985) and provide important foraging grounds for other wader and Grouse chicks (Whittingham 1996 and Redpath and Thirgood 1997).

Flushes can be created by blocking moorland grips and it is recommended that they be situated close to the preferred nesting site of Curlew (burns) so that they are available to chicks (and increasing the habitat diversity of a given area). Payments for blocking grips are available if the moorland is entered into the Wildlife Enhancement Scheme run by English Nature.

3 to provide suitable foraging habitat for adult Curlew

Marginal farmland was identified as the main foraging area of Curlew. There was little evidence of adults feeding on moorland, the vast majority of all feeding observations being in fields. Curlew preferred larger fields and those closer to moorland and used permanent pastures, rough grazings and meadows for foraging (all of the field types available).

Since fields are important foraging areas for Curlew (and other species *e.g.* Golden Plover (Whittingham 1996), Twite (McGhie *et al* 1994) and Black Grouse (Baines *et al* (1996)), it is important to maintain or increase the abundance of invertebrates within fields, while avoiding practices which reduce abundance. Therefore insecticide use should be avoided, as should drainage since a reduction in soil moisture reduces earthworm abundance (Gerard 1967), an important prey of a number of species (e.g. Curlew, (Berg 1993 and pers. obs.), Golden Plover (Whittingham 1996), Lapwing (Berg 1991) and Snipe (Green 1988)).

Since fields are also important nesting areas for a number of waders (e.g. Curlew, Lapwing, Redshank and Snipe), management from this perspective should also be considered. For example, Picozzi *et al* (1996) found that Redshank showed a preference for rushy pastures, and while a high proportion of dense stands are not desirable (EN 1996), some fields should have some coverage (scattered over 10-20% of the field (EN 1996)). Curlew and Snipe are also associated with areas of rush within fields (Baines 1988, M.Grant pers. comm. and pers. obs.).

Many of the key management practices mentioned (and several more) are already recommended within the Pennine Dales ESA scheme. The ESA scheme is a tiered system, with each tier having specific management prescriptions and associated payments for abiding by them. It should be noted, however, that entry into the ESA scheme is optional and many of the recommended prescriptions are within the higher tiers, which tend to be avoided by farmers (A. Brown pers. comm.). Therefore, although these prescriptions are recommended, they may not necessarily be carried out. However, where possible, these management practices should be considered, especially within those areas that are already ESA's. For those areas that do not fall within any of the ESA's, MAFF's Countryside Stewardship Scheme also provides a potential source of financial incentives for managing areas such as upland meadows and pastures to benefit wildlife.

4 Predator control to aid an increase in Curlew productivity

Of the management prescriptions discussed so far, predator control is the most labour intensive (hence expensive), the most difficult to achieve and probably the most contentious (Côté and Sutherland 1995).

Côté and Sutherland (1995) found that two thirds of predator removal programmes they reviewed resulted in increased breeding success or brood size. However, there was limited evidence of longer-term benefits (partly due to lack of data) and they recommended that predator control should be a permanent management procedure if it was to be effective in the long-term.

Though the main study sites in this thesis were keepered, predation rates were high. It is, however, probable that Curlew productivity would be lower still if it were abandoned. M. Grant (pers. comm.) found that nest predation (but not chick predation) was lower in areas where Stoats were more intensively controlled. D. Baines (pers. comm.) has also suggested that predator control could be a major reason why northern England Black Grouse populations have not shown the marked decline that has occurred in some areas of Scotland (where predator control has been reduced).

The main predators of Curlew eggs and chicks during this study were Stoats. If a Stoat comes across a clutch of eggs or brood of chicks, given the opportunity, it will take them all and store the excess prey for consumption later (L.Waddel pers. comm. and pers. obs.). Therefore, since Stoats move over large areas (Sandell 1986), one individual could potentially decimate most nests and broods and it is unlikely that even constant keepering would capture or kill every last one, therefore accounting for the high predation rates on these sites.

Whether the high predation rates observed are an insight into a long-term trend is impossible to establish from data collected over a relatively short period (three years). The results obtained from this study may only be a reflection of the lack of availability of other prey items for Stoats on the moor during the study years.

As previously mentioned, though the main study sites described in this thesis were keepered, Curlew productivity was low, with heavy predation of both nests and chicks taking place. While it could be suggested that these high predation rates were observer related, appropriate measures were taken to reduce this possibility (for example using landscape features to mark nest locations – see nest-finding methodology in chapter 4 for more detail).

In addition, anecdotal evidence suggests that predation was not observer related. For example, the fact that the same techniques for nest finding and marking were used each year, but predation rates were highly variable (18%, 32% and 65% in 1994, 1995 and 1996 respectively), suggesting that the researcher had no influence on the fate of nests. In a study of Curlew in Northern Ireland using similar fieldwork techniques, M.C. Grant (pers. comm.) quantitatively demonstrated that visiting nests and handling eggs had no influence on their survival.

In addition, Götmark (1992) noted that mammals are often believed to follow human scent or tracks in vegetation to nests made by observers, but pointed out that these predators must first learn that these signs are associated with food. When he reviewed 225 papers to investigate researcher disturbance on nesting birds (Götmark 1992) he found no evidence of increased predation by mammals.

In conclusion I would suggest that predator control should be considered if it can be maintained for the long-term, but due to its expense, would suggest that providing suitable nesting and chick rearing habitat should be given priority.

Evaluation of thesis

The research carried out on Curlew on Pennine moors in County Durham successfully answered the questions posed at the beginning of the thesis and resulted in the production of a series of management prescriptions that could be implemented to benefit Curlew breeding on Heather moorland. This was previously an area where information was lacking, an acknowledgement of which can be found in the RSPB working document of the species action plan for Curlew (Newbery & Crockford 1998). This document states that the investigation of the effects of moorland management practices on breeding Curlew such as Heather burning and predator control is essential and of high priority. Clearly, the results of this thesis address many of the issues of interest to the RSPB from the perspective of Curlew breeding ecology on Heather moorland and should be included within the final version of the species action plan for Curlew.

Although, Curlew do breed in lowland areas, it is the uplands of Britain which are their stronghold (see breeding distribution in chapter 1). As such it is in upland areas where what little research has been carried out, has focused. Research has been carried out by the RSPB on Curlew breeding ecology on marginal farmland, a habitat which may also be of major importance for this species, and in conjunction with this research a clearer picture of how uplands can be managed to benefit this species has emerged.

Using the Merlewood Land Classification System (MLCS) (see Bunce *et al* (1981) for description of land classes), an estimate of 4890km^{-2}, 28.9% of the total area of Heather moorland in Britain, had vegetation cover characteristic of Grouse moorland (Hudson 1992). However, Hudson (1992) estimated that the area of Grouse moorland was almost four times greater (16763km^{-2}) than that estimated by MLCS. This results in an estimate of 25.4% of the approximate 66000km^{-2} (29%) of Britain that is upland (Hudson 1992) being managed for Red Grouse. Though Hudson (1992) acknowledges that their estimate of the area of Grouse moor may be high due to estimation technique error, the area of land managed for Red Grouse is clearly relatively large (even when using the lower figure from the MLCS which Hudson (1992) believes to be an underestimate). Therefore Grouse moorland management is potentially very important in the conservation of Curlew.

From the perspective of nesting pairs, the provision of burns is one of the most important management prescriptions recommended to benefit Curlew and this is an area that should be pursued by further research to test findings experimentally. The burning of moorland following the specific size and location recommendations made within this thesis would be a valuable test of predictions made and would be a natural progression of the research carried out thus far.

These results also have practical implications when it comes to upland development. For example, as mentioned in Chapter 1, wind-farm development is increasing in Britain. Referring to the results of this research, any development should avoid areas of recent burn mosaics where possible, as these are likely to hold high densities of breeding Curlew. In addition, as a mitigation measure, prescribed burning could be carried out in areas some distance from the turbines to encourage Curlew (and other species) to nest away from the zone in which they could potentially be affected. If these recommendations of habitat enhancement are followed, the development of wind-farms could actually result in a positive conservation gain.

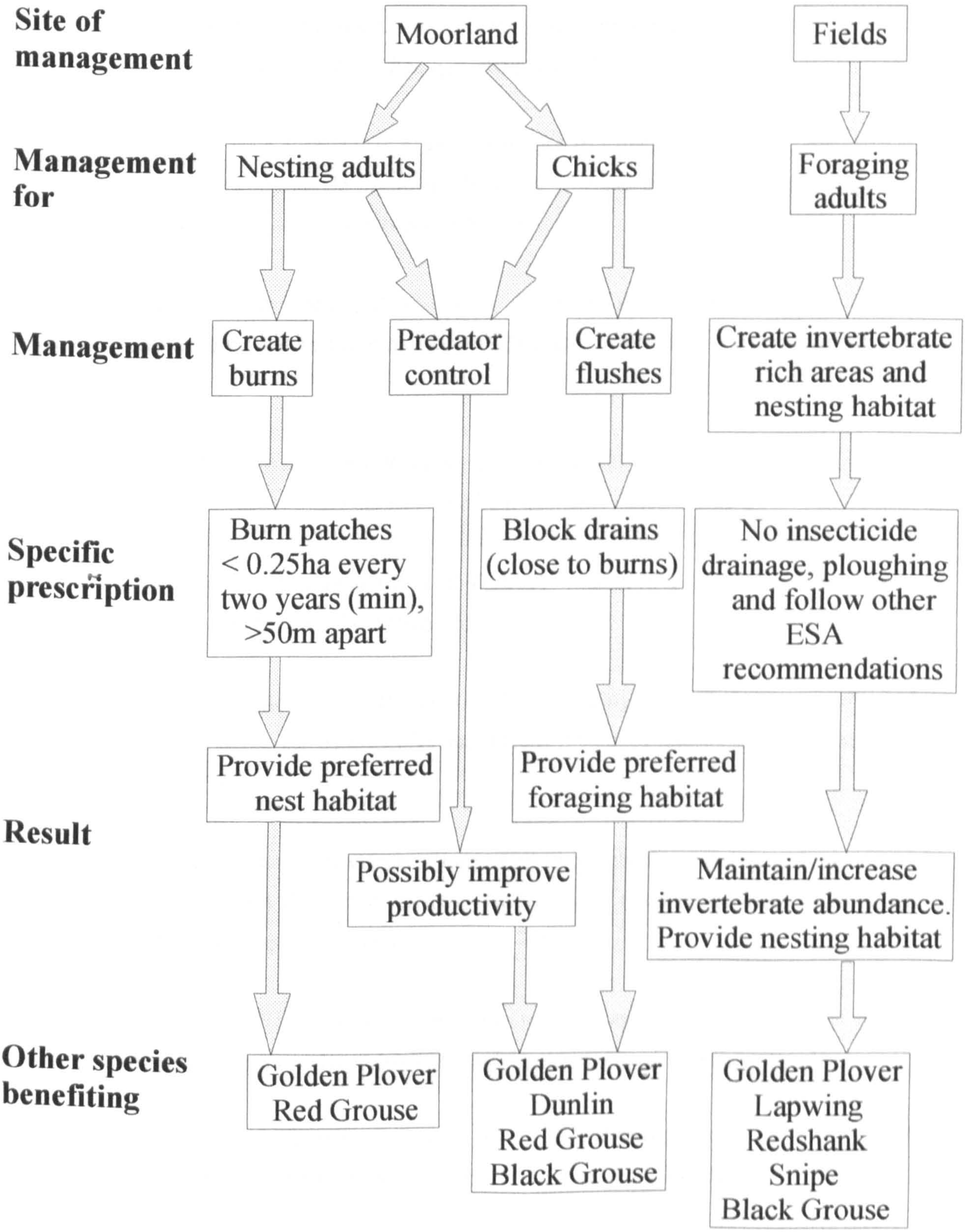
In addition to managing existing Grouse moorlands with a specific burning regime recommended by this research, following the same prescriptions may increase the numbers of Curlew breeding on other Heather moorlands which either don't have a history of Grouse management or where Grouse management has declined. This could be prohibitively expensive in some areas, but may be viable in areas of concern where Curlew numbers are declining as a result of habitat loss.

As well as maintaining or increasing preferred nesting habitat on moorland, appropriate management should also be maintained/carried out on marginal farmland. This research has clearly demonstrated that marginal farmland fields are used extensively by Curlew breeding on moorland. Therefore, if burning of moorland to benefit Curlew is being considered, the surrounding area should be surveyed to determine whether suitable marginal farmland feeding habitat is available relatively close.

Summary of proposed management prescriptions

A summary of the proposed management prescriptions, which would be of benefit to Curlew (and other species), can be seen overleaf in figure 7.1.

Figure 7.1. Management prescription summary



REFERENCES

Aebischer, N.J. & Kenward, R.E. (1993). Compositional analysis of habitat use from animal radio-tracking data. *Ecology* 74(5):1313-1325.

Anderson, P. & Radford, E. (1994). Changes in vegetation following reduction in grazing pressure on the National Trust's Kinder estate, Peak District, Derbyshire, England. *Biological Conservation* 69: 55-63.

Anderson, P. & Yalden, D.W. (1981). Increased sheep numbers and the loss of heather moorland in the Peak District, England. *Biological Conservation* 20:195-213.

Avery, M.L., Winder, F.L.R. & Egan, V.M. (1989). Predation on artificial nests adjacent to forestry plantations in northern Scotland. *Oikos* 55:321-323.

Bainbridge, I.P. & Minton, C.D.T. (1979). The migration and mortality of the curlew in Britain and Ireland. *Bird Study* 25:39-50.

Baines, D., Wilson, I.A. & Beeley, G. (1996). Timing in Black Grouse *Tetrao tetrix* and Capercaillie *Tetrao urogallus* and the distribution of insect food for chicks. *Ibis* 138:181-187.

Baines, D. (1988). The effects of improvement of upland marginal grasslands on the distribution and density of breeding wading birds (Charadriiformes) in Northern England. *Biological Conservation* 45:221-236.

Baines, D. (1991). Factors contributing to local and regional variation in Black Grouse breeding success in Northern Britain. *Ornis Scandinavica* 22:264-269.

Barnard, C.J. & Thompson, D.B.A. (1985). *Gulls and Plovers: the ecology and behaviour of mixed species feeding groups*. Croom Helm. London

Batten, L.A., Bibby, C.J., Clement, P., Elliott, G.D. & Porter, R.F. (1990). *Red Data Birds in Britain.* T & AD Poyser. London.

Baxter, E.V. & Rintoul, L.J. (1953). *The Birds of Scotland.* Oliver & Boyd. Edinburgh.

Beintema, A. J., Thissen, J.B., Tenson, D. & Visser, G.H. (1991). Feeding ecology of Charadriiform chicks in agricultural grassland. *Ardea* 79(1).

Berg, Å. (1991). Ecology of Curlews (*Numenius arquata*) and Lapwings (*Vanellus vanellus)* on farmland. Dissertation. Swedish University of Agricultural Sciences, Dept. of Wildlife Ecology.

Berg, Å. (1992a). Factors affecting nest-site choice and reproductive success of Curlews *Numenius arquata* on farmland. *Ibis* 134: 44-51.

Berg, Å. (1992b). Habitat selection by breeding Curlew *Numenius arquata* on mosaic farmland. *Ibis* 134: 355-360.

Berg, Å. (1993). Food resources and foraging success of Curlews *Numenius arquata* in different farmland habitats. *Ornis Fennica* 70:22-31.

Berg, Å. (1994). Maintenance of populations and causes of population changes of Curlews *Numenius arquata* breeding on farmland. *Biological Conservation* 67:233-238.

Beyer, D.E & Haufler, J.B. (1994). Diurnal verses 24-hour sampling of habitat use. *Journal of Wildlife Management* 58(1): 178-180.

Blair, H.M.S. (1961). *The Birds of the British Isles.* Ed D.A. Bannerman. Oliver & Boyd, Edinburgh.

Boschert, M. & Rupp, J. (1993). Breeding biology of Curlew *Numenius arquata* at a breeding site in the southern Upper Rhine valley. *Vogelwelt* 114(5): 199-221.

Braaksma, S. (1960). The spread of Curlew *Numenius arquata* as a breeding bird. *Ardea* 48:65-90.

Brown, A.F. & Shepherd, K.B.(1993) A method for censusing upland breeding waders. *Bird Study* 40: 189-195.

Bunce, R.G.H., Barr, C.J. & Whittaker, H.A. (1981). *Preliminary description of the land classes for users of the Merlewood Land Classification System.* Merlewood R. & D. Paper 86. Institute of Terrestrial Ecology, Grange-over-Sands.

Bunce, R.G.H. (1987). The extent and composition of upland areas in Britain. In *Agriculture and conservation in the hills and uplands*, edited by M. Bell & R.G.A Bunce. 19-21. (I.T.E. symposium no.23) Grange-over-Sands: Institute of Terrestrial Ecology.

Buse, A. (1988). Habitat selection and grouping of beetles (Coleoptera). *Holarctic Ecology* 11:241-247.

Butterfield, J. & Coulson, J.C. (1983). The carabid communities on peat and upland grasslands in northern England. *Holarctic Ecology* 6: 163-174.

Campbell, R.C. (1994). *Statistics for Biologists.* Cambridge University Press.

Campbell, R.W., Dawes, N.K., McTaggart-Cowen, I., Cooper, J.M., Kaiser, G.W. & McNall, M.C.E. (1990). *The birds of British Columbia.* Vol. 1. Royal British Columbia Mus., Canadian Wildlife Service, Victoria.

Chatwin, T. & Van Den Driessche, R. (1996). Monitoring the long-term effects of prescribed burning on non-game bird wildlife in a grassland ecosystem in Central British Columbia. Transactions of the North American Wildlife and Natural resources Conference (eds. K.G Wadsworth & R.E. McCabe), 61: 180-189.

Côté, I. M. & Sutherland, W.J. (1995). The scientific basis for predator control for bird conservation. *English Nature Research Reports no.144.* English Nature. Peterborough

Coulson, J.C. (1959). Observations on the Tipulidae (Diptera) of the Moor House Nature Reserve, Westmorland. *Trans. R. ent. Soc. Lond.* Vol. 111:157-177.

Coulson, J.C. & Butterfield, J.E.L. (1985). The invertebrate communities of peat and upland grasslands in the North of England and some conservation implications. *Biological Conservation* 34: 197-225.

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

Cox, D.R., (1972). Regression models and life-tables (with discussion). *J.R. Stat. Soc. B.*34:187-220.

Craig, J. (1997). Wind power and new opportunities. *ElectroTechnology* Vol 8, no.2: 28-29. The Institution of Electronics and Electrical Incorporated Engineers.

Cramp, S. Simmons, K.E.L., Brooks, D.J., Collar, N.J., Dunn, E., Gillmor, R. Hollom, P.A.D., Hudson, R. Nicholson, E.M., Ogilvie, M.A., Olney, P.J.S., Roseelaar, C.S., Voous, K.H., Wallace, D.I.M., Wattel, J. & Wilson, M.G. (1983). *Handbook of the birds of Europe, the Middle East and North Africa: The birds of the Western Palearctic Vol. 3, Gulls to Waders.* Oxford University Press. Oxford

Crockford, N.J.(1992). A review of the possible impacts of wind farms on birds and other wildlife. *JNCC.* Peterborough.

Davis, B.N.K. (1967). Bird feeding preferences among different crops in an area near Huntingdon. *Bird study* 14: 227-237.

Dobinson, H.M. & Richards, A.J. (1964). The effects of the severe winter of 1962-63 on birds in Britain. *British Birds* 57:373-434

Dobson, A. & Hudson, P..(1994). The interaction between the parasites and predators of Red Grouse *Lagopus lagopus scoticus*. *Ibis* 137: S87-S96.

Dowding, J.E. & Murphy, E.C. (1996). Predation of New Zealand Dotterels (*Charadrius obscurus aquilonious*) by stoats. *Notornis* 43:146-148.

van der Drift, J. (1951). Analysis of the animal community of a beech forest floor. *Tijdschrift vor entomologie* 94: 1-168.

Eiberle, K. & Matter, J.F. (1985). Population Ecology of Stoat and Weasel. *Z Saeugetierkd* 50(1): 40-46.

Elkins, N. (1988). *Weather and Bird Behaviour*. T and AD Poyser. Calton

English Nature. (1996). *Wildlife enhancement scheme: North Pennine Moorland SSSI's*. English Nature. Peterborough.

English Nature. (1996). *Land management for upland birds*. English Nature. Peterborough.

Erikstad, K.E. (1985). Growth and survival of Willow Grouse chicks in relation to home range size and habitat selection. *Ornis Scandinavica* 16: 181-190.

Erlinge, S. & Sandell, M. (1986). Seasonal changes in the social organisation of male stoats, Mustela erminea: An effect of shifts between two decisive resources. *Oikos* 47: 57-62.

ETSU. (1996). *Birds and wind turbines: can they co-exist?* Proceedings from a seminar organised by ETSU on behalf of the DTI at the Institute of Terrestrial Ecology. Huntingdon on the 26th March 1996.

Evans, P.R. (1991). Seasonal and annual patterns of mortality in migratory shorebirds: some conservation implications. In *Bird population studies*. Ed. C. M. Perrins, J. D. Lebreton & G. J. M. Hirons. Oxford University Press. Oxford. Pp346-359.

Evans, P.R. & Pienkowski, M.W.(1984). Population dynamics of shorebirds. In *Shorebirds: breeding behaviour and populations* edited by J. Burger & B.L. Olla, pgs 83-123. New York, Plenum Press.

Ferns, P. (1992). *Bird life of coasts and estuaries*. Cambridge University Press.

FitzGerald, J. & Carter, N. (1996). *Ruffled feathers and worse - an outline of the legal measures for the protection of birds in the United Kingdom*. Simmons & Simmons. London.

Fowler, J. & Cohen, L. (1988). *Statistics for Ornithologists*. BTO Guide No. 22.

Fretwell, S.D. & Lucas, H.L. (1970). On territorial behaviour and other factors influencing habitat distribution in birds. *Acta Biotheoretica* 19:16-36.

Fuller, R.J. 1982. *Bird habitats in Britain*. T & A.D. Poyser. Berkhemsted.

Galbraith, H.(1989). The diet of Lapwing *Vanellus vanellus* chicks on Scottish farmland. *Ibis* 131: 80-84.

Galbraith, H., Murrey, K., Duncan, R., Whitfield, D.P., & Thompson, D.B.A.. (1993). Diet and Habitat use of the Dotterel *Charadrius morinellus* in Scotland. *Ibis* 135: 148-155.

Gardner, S.M.(1991) Ground beetle (Coleoptera) communities on upland heath and their association with heathland flora. Journal of Biogeography 18:281-289.

Gerard, B.M.(1967). Factors affecting earthworms in pastures. *Journal of Animal Ecology* 36:235-252.

Gibbons, D.W., Reid, J.B. & Chapman, R.A. (1993). *The New Atlas of Breeding Birds in Britain and Ireland*: 1988-1991. T & AD Poyser. London.

Gill, J.P., Townsley, M. & Mudge, G.P. (1996). Review of the impact of wind-farms and other aerial structures upon birds. *Scottish Natural Heritage Review no 21.*

Gimingham, C.H.(1985). Age-related interactions between *Calluna vulgaris* and phytophagous insects. *Oikos* 44: 12-16.

Glutz von Blotzheim, U. N., Bauer, K.M. & Bezzel, E. (1977). *Handbuch der Vögel Mitteleuropas* Vol 7. Akademische Verlagsgesellschaft. Wiesbaden.

Goss-Custard, J.D.(1985) Foraging behaviour of wading birds and the carrying capacity of estuaries. In *Behavioural Ecology: ecological consequences of adaptive behaviour.* Edited by RM Sibly and RH Smith. Blackwell Scientific publications.

Goss-Custard, J.D., Durell, S.E.A. Le V. dit, McGrorty, S., and Reading, C.J. (1982). Use of Mussel *Mytilus edulis* beds by Oystercatchers *Haemotopus ostralegus* according to age and population size. *Journal of Animal Ecology* 51:543-554.

Götmark, F. (1992). The effects of investigator disturbance on nesting birds. In *Current Ornithology*, vol 9 edited by D.M. Power. Plenum Press, New York.

Götmark, F., Blomqvist, D., Johansson, O.C., & Bergkvist, J..(1995). Nest site selection: A trade-off between concealment and view of the surroundings? *Journal of Avian Biology* 26: 305-312.

Graham, G.G. (1988). *The Flora and Vegetation of County Durham.* The Durham Flora Committee and Durham County Conservation Trust.

Grant, S.A. & Hunter, R.F. (1968). Interactions of grazing and burning on heather moors and their implication for heather management. *British Grassland Society* 23:285-293.

Grant, M. (1989). The breeding ecology of Whimbrel (*Numenius phaeopus*) in Shetland with particular reference to the effects of agricultural improvement of heathland nesting habitats. *Ph.D. thesis*. University of Edinburgh

Grant, M. (1992). The effects of re-seeding heathland on breeding Whimbrel *Numenius phaeopus* in Shetland. I. Nest distributions. *Journal of Applied Ecology* 29:501-508.

Grant, M., Chambers, R.E. & Evans, P.R. (1992 a). The effects of re-seeding heathland on breeding Whimbrel *Numenius phaeopus* in Shetland. II. Habitat use by adults during the pre-laying period. *Journal of Applied Ecology* 29:509-515.

Grant, M., Chambers, R.E. & Evans, P.R. (1992 b). The effects of re-seeding heathland on breeding Whimbrel *Numenius phaeopus* in Shetland. III. Habitat use by broods. *Journal of Applied Ecology* 29:516-523.

Grant, M. (1994). Guidelines for County Antrim Curlew study 1994 (unpublished).

Grant, M. & Smith, M. (1996). Productivity and habitat requirements of breeding Curlew (*Numenius arquata*) on Marginal farmland in the Northern Pennines. *RSPB unpublished internal interim report.*

Grant, M. (1997). Breeding Curlew in the UK: RSPB research and implications for conservation. *RSPB conservation review no. 11.*

Grant, S.A. (1968). Heather regeneration following burning: a survey. *British Grassland Society* 23:26-33.

Grant, S.A. & Milne, J.A. (1981). Heather management. *Blackface Journal* 33:13-17.

Green G.H., Greenwood, J.J.D. & Lloyd C.S.(1977). The influence of snow conditions on the date of breeding of wading birds in north-east Greenland. *Journal of Zoology*, London 183:311-328.

Green, R.E. (1988). Effects of environmental factors on the timing and success of Common Snipe *Gallinago gallinago*. *Journal of Applied Ecology* 25:79-93.

Greenslade, P.J.M. (1964). Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). *Journal of Animal Ecology*, 33: 301-310.

Halsall, N.B. & Wratten, S.D. (1988). The efficiency of pitfall trapping for polyphagous predatory Carabidae. *Ecological Entomology* 13: 293-299.

Harding, N.J., Green, R.E. & Summers, R.W.(1994*). The effects of future changes in land use on upland birds in Britain.* RSPB/ Birdlife International report. The Royal Society for the Protection of Birds, Edinburgh.

Harris, S., Cresswell, W.J., Forde, P.G., Trewhella, W.J., Woollard, T. & Wray, S. (1990). Home-range analysis using radio-tracking data-a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* 20 (no's 2/3):97-123.

Hassell, M.P. & May, R.A. (1985). From individual behaviour to population dynamics. In *Behavioural Ecology : ecological consequences of adaptive behaviour* edited by R.M. Sibly and R.H. Smith. Blackwell Scientific Publications. Oxford.

Haworth, P.F. & Thompson, D.B.A..(1990). Factors associated with the breeding distribution of upland birds in the South Pennines, England. *Journal of Applied Ecology* 27. 562-577.

Hill, M.O. & Evans, D.F., (1977). The vegetation of upland Britain. In *The future of Upland Britain* (Vol. 2). Edited by R.B. Tranter. 436-447. Centre for agricultural strategy. Reading.

Hillery, C. & Parker, M. (1990). *Durham City and Country*. Discovery Guides Ltd. Durham.

Holpainen, J.K.(1992). Catch and sex ratio of Carabidae (Coleoptera) in pitfall traps with ethylene glycol or water. *Pedobiologia* 36:257-261.

Hoyt, D.F. (1976). The effect of shape on the surface-volume relationships of birds' eggs. *The Condor* 78: 343-349.

Hoyt, D.F. (1979). Practical measures of estimating volume and fresh weight of bird eggs. *Auk* 96: 73-77.

Hudson, P.J., (1988). Spatial variations, patterns and management options in upland bird communities. In *Ecological change in the uplands* edited by M.B. Usher and D.B.A. Thompson. Blackwell Scientific Publications.

Hudson, P.J. (1992). *Grouse in Space and Time: the population biology of a managed gamebird.* The Game Conservancy. Hampshire.

ITE. (1982). *Vegetation change in Upland landscapes.* Institute of Terrestrial Ecology. Cambridge

ITE.(1989). *Heather in England and Wales.* Institute of Terrestrial Ecology. Cambridge

Kacelnik, A. & Krebs, J.R.(1985) Learning to exploit patchily distributed food. In *Behavioural Ecology: ecological consequences of adaptive behaviour.* Edited by RM Sibly and RH Smith. Blackwell Scientific publications.

Kaplan, E.L. & Meier, P.(1958). Nonparametric estimation from incomplete obdervations. *J. Am. Stat. Assoc.* 53:457-481.

Kenward, R. (1987). *Wildlife Radio Tagging- equipment, field techniques and data analysis.* Academic Press. London.

Kenward, R.E.(1978). Radio-transmitters tail-mounted on Hawks. *Ornis Scandinavica* 9:220-223.

Kenward, R.E., Robertson, P.A., Coates, A.S., Marcstrom, V. & Karlbom, M.(1993). Techniques for radio-tagging pheasant chicks. *Bird Study* 60:51-54.

King, C.M. (1990). Stoat. Pgs:228-312 in King, C.M. (ed). *The handbook of New Zealand Mammals.* Oxford University Press, Auckland.

Kipp, M. (1982). Ergebnisse individueller Farbberingung beim grosser Brachvogel und ihre Bedeutung fur den Biotopsschutz. *Beih. Veröff. Naturschutz Landschaftspflege Bad.-Württ.* 25:87-96.

Lack, D. (1954). *The Natural Regulation of Animals.* Oxford University Press.

Lack, P.C. (ed.). (1986). *The Atlas of wintering Birds in Britain and Ireland.* T & A D Poyser.

Lance, A.N. (1983). Performance of sheep on unburned and serially burned blanket bog in western Ireland. *Journal of Applied Ecology* 20:767-775.

Larsen, T., Sordahl, T.A., & Byrkjedal, I. (1996). Factors related to aggressive nest protection behaviour: a comparative study of Holarctic waders. *Biological Journal of the Linnean society* 56:409-439.

Lovat, Lord (1911). The Grouse in health and disease: being the final report of the committee of inquiry on Grouse disease. 2 vols. Smith Elder. London.

MAFF. (1994). *The Pennine Dales Environmentally Sensitive Areas - guidelines for farmers.* MAFF.

Malloch, A.J.C. (1990). *A computer program to aid the assignment of vegetation data to the communities and sub-communities of the National Vegetation Classification.* Unit of Vegetation Science. University of Lancaster.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittington, P. (1990). *Population trends in British Breeding Birds*. British Trust for Ornithology. Hertfordshire.

Martin, T.E. (1988). Habitat and the area effects on forest bird assemblages- is nest predation an influence? *Ecology* 69: 74-84.

Matthews, D.E., Farewell, V.T. (1996). *Using and understanding medical statistics.* Karger. Switzerland.

Mayfield, H. (1961). Nesting success calculated from exposure. *The Wilson Bulletin* 73(3): 255-261.

Mayfield, H. (1975). Suggestions for calculating nest success. *The Wilson Bulletin* 87(4): 456-466.

McDonald, R.A. & Harris, S. (1998). *Stoats and Weasels*. The Mammal Society. London.

McGhie, H.A., Brown, A.F., Reed, S. & Bates, S.M. (1994). Aspects of the breeding ecology of twite in the south Pennines. *English Nature research reports no. 118.* English Nature. Peterborough.

Micol, T., Doncaster, C.P. & Mackinlay, L.A., (1994). Correlates of local variation in the abundance of Hedgehogs *Erinaceus europaeus*. *Journal of Animal Ecology* 63: 851-860.

Miller, G.R. (1979). Quantity and quality of the annual production of shoots and flowers by *Calluna vulgaris* in north east Scotland. *Journal of Ecology* 67:109-129.

Miller, G.R.(1980). The burning of heather moorland for Red Grouse. *Bull. Ecol.* 11.3: 725-733.

Miller, G.R., Miles, J. & Heal, O.W. (1984). *Moorland management: a study of Exmoor*. Institute of Terrestrial Ecology. Cambridge.

Moreby, S.J. (1987) An aid to the identification of arthropod fragments in the faeces of gamebird chicks (Galliformes). *Ibis* 130: 519-526.

Mowforth, M.A. & Sydes, C. (1989). *Moorland management: a literature review. Research & survey in nature conservation no. 25.* Nature Conservancy Council. Peterborough.

Muirburn Working Party, (1977). *A guide to good muirburn practice*. H.M.S.O. Edinburgh.

Mulder, J.L. & Swann, A.H.(1988). *De Vos in het Noordhollands Duinreservaat. Deel 5:De Wulpenpopulatie*. Rijkinstituut voor Natuurbeheer, Arnhem.

Murphy, E.C. & Dowding, J.E. (1994). Range and diet if stoats *Mustela erminea* in a New Zealand Beech Forest. *New Zealand Journal of Ecology* 18:11-18.

Murphy, E.C. & Dowding, J.E. (1995). Ecology of the stoat in *Nothofagus* forest:home range, habitat use and diet at different stages of the beech mast cycle. *New Zealand Journal of Ecology* 19:97-109.

Myberget, S. (1985). Egg predation in an island population of Willow Grouse *Lagopus lagopus*. *Fauna Norv Ser* C 8(2):82-87.

NCC. (1986). *Nature Conservation and Afforestation in Britain.* Nature Conservancy Council. Peterborough.

NCC. (1990). *Nature conservation and agricultural change.* Nature Conservancy Council. Peterborough.

Nethersole-Thompson, D. & Nethersole-Thompson, M. (1986). *Waders: Their Breeding haunts and watchers.* T & A.D. Poyser.

Newbery, P. & Crockford, N. (1998). Species Action Plan 0541 Curlew *Numenius arquata.* Unpublished working document. RSPB. Sandy.

O'Brien, M. & Smith, K.W. (1992). Changes in the status of waders breeding on wet lowland grasslands in England and Wales between 1982 and 1989. *Bird Study* 39: 165-176.

Pampush, G. J. & Anthoney, R.G. (1993). Nest success, Habitat utilisation and nest-site selection of long billed Curlews in the Columbia Basin, Oregon. *The Condor* 95. 957-967.

Parish, D.M.B. & Coulson, J.C. (In prep.) The avoidance of cover at the field edge by breeding Lapwings *Vanellus vanellus.* University of Durham.

Parker, G.A. & Sutherland, W.J. (1986). Ideal free distribution when individuals differ in competitive ability: phenotype-limited ideal free models. *Animal Behaviour* 34:1222-42.

Parker, M. & Tallentire, L. (1990). *Teesdale and the High Pennines.* Discovery guides Ltd. Durham.

Parr, R. (1980). Population study of Golden Plover *Pluvialis apricaria,* using marked birds. *Ornis Scandinavica* 11:179-189.

Parr, R. (1993). Nest predation and numbers of Golden Plovers *Pluvialis apricaria* and other moorland waders. *Bird Study* 40:223-231.

Percival, S. & Smith, C. 1992. Habitat requirements of Golden Plover: A Pilot Study. *English Nature Research Reports: No 1.*

Perrins, C.M. & Birkhead, T.R. (1983). *Avian Ecology.* Blackie. Glasgow.

Perrins, C.M.(1970). The timing of birds' breeding season. *Ibis* 112:242-255.

Philips, J.,Watson, A. & MacDonald, A. (1993). *A Muirburn code*. Scottish Natural Heritage.

Philipson, M. (1954). North-eastern bird studies. The Curlew and the Black Grouse. In *Lakeland Ornithology* (ed. E. Blezard), pp14-22. Transactions of the Carlisle Natural History Society, vol 8.

Picozzi, N., Catt, D.C. & Cummins, R.P.(1996). Breeding waders in the Caingorms Straths ESA in 1995. *Scottish Birds* 18 (4):197-204.

Prater, A.J. (1981). *Estuary birds of Britain and Ireland.* T & A.D. Poyser. Carlton.

Ratcliffe, D.A. (1976). Observations on the breeding Golden Plover in Great Britain. *Bird Study* 7:81-93.

Ratcliffe, D.A. (1986). The effects of afforestation on the wildlife of open habitats. In *Trees and wildlife of Scottish uplands*, edited by D. Jenkins. 46-54. (ITE symposium no.17.) Abbots Ripton. Institute of Terrestrial Ecology.

Ratcliffe, D.A. (1990). *Birds of Mountain and Upland.* Cambridge University Press.

Redpath, S.M. & Thirgood, S.J. (1997). *Birds of Prey and Red Grouse*. London. Stationery Office.

Redmond, R.L. & Jenni, D.A. (1986). Population ecology of the Long-billed Curlew (*Numenius americanus*) in western Idaho. *Auk* 103:755-767

Reed, T.M. (1985 a). Grouse Moors and Wading Birds. *The Game Conservancy Annual Review No. 16*: 57-60.

Reed, T.M. (1985 b). Estimates of British breeding wader populations. *Wader Study Group Bulletin* vol. 45:11-12.

Robson, G. (1993). A study of lowland farm field usage by birds. *Unpublished B.Sc. research project.* University of Sunderland.

Robson, G., Percival, S.M. & Brown A.F. (1995). The breeding ecology of Curlew: a pilot study. *English Nature research report no.127.*

Rodwell, J.S. (1991*). British Plant Communities. Volume 2 Mires and Heaths.* Cambridge University Press.

Rodwell, J.S. (1991). *British Plant Communities. Volume 3: Grasslands and Montane Communities.* Cambridge University Press.

RSPB. (1998). *Species Action Plan: Curlew.* Unpublished working document. RSPB.

Sandell, M.(1986). Movement patterns of male stoats *Mustela erminea* during the mating season. *Oikos* 47: 63-70.

Sharrock, J.T,R. (1976). *Atlas of Breeding Birds in Britain and Ireland.* T & AD Poyser.

Southwood, T.R.E. (1978). *Ecological methods.* Chapman & Hall.

Southwood, T.R.E. & Cross, D.J. (1969). The ecology of Partridge III. Breeding success and the abundance of insects in natural habitats. *Journal of Animal Ecology* 35:497-509.

Stillman, R.A. & Brown A.F. (1994). Population sizes and habitat associations in upland breeding birds in the south Pennines, England. *Biological Conservation* 69:307-314.

Stroud, D.A., Reed, T.M., Pienkowski, M.W. & Lindsay, R.A. (1987). *Birds, Bogs and Forestry: the Peatlands of Caithness and Sutherland.* Nature Conservancy Council. Peterborough.

Stroud, D.A, Reed, T.M. & Harding, N.J. (1990). Do moorland breeding waders avoid plantation edges. *Bird Study* 37(3): 177-186.

Sutherland W. J. & Hill, D.A. (1995). *Managing habitats for conservation.* Cambridge University Press. Cambridge.

Sutherland, W.J. & Parker, G.A. (1985). Distribution of unequal competitors. In *Behavioural Ecology: ecological consequences of adaptive behaviour* edited by R.M. Sibly & R.H. Smith. Blackwell Scientific Publications. Oxford.

Swihart, R.K. & Slade, N.A. (1985). Testing for independence of observations in animal movements. *Ecology* 66:1176-1184.

Thibault, M. & McNeil, R. (1994). Day/night variation in habitat use by Wilson's Plovers in Northeastern Venezuela. *Wilson Bulletin* 106(2): 299-310.

Thompson, D.B.A. & Barnard, C.J. (1983). Anti-predator responses in mixed species associations of Lapwings, Golden Plovers and Black-headed Gulls. *Animal Behaviour* 31:585-593.

Thompson D.B.A., MacDonald, A.J., Marsden, J.H. & Galbraith, C.A.(1995). Upland Heather moorland in Great Britain: A review of international importance, vegetation change and some objectives for nature conservation. *Biological Conservation* 71: 163-178.

Thompson, D.B.A., Stroud, D.A. & Pienkowski, M.W. (1988) Afforestation and upland birds: Consequences for population ecology. In *Ecological change in the uplands*, edited by M.B. Usher and D.B.A. Thompson. Blackwell Scientific Publications. Cambridge.

Thompson, D.B.A., Thompson, P.S. & Nethersole-Thompson, D.(1986). Timing and breeding performance in a population of greenshanks (*Tringa nebularia*). *Journal of Animal Ecology* 55:181-199.

Thorburn, A. (1984). *Thorburn's Mammals*. Peerage Books. London.

Topping, C.J. & Sunderland, K.D. (1992). Limitations to the use of pitfall traps in ecological studies exemplified by a study of spiders in a field of Winter wheat. *Journal of Applied Ecology* 29:485-491.

Usher, M.B. (1990). Assessment of Conservation Values: The use of water traps to assess the arthropod communities of heather moorland. *Biological Conservation* 53: 191-198.

Usher, M.B. (1992). Management and diversity of arthropods in *Calluna* heathland. *Biodiversity and Conservation* 1:63-79.

Watson, D. (1977). *The Hen Harrier.* T&AD Poyser.

Watson, A. & Miller, G.R.(1977). *Grouse Management.* The Game Conservancy. Booklet 12.

Westerberg, S. (Ed.). (in prep*).* *The summer distribution atlas of breeding birds in County Durham.*

Whitham, T. (1980). The theory of habitat selection examined and extended using Pemphigus aphids. *American Naturalist* 115:449-466.

Whittingham, M. J.(1996). Habitat requirements of breeding Golden Plover *Pluvialis apricaria. Ph.D. Thesis*. University of Sunderland.

Whittingham, M.J. (1997). The use of radio telemetry to measure the feeding behaviour of breeding European Golden-Plovers. *Journal of Field Ornithology* 67(3): 463-470.

Whittingham, M. J., Percival, S.M. & Brown, A.F.(In prep) Nest site selection by Golden Plover: Why do shorebirds avoid nesting on slopes?. University of Sunderland.

Whittingham, M. J., Percival, S.M. & Brown, A.F.(In prep) Feeding site selection by adult Golden Plover during the breeding season?. University of Sunderland.

Wood, A.G. (1986). Diurnal and nocturnal territoriality in the Grey Plover at Teesmouth, as revealed by radio telemetry. *Journal of Field Ornithology* 57(3):213-221.

Woolfenden, G.E. & Roher, S.A. (1969). Breeding birds in a Florida suburb. *Bull. Fla. State Mus. Biol. Ser.* 13:1-83.

Yalden, D.W. (1991). Radio-tracking Golden Plover *Pluvialis apricaria* chicks. *Wader Study Group Bulletin* 63:41-44.

Zar, J.H.(1996). *Biostatistical analysis*. Prentice Hall International Publications. USA.

APPENDICES

Appendix 1. Species list – in order mentioned in text

Common name	Scientific Name
Curlew	*Numenius arquata*
Heather	*Calluna vulgaris*
Red Grouse	*Lagopus lagopus*
Stoat	*Mustela erminea*
Soft Rush	*Juncus effusus*
Bracken	*Pteridium aquilinum*
Fox	*Vulpes vulpes*
Rye-grass	*Lolium perenne*
Cocks-foot	*Dactylis glomerata*
White Clover	*Trifolium repens*
Sheep's Fescue	*Festuca ovina*
Mat-Grass	*Nardus stricta*
Wavy-hair grass	*Deschampsia flexuosa*
Purple-moor Grass	*Molinia caerulea*
Heath Bedstraw	*Galium saxatile*
Bilberry	*Vaccinium myrtillus*
Bell Heather	*Erica cinerea*
Cross-leaved heath	*E. Tetrolix*
Crowberry.	*Empetrum nigrum*
Golden Plover	*Pluvialis apricaria*
Lapwing	*Vanellus vanellus*
Oystercatcher	*Haematopus ostralegus*
Sitka Spruce	*Picea sitchensis*
Lodge-pole Pine	*Pinus contorta*
European Larch	*Larix decidua*
Dunlin	*Calidris alpina*
Redshank	*Tringa totanus*
Carrion Crow	*Corvus corone*
Short-eared Owl	*Asio flammeus*
Hen Harrier	*Circus cyaneus*
Whimbrel	*Numenius phaeopus*
Twite	*Carduelis flavirostris*
Hare's Tail Cotton Grass	*Eriophorum vaginatum*
Dwarf Gorse	*Ulex minor*
Star Sedge	*Carex echiinata*
	Sphagnum recurvum
	S. auriculatum
Sharp-flowered Rush	*Juncus acutiflorus*
Common Marsh-bedstraw	*Galium palustre*
Dotterel	*Charadrius morinellus*
Black-tailed Godwit	*Limosa limosa*
Long-billed Curlew	*Numenius americanus*

Appendix 1. Species list (continued)

Common name	Scientific Name
Cheatgrass	*Taeniatherum asperum*
Weasel	*Mustela vulgaris*
Rook	*Corvus frugilegus*
Lesser Black-backed Gull	*Larus fuscus*
Kirtland's Warbler	*Dendroica kirtlandii*
Mourning Dove	*Zenaida macroura*
Raven	*Corvus corax*
Big Sagebrush	*Artemesia tridentata*
Song Thrush	*Turdus philomelos*
Sparrowhawk	*Accipiter nisus*
Pheasant	*Phasianus colchicus*
Peregrine	*Falco peregrinus*
Grey Partridge	*Perdix perdix*
Black Grouse	*Tetrao tetrix*
Capercaillie	*Tetrao urogallus*
Ptarmigan	*Lagopus mutus*
Snipe	*Gallinago gallinago*

Appendix 2. Chick locations in relation to habitat availability

Figure 1. 1994 nest 1 brood

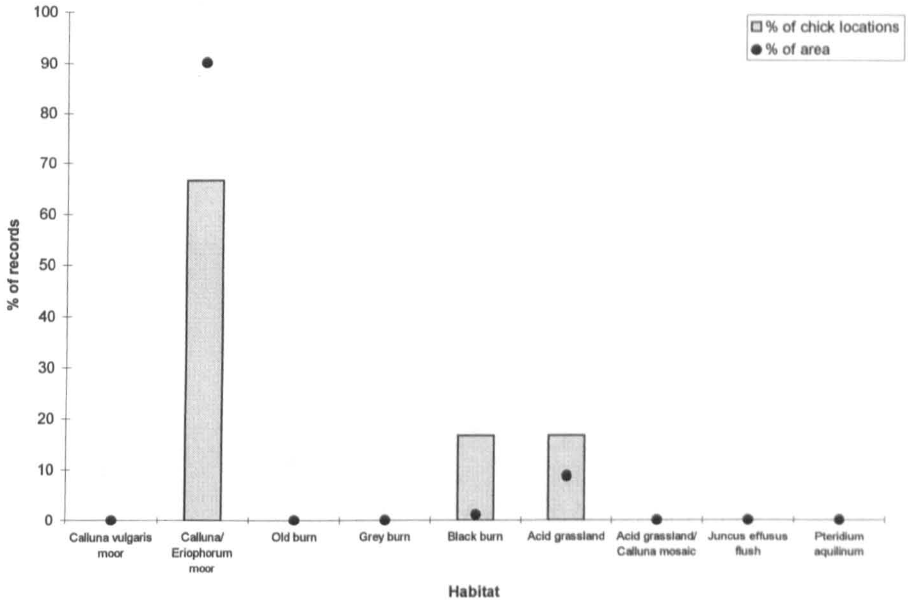


Figure 2. 1994 nest 3 brood

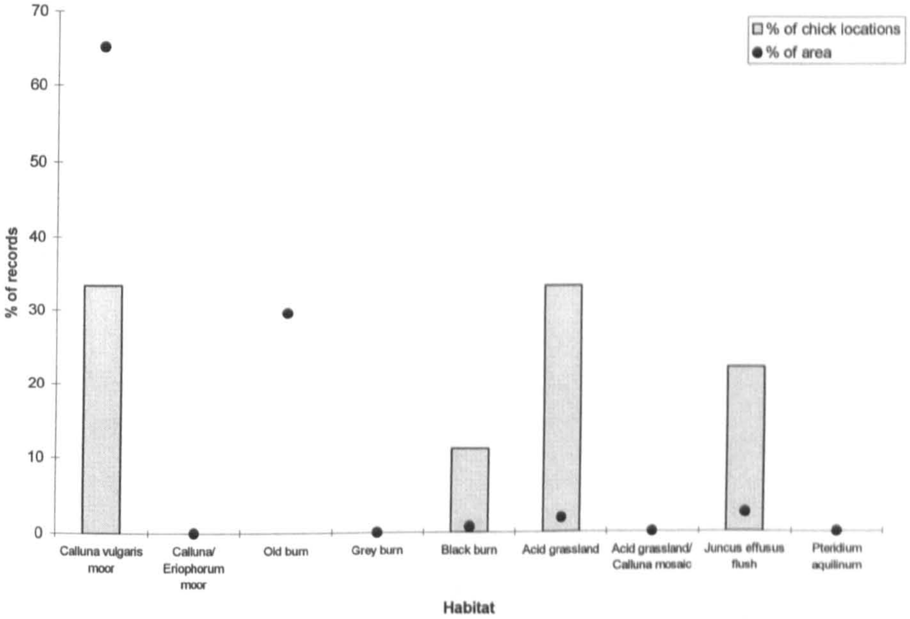


Figure 3. 1994 nest 9 brood

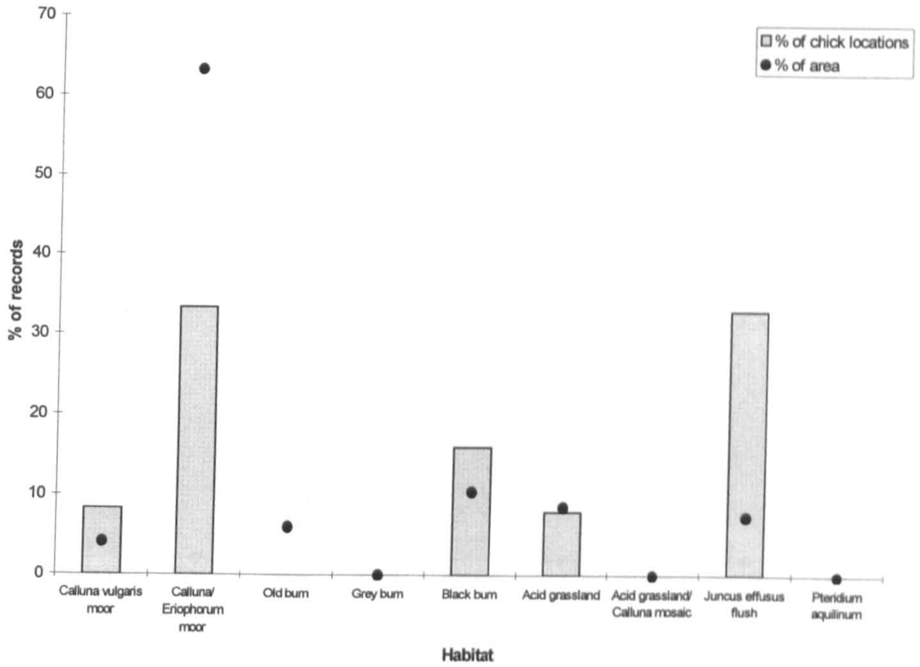


Figure 4. 1994 nest 13 brood

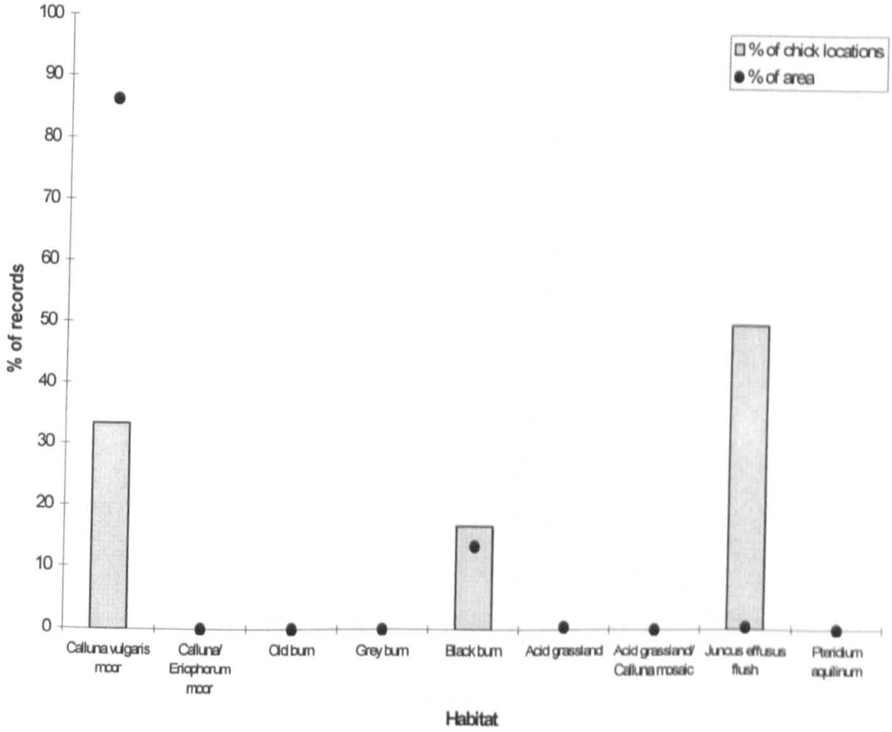


Figure 5. 1995 nest 2 brood

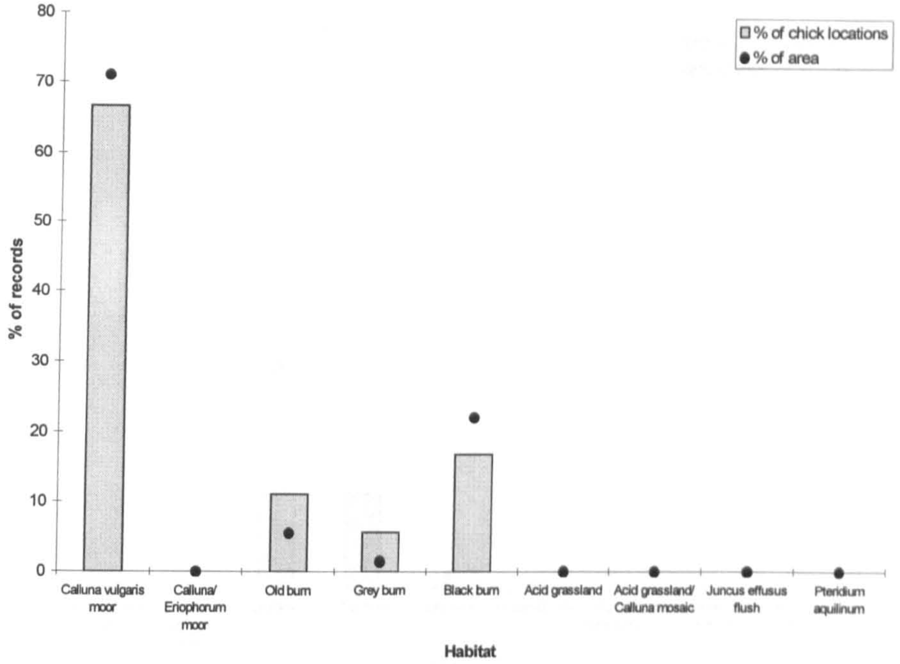


Figure 6. 1995 nest 7 brood

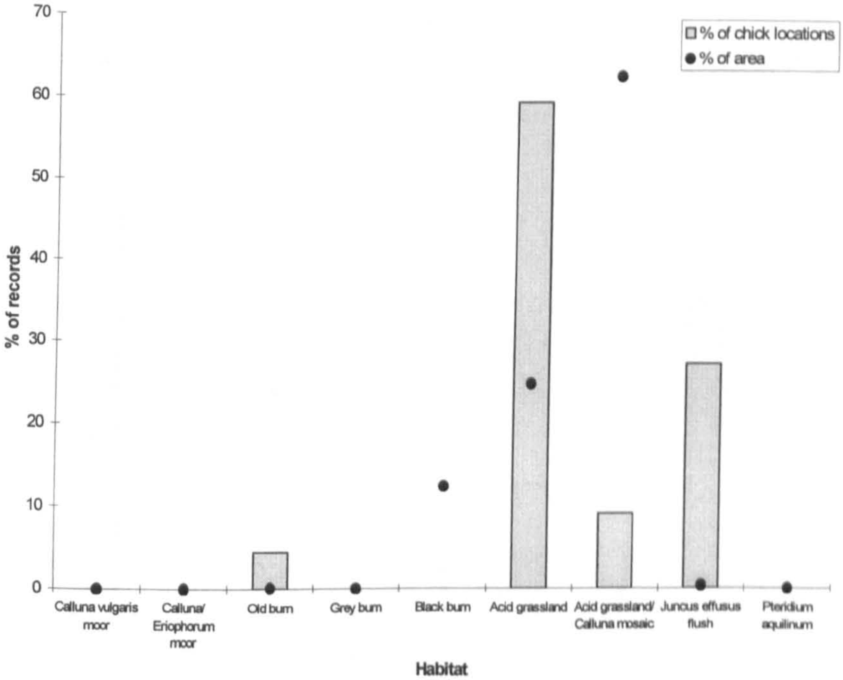


Figure 7. 1995 nest 9 brood

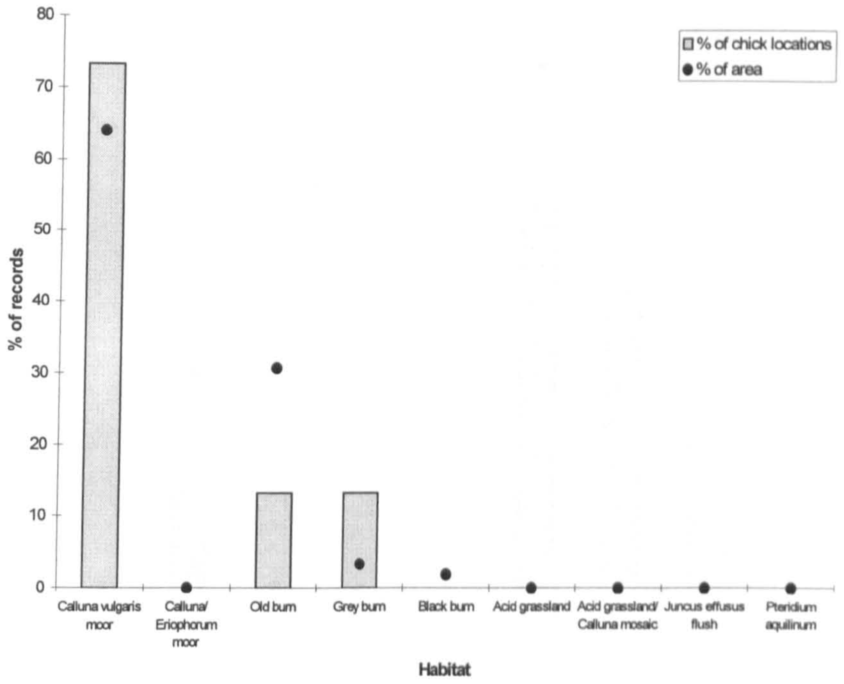


Figure 8. 1995 nest 12 brood

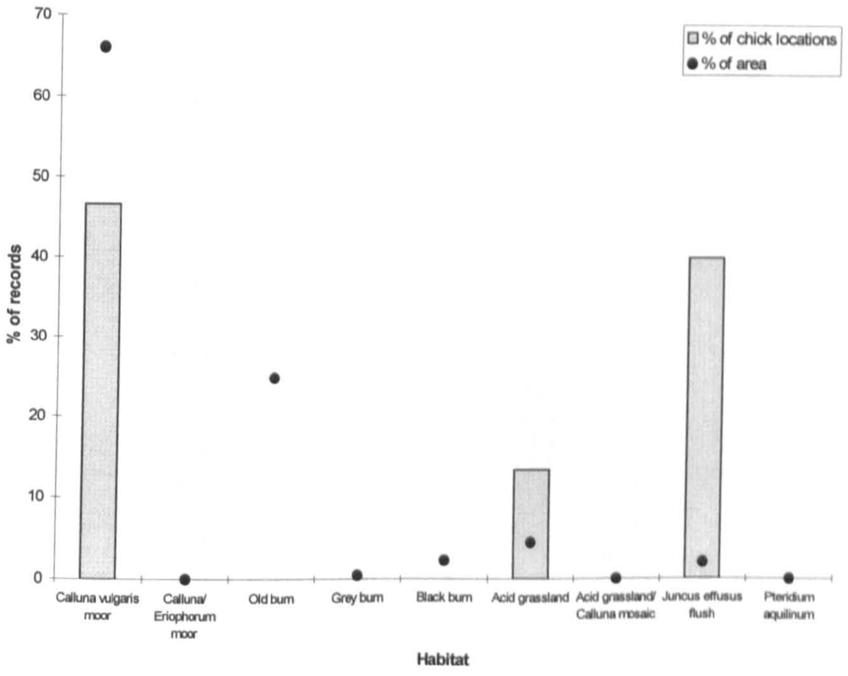


Figure 9. 1995 nest 14 brood

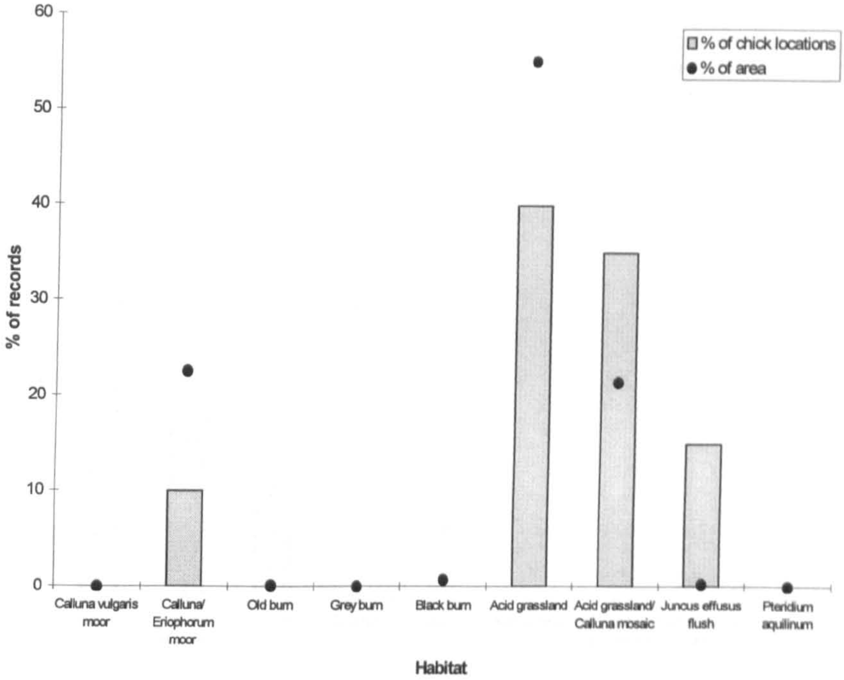


Figure 10. 1995 nest 15 brood

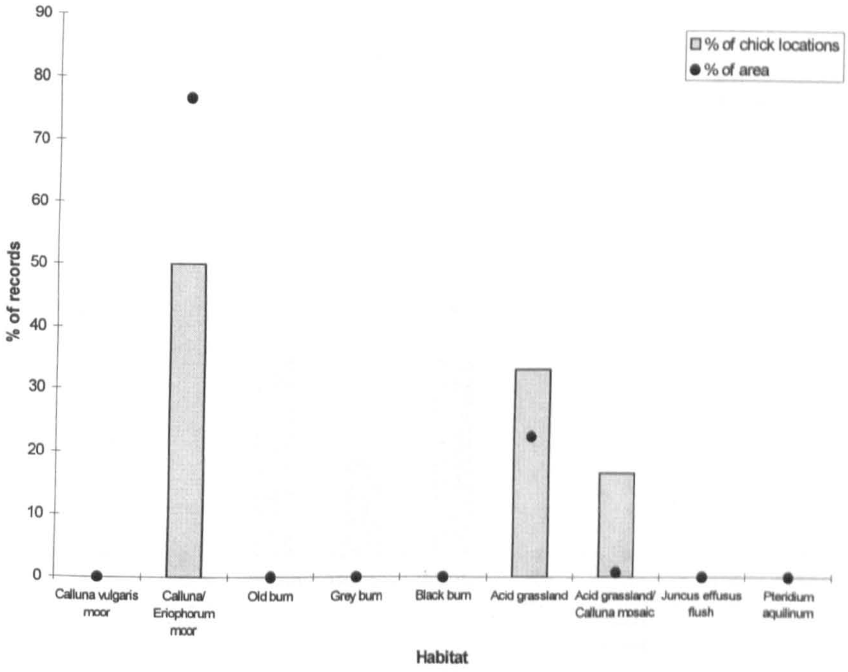


Figure 11. 1995 nest 17 brood

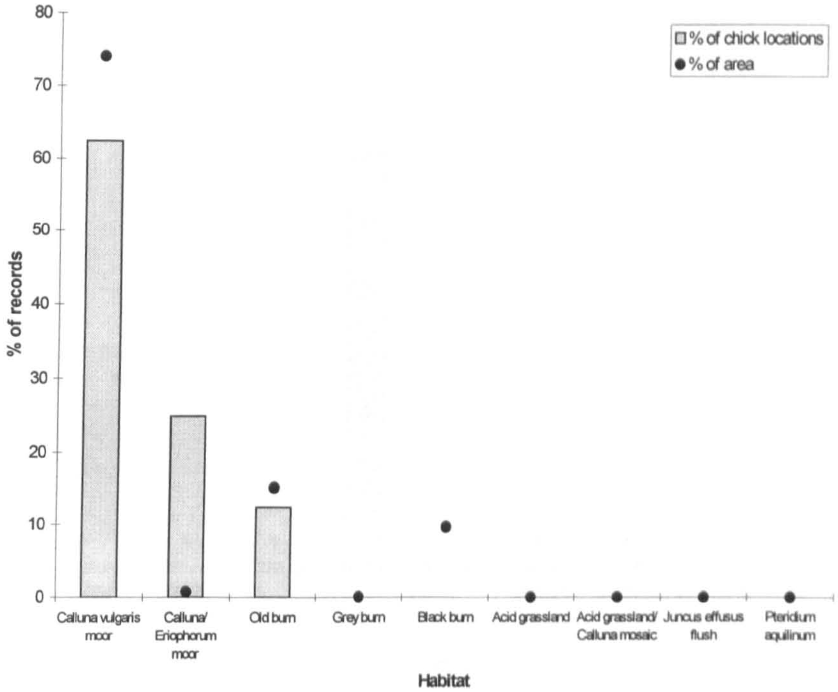


Figure 12. 1996 nest 1 brood

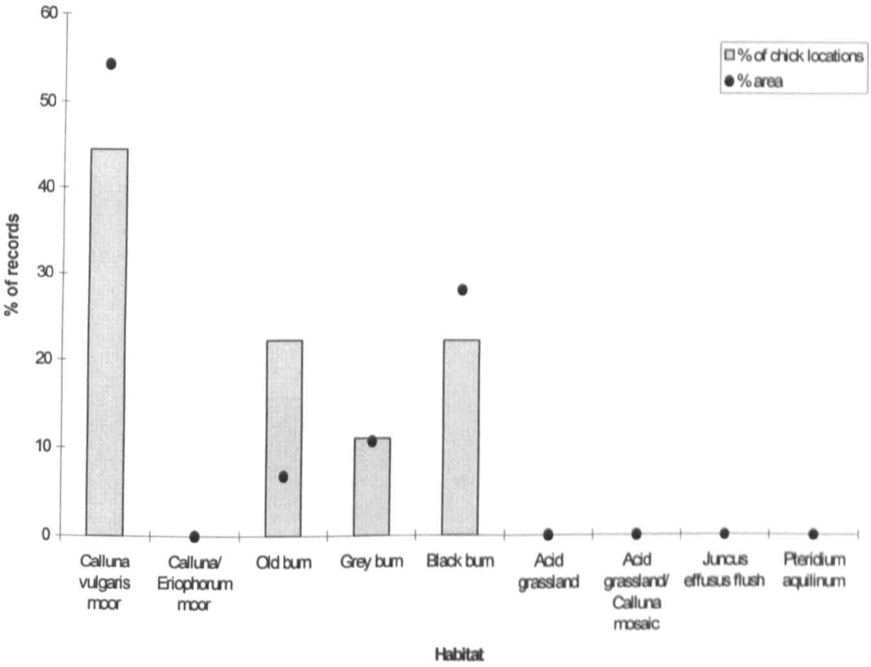


Figure 13. 1996 nest 6 brood

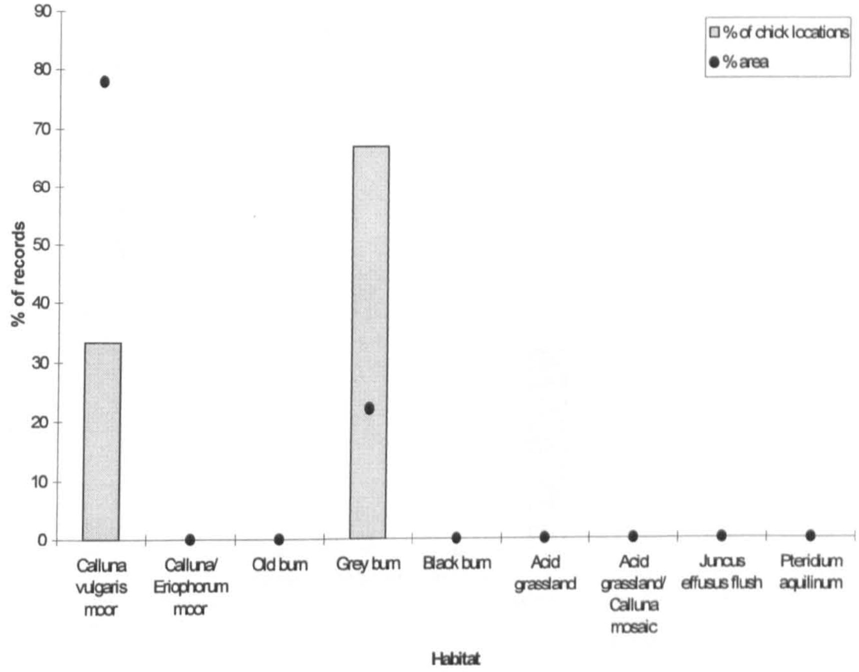


Figure 14. 1996 nest 13 brood

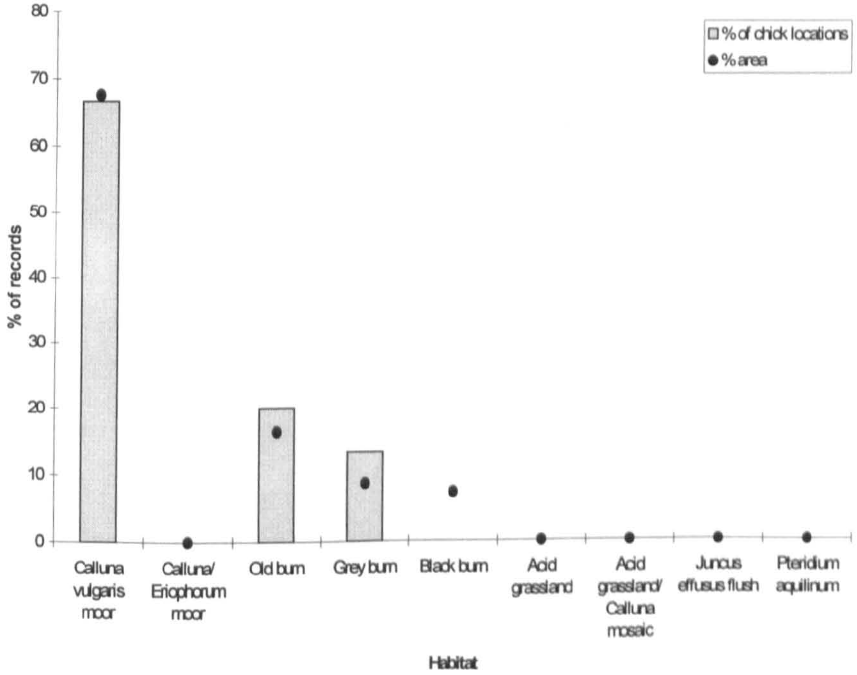
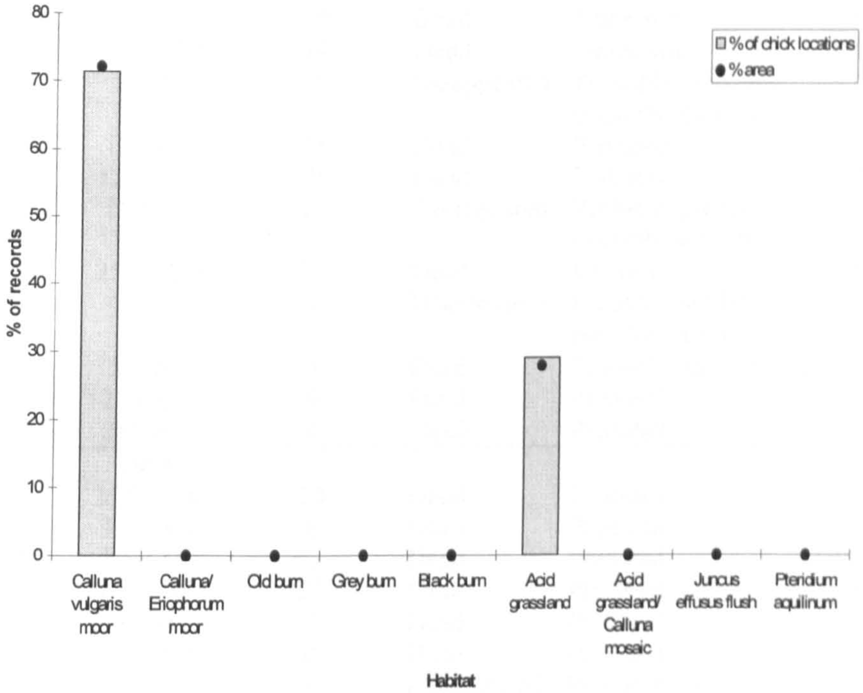


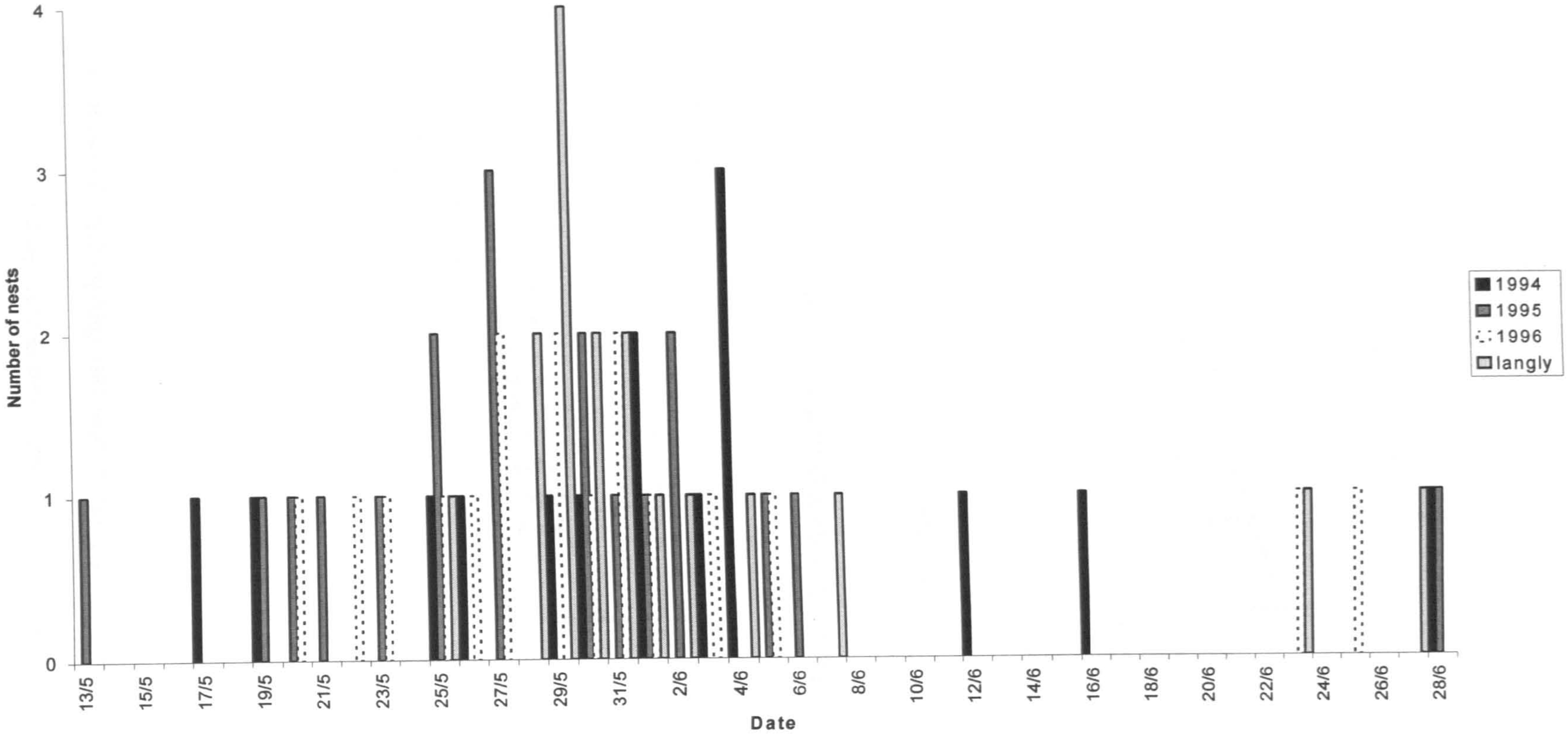
Figure 15. 1996 nest 17 brood



Appendix 3. Fate of radio-tagged chicks and radio-tags

Chick	Dates	Days observed	Fate of chick	Cause	Fate of tag
	1994				
C1N1	29/5 - 12/6	15	Dead	Unknown	Recovered
C1N3	30/5-17/6	19	Dead	Unknown	Recovered
C1N5	1/6-2/6	1	Disappeared	Probably predated/ possibly radio failure	Unrecovered
C1N7	12/6-5/7	25	Dead	Predated	Recovered
C2N7	12/6-20/6	9	Dead	Unknown	Recovered
C3N7	12/6-1/7	21	Disappeared	Probably predated/ possibly radio failure	Unrecovered
C1N9	25/5-20/6	27	Dead	Unknown	Recovered
C1N10	1/6-2/6	1	Disappeared	Probably predated/ possibly radio failure	Unrecovered
C3N13	5/6-8/6	4	Dead	Probably bad weather	Recovered
C1N14	28/6-6/7	9	Dead	Predated	Recovered
C2N14	28/6-6/7	9	Dead	Predated	Recovered
	1995				
C1N2	25/5-21/6	28	Dead	Predated	Recovered
C1N7	31/5-5/6	6	Dead	Predated	Recovered
C2N7	1/6-13/6	13	Dead	Predated	Recovered
C3N7	6/6-30/6	25	Dead	Predated	Recovered
C1N8	27/5-31/5	5	Dead	Predated	Recovered
C1N9	29/5-28/6	31	Dead	Predated	Recovered
C1N10	30/5-31/5	1	Disappeared	Probably predated/ possibly radio failure	Unrecovered
C2N10	30/5-31/5	1	Disappeared	Probably predated/ possibly radio failure	Unrecovered
C1N12	31/5-26/6	27	Dead	Predated	Recovered
C2N12	31/5-9/6	10	Dead	Predated	Recovered
C3N12	9/6-14/6	5	Disappeared	Probably predated/ possibly radio failure	Unrecovered
C1N14	2/6-6/7	35	Fledged	N/A	Recovered
C1N15	6/6-15/6	10	Dead	Probably bad weather	Recovered
C2N15	6/6-15/6	10	Dead	Probably bad weather	Recovered
C1N16	2/6-6/6	5	Dead	Predated	Recovered
C2N16	6/6-7/6	2	Dead	Predated	Recovered
C1N17	22/5-31/5	10	Dead	Predated	Recovered
C1N19	7/6-12/6	6	Dead	Predated	Recovered
C2N19	7/6-12/6	6	Dead	Predated	Recovered
	1996				
C1N1	28/5-6/7	40	Fledged	N/A	Unrecovered
C2N1	28/5-6/6	10	Dead	Probably bad weather	Recovered
C1N6	1/6-13/6	13	Dead	Predated	Recovered
C2N6	6/6-13/6	8	Dead	Predated	Recovered
C1N13	31/5-6/7	38	Fledged	N/A	Unrecovered
C2N13	31/5-17/6	18	Disappeared	Probably predated	Recovered
C1N14	31/5-3/6	7	Dead	Predated	Recovered
C1N16	5/6-8/6	4	Dead	Predated	Recovered
C1N17	25/6-6/7	12	Dead	Predated	Recovered

Appendix 4. Hatch dates of all clutches.



Appendix 5. Chick growth rate charts.

Figure 1. Chick growth rate (bill length against age)

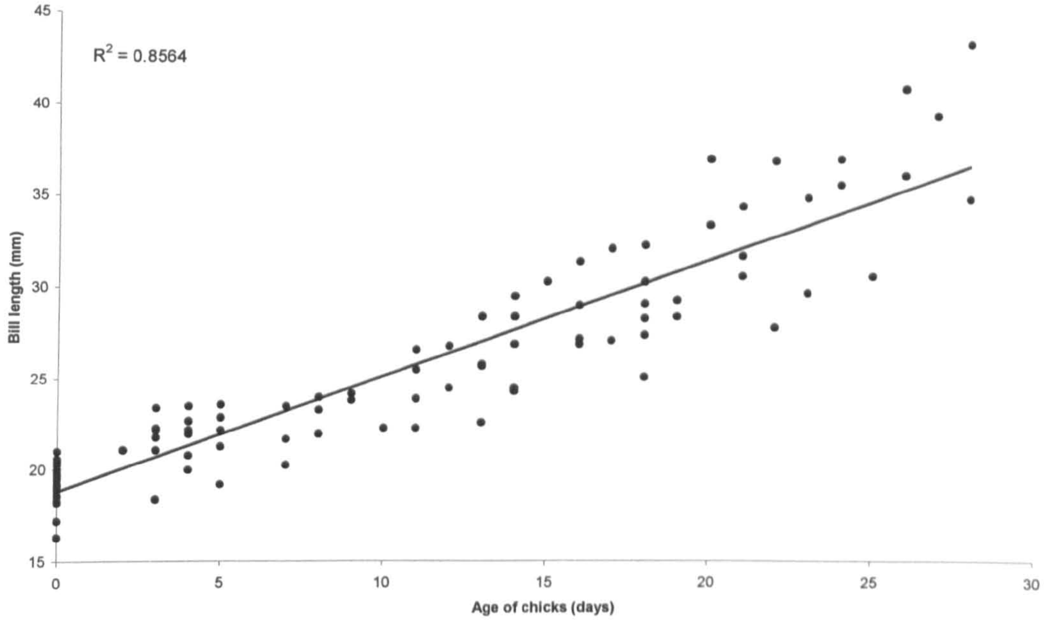


Figure 2. Chick growth rate (right tarsus & toe length against age)