Austin, Graham E. (1992) *The distribution and breeding performance of the buzzard Buteo buteo in relation to habitat: an application using remote sensing and Geographical Information Systems.*

PhD thesis

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The Distribution and Breeding Performance of the Buzzard *Buteo buteo* in Relation to Habitat:

An application using remote sensing and Geographical Information Systems.

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This thesis is submitted in candidature for the degree of Doctor of Philosophy,

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October 1992.

ACKNOWLEDGEMENTS

I would like to thank my supervisor David Houston for his advice, help and encouragement throughout the course of this study and Stephen Phillips and Graham Coombs for the use of departmental facilities. The study was funded by the Natural Environment Research Council and supported as a case award through the Nature Conservancy Council for Scotland and its subsequent incarnations. I owe many thanks to personnel involved with both organisations.

The technical side of this project would have been all but impossible had it not been for the help and assistance of many persons and I offer apologies for any names I inadvertently omit. For the use of the NERC Computing Services image processing facilities at Monks Wood Experimental Station, Cambridge during the early days of processing of satellite imagery I would like to thank Barry Wyatt. A special vote of thanks goes to Neil Veitch for giving up his own time to coach and hand hold during the learning period of this exercise. Subsequently this work continued on NERC computing services equipment at British Geological Survey, Edinburgh and I would like to thank Graeme Atkinson of NCS for making these facilities available. Finally in connection with the satellite imagery work I would like to thank Angela Morrison for her assistance in acquiring images. Much work was carried out in the Glasgow University Department of Topographic Science and I would like to thank Prof. Gordon Petrie for access to his department and use of facilities plus his enormous enthusiasm during the course of the work. Many, many thanks are due to Tony Ibbs of Laser-Scan Ltd / Glasgow University Topographic Science Department for help while setting up and getting to grips with the Laser-Scan Geographical Information System and his indispensable help with writing of computer programs. Thanks also to the anonymous voices at the end of the Laser-Scan help line. For statistical advise I would like to thank James Currall, Neil Metcalfe and Pat Monaghan. Wylie Horn did a fine job of proof reading an earlier draft of this thesis and if it was not for the diligence with which he undertook this task this thesis might still contain many (more?) embarrassing typographic blunders.

One the more down to earth side I would like to thank everybody who gave me assistance during fieldwork. Mike Madders of RSPB was pleased to help with the locations of buzzard nests past and present on south-east Mull and special thanks are due to Steve Petty and David Anderson for allowing me access to their Loch Eck study area and taking me around their buzzard nest sites. During the first year of fieldwork David Jardine made available a 'cabin in the woods' which served as a field base in Argyll and provided entertainment in the form of pine martins beneath the floorboards, lashings of ice cold water from a frozen stream and spooky nights.

Last, but by no means least, I would like to raise a glass to my partner in crime, Chris Thomas, with whom I worked closely, both during fieldwork and back in Glasgow. Chris' contribution to this project cannot be overstated. He provided practical help in the field, friendship, moral support during taxing times and together we plunged into the deep end of computer mapping and image analysis.

DECLARATION

I declare that the work described in this thesis has been carried out by myself unless otherwise cited or acknowledged. It is entirely of my own composition and has not, in whole or in part, been submitted for any other degree.

Graham Austin
G. E. Austin
October 1992

CONTENTS:

SUMMARY

The British uplands support a rich assemblage of a number of predatory and scavenging birds, including golden eagle, merlin, red kite, hen harrier, raven and buzzard, with nationally and internationally important populations of some of these species. A feature all these species have in common is the requirement for large foraging ranges by individuals which means that large tracts of suitable habitat are necessary to support viable populations. Current changes in upland land use such as afforestation and changing agricultural practises give cause for concern. The conservation of these species and others like them requires a greater understanding of how these birds interact with the landscape and how their distribution and breeding performance reflects their habitat. Ecologists are becoming increasingly aware of the potential of Geographical Information Systems (GIS) for exploring these relationships between animal species and their habitat. In this thesis, the buzzard was chosen as a model species to explore ways of predicting bird distributions and breeding performance from readily available data using GIS.

This study was carried out in mid-Argyll, Scotland. The distribution and breeding performance of buzzards was determined for a number of study areas, chosen to represent the full spectrum of habitats to be encountered in mid-Argyll, during 1989 and 1990. Parameters of breeding performance used were laying date, clutch size, initial brood size and fledging success. Brood quality was also assessed, based on nestling growth.

The breeding performance of buzzards in mid-Argyll was included in a comparison of published data from studies elsewhere in Britain. Laying dates were found to be consistent throughout the country while clutch size, initial brood size and fledging success were seen to differ between studies. No patterns which might relate to latitudinal or climatic trends were apparent and differences were considered to be due to overall habitat differences between the regions considered. While buzzards in mid-Argyll tended to produce low clutch sizes the population as a whole showed high fledging success. While buzzards nestlings in mid-Argyll had good survival rates the high fledging success is probably best explained by absence of human interference, malicious or otherwise in this area.

An important consideration when looking at the distribution of a bird such as the buzzard is whether this might be influenced by nest site availability. Buzzards in mid-Argyll used a number of

distinct nest site habits. While the majority of buzzards nested in trees, a substantial proportion were found nesting on steep banks and crags. Considering the adaptability of buzzards in their choice of nest site and the abundance of acceptable sites it was considered that the availability of potential nest sites was unlikely to influence buzzard distribution in mid-Argyll.

Whether or not buzzards used bank or crag sites was not related to the availability of alternative tree sites. Buzzards nesting on vegetated banks showed significantly earlier laying dates than those nesting in other nest site habits and it was suggested that buzzards occupying high quality habitat, which might allow females to attain good body condition early in the season, might be adopting the bank nest site habit in order to gain protection from unfavourable weather conditions, when producing early clutches.

Further consideration of buzzard distribution, breeding performance and habitat utilisation made use of a GIS to manipulate the habitat data. The system used was the Horizon GIS from Laser-Scan Ltd. While ideally one would wish to have included data concerning all aspects of the environment which might influence buzzards, the purpose of the exercise was to produce predictive models and so only those data sets which were already available or readily obtainable, for both the areas from which the models were to be developed and for areas for which predictions were to be made were included. Vegetation was mapped using a classification derived from the analysis of satellite imagery produced by the Landsat 5 thematic mapper. Using GIS and correspondence analysis these data were equated with data from a vegetation survey based on interpretation of aerial photographs which covered part of the study area and which was made available to this project. The topography of the landscape was described by constructing a digital terrain model from data based on ordnance survey 1:50,000 scale maps. From these data, separate data sets representing altitude, slope of the land, land aspect and land ruggedness were developed. Data of potential human disturbance were included in the form of cultural artefacts (roads, habitations) based on those represented on ordnance survey 1:50,00 scale maps. Climatic data were not included due to the strong relationship between climate and topography. Had they been included this would lead to duplication of data. Prey availability was not included as it was not considered feasible to measure this over the large areas to be included in the database but more importantly it would never be available when modelling the effects of land use change.

A utilisation / availability analysis using Bonferroni simultaneous confidence intervals investigated habitat preferences of buzzards in mid-Argyll. Buzzard sightings made over a six month period were considered in relation to vegetation cover data extracted from the GIS. Observations made from vehicles were treated separately from those made on foot and there was broad agreement between the two methods. The analyses indicated positive selection by buzzards of upland perennial grassland and negative selection for heath and bog. During the pre nesting season positive selection for broad-leaved woodland and negative selection for agricultural grassland was also detected. However a shift in habitat between the pre nesting season and the nesting season was not suspected, as the failure to detect such preferences during the nesting season was probably due to low observer effort in agricultural grassland during this time and the exclusion of observations around known nest sites in woodland. These preferences were probably explained by differential prey availability between habitats, those vegetation cover types offering unrestricted visibility being preferred.

The distribution of buzzards was investigated in several areas of mid-Argyll with a view to developing models which would allow distributions to be predicted either in other areas of Argyll or in the same areas after modelling envisaged changes in land use. Inductive modelling procedures using habitat data extracted from the GIS and both discriminant function analysis and logistic regression analysis produced models which, when tested, proved to have considerable predictive power. Previous studies of this kind have been successful in predicting the distribution of species. However, the model developed here allowed the distribution of individuals within a species distribution to be predicted. The centres of buzzard home ranges tended to be associated with areas of varied landscape. Furthermore vegetation cover preferences indicated by the analysis of habitat utilisation were reflected in the vegetation cover features useful in predicting the presence of a home range centre.

A similar approach was also used to develop models which could predict aspects of buzzard breeding performance based on the habitat in the vicinity of nest sites. No model was developed which could successfully predict the timing of breeding, however it was possible to predict clutch sizes and brood quality. It is not, however, possible to say whether this is directly due to the influence of habitat or whether birds of different individual quality are occupying different habitats. However this does not affect the application of these models.

While during the course of this overall piece of work a number of interesting facts concerning ecological relationships between buzzards and their environment have emerged, perhaps more importantly I have been able to demonstrate how recent innovations in technology can be usefully employed to look at the spatial relationships between an animal species and its environment in new ways. Such studies can only compliment traditional ecological techniques in the future and provide a platform for further research.

CHAPTER 1: INTRODUCTION

CONTENTS:

BACKGROUND

The uplands of Britain support a unique assemblage of birds (Ratcliffe & Thompson 1988). The open landscapes, that have been created by management for grouse, red deer and sheep, are important breeding and foraging areas for many of these species. Consequently, the impact of land use change on these communities, especially the loss of this open land to forestry has been considered cause for much concern, research and public debate (e.g. Thompson, Stroud & Pienkowski 1988, Ratcliffe 1990). Of particular interest are the rich communities of predatory and scavenging birds, including golden eagle *Aquila chrysaetos*, red kite *Milvus milvus*, hen harrier *Circus cyaneus*, merlin *Falco columbarius*, buzzard *Buteo buteo*, short-eared owl *Asio flammeus* and raven *Corvus corax*. This list includes species with high profiles for conservation management.

A feature common to all these species is the need by individuals for extensive foraging ranges and so vast tracts of suitable land are required to hold viable populations. It is not, therefore, possible to ensure their continued survival by conservation measures such as the notification of Sites of Special Scientific Interest or by the establishment of local nature reserves. If viable populations of these birds are to be maintained, land use policy over whole regions must be influenced. This requires a much more detailed knowledge of how these birds interact with the landscape, and how habitat affects their distribution and breeding performance, than is currently available.

The current study is concerned with increasing our knowledge for one of these species, the buzzard and to use this species as a model to explore ways of predicting bird distributions and breeding performance from readily available habitat data. The buzzard has been the subject of a number of studies in both Great Britain and continental Europe and its general biology is therefore better known than some of the other species of upland predatory and scavenging birds, making it a particularly suitable candidate for this study.

HISTORY OF THE BRITISH UPLANDS

The British uplands are, broadly speaking, the open landscapes of unenclosed heaths, grasslands, peat bogs and rocky terrain lying above the limits of cultivation (Ratcliffe 1990). Before the influence of man was felt in the British uplands the natural climax vegetation over much of this landscape was woodland, the precise character of which varied from region to region. The extensive woodland clearance reached even remote areas such as Argyll about 1400 yrs.b.p. (Birks 1988). Sheep farming came to predominate in Scotland from the late 18th. century, and this process was complete by about 1830. From about 1860 management of land for red deer and grouse also became important in some areas, particularly the north of England and east and central Scotland (Sydes & Miller 1988).

Sheep numbers in Britain as a whole remained more or less constant from 1875 to 1966, the time of the last agricultural census, at about 69 million individuals (MAFF 1968). There was, however, a shift away from lowlands sheep farming towards the uplands during this period, resulting in higher sheep numbers in many upland areas. The brunt of this impact has been felt in England and Wales. In Scotland most change has taken place in the north- west and north-east, but even in areas such as Argyll, where no overall increase in sheep numbers has been noted, grazing pressure in the uplands is likely to have increased due to loss of open hill grazing to seeded pasture and afforestation. Sydes & Miller (1988) report a loss of 0.5 x 10^6ha. of open hill grazing in Scotland since 1940.

The last three quarters of the present century have so far seen a rapid expansion of afforestation. Since 1924 nearly 1 x 10^6ha. of Britain has been afforested. The main expansion in Scotland has occurred since 1960 and currently 14% of the land area of Scotland is under forestry (Thompson *et al* 1988). Until recently the rate of afforestation, for the country as a whole, stood at about 30,000ha. per annum, and this was expected to continue into the next century (Sykes, Lowe & Briggs 1989), however, since 1990 afforestation has declined due to the cessation of taxation advantages for private investors.

UPLAND VEGETATION

The definition of what features characterise the upland environment is difficult and tends to be somewhat intuitive. The term upland can be misleading implying, as it does, land above a certain altitude, whereas the definitive feature is actually its ecological character (Ratcliffe 1990) and habitat of a truly upland character may extend down to sea level, for example in western Scotland. Currently about 30% (7.7 x10^6ha.) of Britain is covered in vegetation of an upland nature. Of this, 40% (3.1 x10^6ha.) is man-made, that is, agricultural grassland or commercial forestry. The remainder (4.6 x10^6ha.) can be described as semi-natural, that is, the vegetation cover has been induced by mans' activities but derived principally from natural species. This falls into three main categories, upland grassland, bog and moorland, representing 31% (3.8 x10^6ha.), 37% (1.7 x10^6ha.) and 32% (1.5 X10^6ha.) respectively (Bunce

& Barr 1988). Bog is characterised by species such as *Eriophorum angustifolium, Tricophorum cespitosum,* and *Molinia caerulea* with a carpet of moss, principally *Sphagnum sp.* Moorland is characterised by cover species such as *Calluna vulgaris, Vaccinium myrtillus* and *Nardus stricta.* The upland grasslands are characterised by perennial grasses such as *Festuca ovina* and *Agrostis tenuis* with bracken *Pteridium aquilinum* commonly present as an invasive species (Bunce & Barr 1988).

UPLAND LAND USE

If we consider the land use in these upland areas we arrive at the following breakdown for Britain as a whole. The greater proportion is under agricultural use (3.8×10^6ha.), this being mainly comprised of inbye and outbye grazing. Inbye refers to that part of the land, enclosed within the mountain wall, that is maintained through cultivation by ploughing, reseeding and fertilising. Outbye refers to that part of the land not subject to cultivation and generally outside the mountain wall, over which livestock have free range. Of these two, land used as outbye exceeds that used for inbye for the country as a whole (accounting for 35% and 28% of upland land use respectively). This difference is even more marked in regions such as the west of Scotland where the ratio of outbye to inbye will be much greater. Management of the open hill as deer forest and grouse moor (17% & 6% of the uplands respectively) are also major land uses, especially in Scotland and the north of England. Of the remainder most is under commercial forestry (Bunce & Barr 1988).

VEGETATION COVER AND LAND USE CHANGE

Even though most of the British uplands can no longer be described as natural habitat, it has developed a distinct fauna and flora of its own, including many species no longer encountered elsewhere in the country. As the vegetation we see in the uplands has been shaped largely by mans' activities it follows that changes in land use will inevitably lead to habitat changes that will, in turn, affect upland species.

Since 1940, 30% of the British uplands have been transformed or modified by land use practises (Thompson *et al* 1988). The planting of trees, mainly alien species, such as Sitka spruce which alone accounts for 60% of forestry in Scotland has obvious impact on habitat structure, as does agricultural change, be this improvement of marginal ground to give inbye or even arable land, or reclamation of hill ground. Other activities, however, also work to bring about change. Both burning and grazing pressure are inversely correlated with the structural complexity of the vegetation. Under pressure of grazing woodland and scrub give way to dwarf scrub and this in turn may be replaced by grasslands, especially on wetter, acid soils where deciduous grasses come to predominate. Heavy grazing of perennial grassland may lead to the increased invasion of bracken (Sydes & Miller 1988).

CURRENT CHANGE IN LAND USE

Economic enterprises in the British uplands often operate on the margins of financial viability, and the major land uses, hill farming and forestry, are subject to public policy (Mowle & Bell 1988). Until recently private forestry attracted high levels of subsidy, and hill farming continues to do so. Consequently, terms that may be applied along with such subsidies, or the removal of such subsidies, have the potential to influence significantly the nature of upland land use and in turn habitat.

Despite withdrawal of subsidies to the private forestry sector affecting the overall rate of forestry expansion afforestation is still likely to continue into the next century. In the past much afforestation has taken place on blanket bog, this being agriculturally unproductive land and hence comparatively inexpensive to acquire. In Argyll, for example, 30% of blanket bog on the Kintyre peninsula has been planted since 1945, and concern has been expressed as to the scale of this loss (Thompson *et al* 1988). Incentives offered causing agricultural land to be taken out of production may make hitherto more expensive land affordable for forestry concerns leading to afforestation of, for example, marginal land.

Changes in the economics of hill farming and improvements in veterinary care of hill stock will also have their effects. As the economics of hill farming fluctuate, the financial viability of managing marginal land changes and this will be mirrored by the degree to which either marginal and hill ground is reclaimed or formerly reclaimed land is left to deteriorate from an agricultural perspective. Economics may also influence stocking densities and hence grazing pressure put upon the land. This may also be influenced by both improvements in veterinary care and changes in livestock management, particularly the practises of over wintering and lambing of sheep off the open hill, and supplementary winter feeding. With stocking densities on the open hill no longer limited by the quantity of winter grazing available, higher numbers could be summered here and hence grazing pressure during the growing season increased. The vast majority of hill farming concerns rely on subsidy for commercial viability and any reviews in agricultural policy could have a far reaching impact on the upland environment.

Insufficient culling of red deer in the uplands has led to greatly overstocked deer forest and there is pressure to reduce the current stock drastically. Numbers of red deer are currently higher in Scotland than at any time since records began (Clutton-Brock & Albon 1989). While the high mortality of red deer resulting from overstocking may provide a source of carrion for species able to utilise this as a food resource, the heavy grazing pressure also resulting from over stocking will have the detrimental effects on habitat already described. If targets for reduction of deer numbers, proposed by the Red Deer Commission, are implemented this could dramatically affect many upland areas.

Increased human disturbance to wildlife, through recreational pursuits such as skiing and hill walking, is another factor that must be acknowledged. The impact of this tends to be more localised than the other factors mentioned but within areas where it occurs can have serious consequences (Thompson *et al* 1988, Ratcliffe 1990).

LAND USE AND UPLAND BIRDS

Studies from several regions of Britain have shown adverse effects of land use changes, specifically afforestation of former sheepwalk and moorland, upon some upland birds, including predatory and scavenging species. In mid Wales, for example, ravens occupying the more afforested territories appeared to produce smaller clutches than those in more open territories (Newton, Davis & Davis 1982). In northern England and southern Scotland the amount of afforestation in raven territories was found to be inversely correlated with their productivity, and it was suggested that some territories on marginal land had probably become non-viable due to improved sheep husbandry (Marquiss, Newton & Ratcliffe 1978). These effects on ravens were considered in both cases to be due to the reduced availability of sheep carrion which appeared to be an important component of the diet of these two populations. A similar trend in response to afforestation has been reported for golden eagles in southern Scotland (Marquiss, Ratcliffe & Roxburgh 1985). The distribution of the golden eagle has been related to the availability of sheep carrion during the winter months while their productivity has been related to the availability of live prey such as grouse and mountain hare (Watson, Langslow & Rae 1987) and this may explain the loss of eagles from areas that become heavily afforested. In Wales the amount of forestry within a pairs territory influenced at which stage of the nesting cycle success or failure tended to occur in red kites (Newton, Davis & Moss 1981). There is strong evidence that unlike ravens, buzzards in mid Wales did not display any changes in productivity or territory occupancy with afforestation of sheepwalk, and it was suggested that this was because the buzzards were less dependent upon sheep carrion than were the ravens (Newton, Davis & Davis 1982). This appears to contrast with the situation in southern Scotland were Mearns (1983) reports a decline in buzzards of 93% between 1946 and 1981 which he attributed to afforestation. There is, therefore, substantial evidence that change in land use can influence the distribution and productivity of some of these species.

THE GENERAL BIOLOGY OF THE BUZZARD

The general biology of the buzzard has been studied in Devon (Dare 1961), the New Forest in Hampshire (Tubbs 1974) and in Germany (Mebs 1964). Social behaviour has been described (e.g. Dare 1961, Tubbs 1974, Weir & Picozzi 1975) and dispersal and mortality investigated (Picozzi & Weir 1976, Mebs 1964). Dispersion and territoriality has been investigated in Speyside (Picozzi & Weir 1974, Weir & Picozzi 1983), the Lake District of northern England (Holdsworth 1971), north Wales (Dare 1989, Dare & Barry 1990) and the west of Scotland (Maguire 1979, Mitchell 1983). Some of these studies together with several others from continental Europe have looked at diet (e.g. Dare 1961, Mebs 1964, Tubbs 1974, Pinowski & Ryszkowski 1962, Holdsworth 1971). Several studies have looked at how habitat and changes therein may affect distribution and breeding performance (Newton, Davis & Davis 1982, Picozzi & Weir 1974, Dare 1989, Dare & Barry 1990, Tubbs & Tubbs 1985).

Buzzards are at their commonest where habitat is diverse such as the wooded farmland of south-west England, Wales, the England Lake District and the west of Scotland but less so in forested and mountainous regions (Sharrock 1976, Lack 1986, Thom 1986). Within upland regions the higher mountains and bleak moorlands are rarely claimed by territorial birds (Dare 1961, Tubbs 1974, Weir & Picozzi 1983, Dare 1989, Dare & Barry 1990). This preference for more diverse habitats is reflected by individual breeding performance of pairs occupying different habitats (Picozzi & Weir 1974, Dare 1989). In Great Britain buzzards are sedentary throughout the country although this is not true in many parts of the species range. Some of the above studies have indicated that buzzards hold distinct and defended territories throughout the year (Dare 1961, Picozzi & Weir 1974, Weir & Picozzi 1983) while others imply this behaviour may be less marked at lower population densities and outside the breeding season (Tubbs 1974). The area occupied by a pair of buzzards varies throughout their range although comparisons between studies are confounded by the different methods authors have used to deduce territory or home range size.

A pair of buzzards will occupy their home range throughout the year. A given pair are likely to maintain a number of nest sites, usually clustered towards the centre of the home range and will alternate between these from year to year (Tubbs 1974, Brown 1976). They are adaptable in their choice of sites, and nests may be positioned in trees, on rocky crags, on the face of steep banks or even on the ground. Buzzard pairs do not necessarily attempt to breed every year and in any one year up to 25% may not attempt to do so (Brown 1976). A clutch of 2 to 4 (rarely 1 to 6) is laid usually between the last week in March and the first week in May, with a peak around mid April (Tubbs 1974, Brown 1976). There is some evidence that birds further north in Britain produce on average larger and earlier clutches (Tubbs 1972). Eggs are laid at two to three day intervals and incubation probably begins with the first egg (Tubbs 1974, Brown 1976, Dare 1964). Hatching is therefore asynchronous, after an incubation period variously estimated at between 33 and 38 days (Mebs 1964, Dare 1964, Tubbs 1974, Brown 1976). There is probably a trend for a decrease in incubation period from first to last laid eggs (Brown 1976). Young are brooded by the female for the first 10 days, the male provisioning the entire family (Dare 1964, Tubbs 1974). Thereafter he is joined in this by the female. Young remain in the nest up to an age of between 40 and 55 days after which they will remain with their parents for anywhere between 1 and 5 months (Dare 1964).

Buzzards are catholic in their choice of prey. The principal prey species are generally small vertebrates including voles (*Microtus, Clethrionomys & Arvicola*), mice (*Apodemus*) and other rodents (e.g. *Sciurus, Rattus,* & Muridae) while insectivores are also important, especially moles (*Talpa europaea*) and shrews (*Sorex, Neomys & Crocidura*). Reptiles and amphibians are also important and invertebrates are commonly taken. Throughout the buzzards range, Microtus voles form the most important single group of prey items (*Microtus arvensis* in mainland Europe and *Microtus agrestis* in Great Britain) (Dare 1961. Pinowski & Ryszkowski 1962, Mebs 1964, Tubbs 1974, Brown 1976). In Great Britain, unlike on mainland Europe, rabbits (*Oryctolagus cuniculus*) are a major prey species whenever they are available (Dare 1961, Tubbs 1974, Brown 1976, Maguire 1979). Some populations have been found to take a large quantity and variety of songbird species, particularly Corvids (*Garrulus, Corvus, Pica*), and game birds may also be taken (Dare 1961, Tubbs 1974). Carrion from sheep and deer is considered important to some British populations (mid and north Wales and western Scotland) (Newton, Davis & Davis 1982, Dare 1989). The underlying feature of this is the great adaptability and versatility of the buzzard as a predator.

Changes in the fortunes and distribution of buzzards in Britain have been well catalogued (Moore 1957, Taylor, Hudson & Horne 1988). Less than two hundred years. ago buzzards were found throughout Great Britain and Eire. The advent of game keeping and subsequent persecution removed buzzards from much of their former range. By the outbreak of World War One they were confined to western-Scotland, the Southern Uplands of Scotland, the English Lake District, Wales and the West Country of England. Since this time, reduced persecution, especially during the First and Second World Wars, appears to have aided their recovery. By 1954, when Moore (1957) conducted his survey, they had regained much of their present ground. Since that time a consolidation of this range has been detected (Taylor *et al* 1988). Further expansion is probably still hampered by continued persecution in otherwise suitable habitat (Cadbury *et al* 1986). This is probably the case in east and north-east Scotland and the Welsh border counties of England where much apparently suitable habitat remains unoccupied. The current population in Great Britain may be upwards of 12,000 pairs (Taylor *et al* 1988).

LAND USE AND BUZZARDS

Can we explain why it is that, as described above, the buzzard has maintained its population and productivity in the face of land use change in some areas (e.g. mid Wales) while being dramatically reduced by apparently similar change elsewhere (e.g. southern Scotland)? To answer this we need to know exactly what habitat features are important to buzzards and how these features mesh together to produce a landscape favourable to the birds. This will provide a key to exploring exactly what it is about a given change in habitat that dictates whether or not birds will be affected and so provide conservationists with guide-lines for land management plans that would minimise adverse changes or maximise favourable changes.

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CHAPTER 2: STUDY AREA

CONTENTS:

STUDY AREA

The current study was carried out in Strathclyde, Scotland. The overall region of interest extends to about 2000 square kilometres (Figure 2.1). This area covers the districts of Lorn in mid-Argyll, the Cowal peninsula and the south-east quarter of the Isle of Mull.

Within this overall area of interest three distinct study areas were chosen for detailed work. These areas were chosen so that when considered together they represent a sample of the complete spectrum of habitats seen within the overall region of interest. These three areas are described below:

North-Lorn; an area of 140 square kilometres centred to the east and south-east of Oban, includes the watersheds of Glen Lonan, Glen Feochan and Glen Euchar. This area is characterised by rounded hills and deep glacial valleys. The floors of the glens contain rich improved pasture which, in glen Feochan and glen Euchar, is fenced off from the open hill ground (Figure 2.2). The open hill ground is principally sheep walk with large expanses of perennial upland grassland, blanket bog and localised patches of heather moor (Figure 2.3). Much of the area as been given over to forestry plantations and currently contains large blocks at all stages from new plant through to mature and clear-fell.

South-Lorn; an area of 43 square kilometres centred to the north of Lochgilphead includes the hill ground bounded by Kilmichael Glen to the east and the A816 road north from Lochgilphead to the west. This area is one of relatively rounded hills, with upland perennial grassland, blanket bog and considerable tracts of heather moor (Figure 2.4). The lower slopes around the periphery of the hill ground often have expanses of forestry plantation at various stages of development (Figure 2.5). To the west the area is surrounded by relatively flat, improved pasture land. To the east there are large expanses of forestry plantation and open hill ground.

Glen Lochy; an area of 35 square kilometres includes the Glen Lochy watershed between Tyndrum to the east and the confluence of the rivers Lochy and Orchy to the west. This is a relatively high altitude, glacial valley surrounded by high mountainous country. The lower slopes of the glen are almost completely given over to forestry plantations representing a mosaic of forestry types (Figure 2.6).

In addition to these three areas, which were worked by myself, data from two other areas, where other raptor workers were active, were incorporated into this study. The distribution of buzzard territories had been establish in 1987 for an area of south-east Mull by Mr. Mike Madders, RSPB. who also provided some nest site locations for 1989 and 1990. Buzzard distribution data from this area for 1987 was believed to be reasonably complete. Similarly, details of the locations of a sample of buzzard nests from the Cowal peninsula was provided by Mr. Steve Petty and Mr. David Anderson who allowed me to collect nest histories for nests they found. These two additional areas are described below:

South-east Mull; an area of 50 square kilometres centred on Loch Don extending north to Duart Point, south to Loch Spelve and west to a line running south from Craignure. This area is low lying and very flat. It is characterised by semi-improved pasture of low agricultural quality and wet heath. To the south there are expanses of grazed deciduous woodland. There are several large forestry plantations to the west where the area backs onto the higher hills supporting a vegetation cover of wet heath.

Cowal peninsula; centred on Loch Eck. This is an area of low lying glens surrounded by rugged mountains. The area has been heavily afforested, with the majority of the glen floors and sides planted. The forestry here is old and established, with a mosaic of age classes and tree species, and has entered the second rotation (Figure 2.7). Agricultural land is not extensive except towards the west of the area. Above the forestry plantations are extensive areas of wet heath, on which, in recent years grazing by sheep has been much reduced (Petty & Anderson pers.com.).

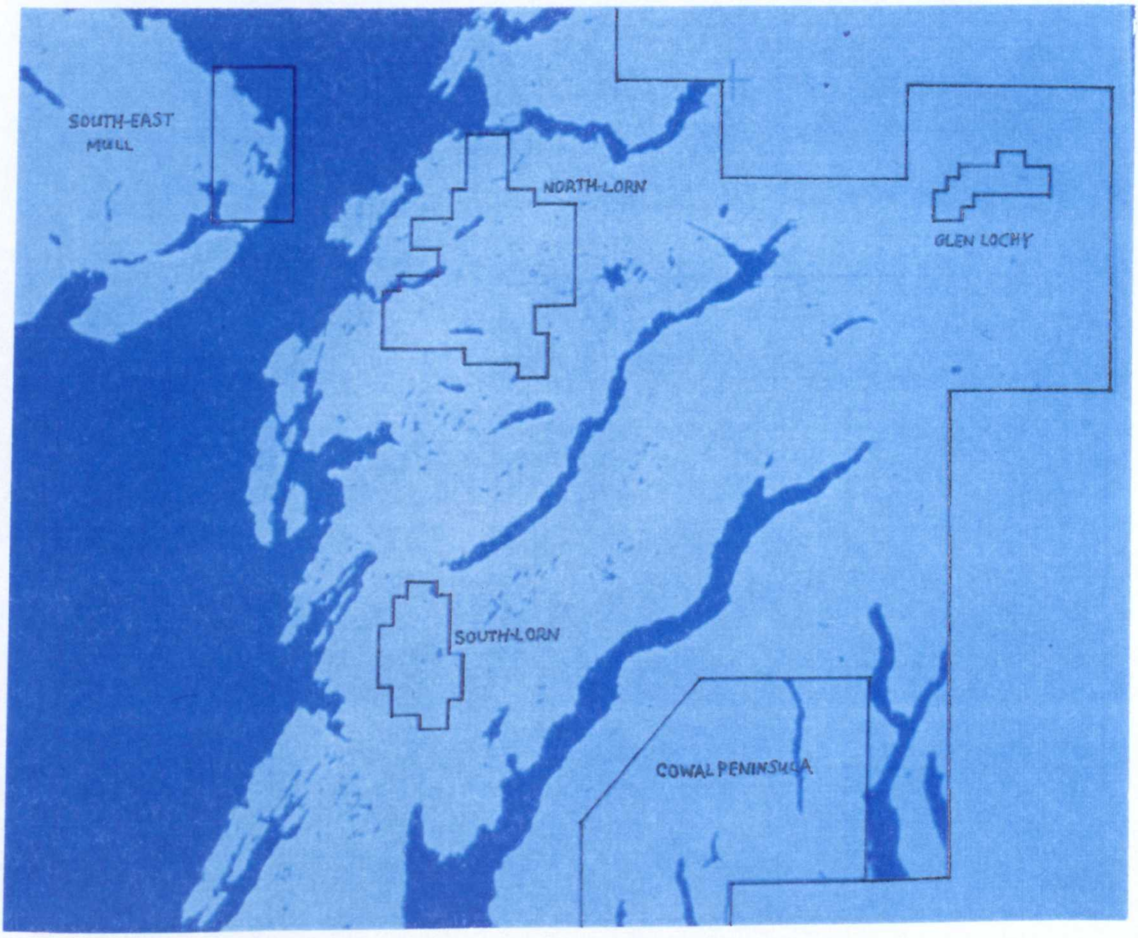

Figure 2.1: Map of overall study region in mid-Argyll, with intensive study areas delineated.

Figure 2.2: Glen Lonan, in the north-Lorn study area.
The floors of the glens in this area have been improved by ploughing and reseeding and in some parts have been fenced off from the surrounding hill ground open hill ground.

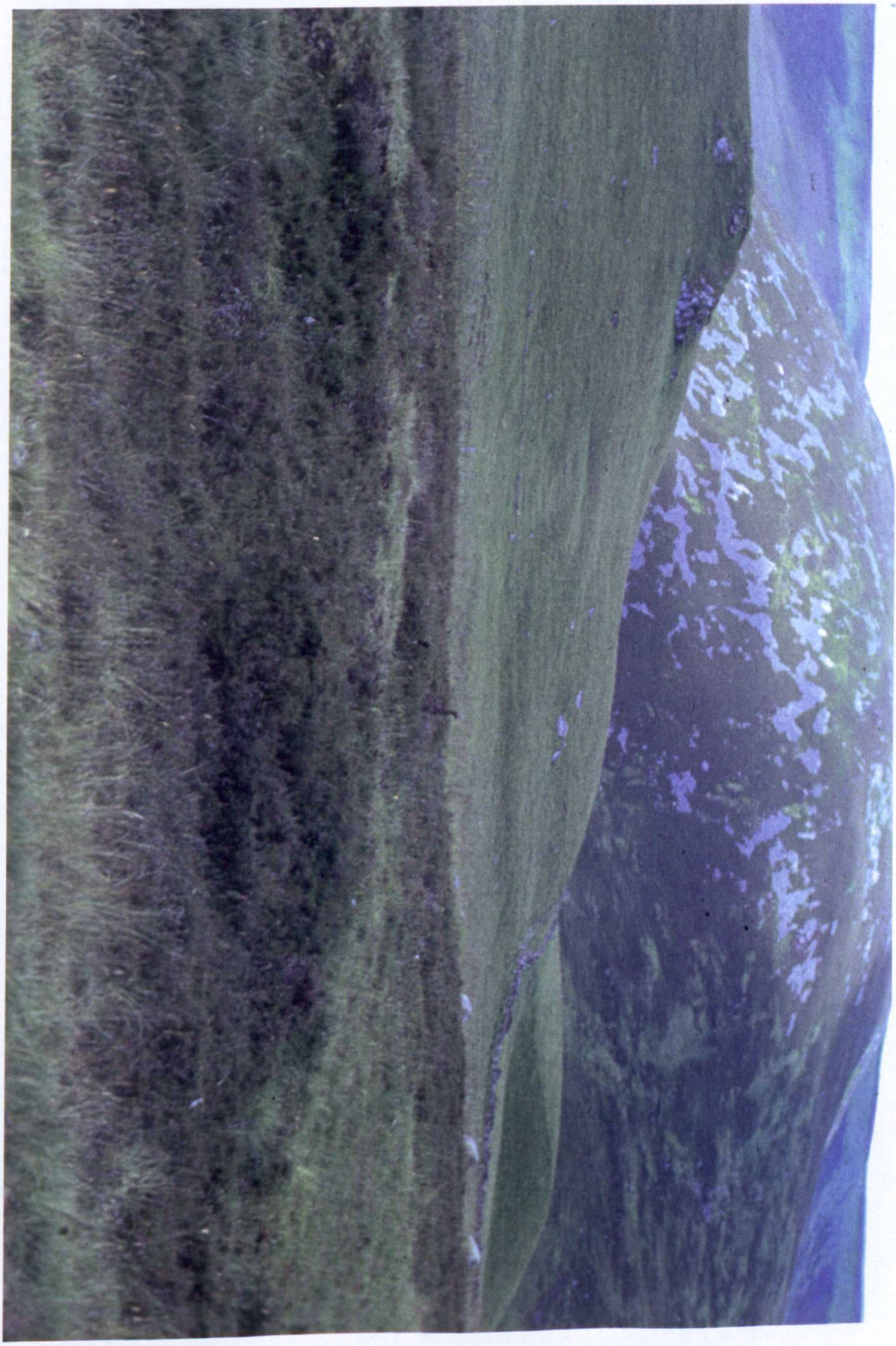

Figure 2.3: Hill ground above Glen Feochan, in the north-Lorn study area.
The open hill ground is principally sheep walk with large expanses of perennial grassland, blanket bog and patches of heather moor.

Figure 2.4: Hill ground above Kilmichael Glen, in the south-Lorn study area.
This is an area of rounded hills which, in some areas where grazing pressure is relatively low, such as that shown here, support a rich vegetation cover

Figure 2.5: North end of the Kilmichael Glen, in the south-Lorn study area.
The lower slopes around the periphery of the hill ground often have expanses of forestry plantation at various stages of development.

Figure 2.6: Glen Lochy.
This is a relatively high glacial valley, surrounded by high mountainous country. The lower slopes of the glen are almost completely given over to forestry plantations.

Figure 2.7: Loch Eck, on the Cowal peninsula.
The area has been heavily afforested, with the majority of the glen floors and sides planted. The forestry here is old and established, with a mosaic of age classes and tree species.

CHAPTER 3: GENERAL METHODS

CONTENTS:

SECTION I: INTRODUCTION AND GENERAL METHODS

INTRODUCTION

As stated in Chapter 1, one of the principal aims of this study is to investigate how buzzard breeding performance may be influenced by the environment. A measure of breeding performance is therefore required. Ideally, one would wish to measure lifetime reproductive success, however, such data are rarely available for long lived birds such as buzzards. This is particularly unfortunate as individuals of such species entering the breeding population potentially have many years of breeding attempts ahead of them, and what we observe in a single year may not be representative of the overall breeding performance of that individual or pair. It is, therefore, necessary to resort to measures of short term reproductive performance. Typically parameters of breeding performance used in studies of this kind will include the laying date, clutch size, brood size or number of nestlings successfully reared to fledging.

In raptorial birds there is much circumstantial evidence to suggest that the ultimate outcome of a breeding attempt is related to laying date, that is, early laying leads to increased breeding success (Newton 1979), and this has now been demonstrated for a number of species (e.g. Dijkstra, Vuursteen, Daan & Masman 1982, Newton & Marquiss 1984). There is considerable evidence that egg laying in raptors appears to commence as soon as the female has been able to accumulate sufficient energy for egg production (e.g. Dijkstra *et al* 1982, Newton & Marquiss 1984, Korpimäki 1987, Daan, Dijkstra, Drent & Meijer 1989, Pietiäinen 1989). Laying date is therefore an indicator of the body condition of the female and so may be indicative of the quality of the food supply available prior to the commencement of the breeding attempt. The post fledging period is undoubtedly important for predatory birds and there is evidence that late fledged young have a decreased chance of survival while early fledged young are more likely to be recruited into the breeding population (Newton & Marquiss 1984).

The initial clutch size sets the upper limit to potential breeding success and there is considerable evidence that raptors produce smaller clutches as the season progresses (e.g. Newton & Marquiss 1984, Pietiäinen, Saurola & Vaisanen 1986, Pietiäinen 1989). This would be selective in that it would reduce the parental investment in young that will fledge late in the season and so have a reduced chance of survival. Some raptor studies have shown that nestling growth and survival of individual nestlings to fledging is consistent between broods of different sizes (e.g. Moss 1979, Hiraldo, Veiga & Máñez 1990) while adult survival is not compromised by rearing large broods (Korpimäki 1988). Consequently one would expect clutch size, brood size and fledging success to be positively related to ultimate reproductive success.

GENERAL METHODS

In order to obtain a reasonable sample size of buzzard breeding attempts, nest histories were recorded for all active nests located within the overall study region. Fieldwork effort however was concentrated in three of the study areas, these being north-Lorn, south-Lorn and Glen Lochy. In these three areas the aim was to locate all territorial pairs and follow breeding attempts whenever the active nests could be located. The timing of nest visits was largely dictated by the schedule of other fieldwork as nest sites were widely spaced and it was necessary to continue nest searching throughout the field season in order to obtain a reasonable sample size. The aim was, however, to achieve for each nest, one visit during incubation, at least one visit at the time hatching was expected, at least one visit during the mid term of the nestling period and one visit immediately prior to the time when fledging was expected. Additional nest history data were obtained for a sample of nests from the Cowal peninsula and south east Mull from sites found by other workers although no effort was made to locate all buzzard pairs within the boundaries of these two areas.

When nests were found which contained eggs, each egg was weighed to the nearest 0.1g. using a pesola 50g. spring balance, the length and breadth measured to the nearest 0.1mm. using dial callipers and each was individually marked using a permanent marker pen to aid subsequent identification. Standard photographs of the eggs were taken whenever this was practical. Buzzard clutches invariably show a gradation in the degree of egg patterning from a heavily patterned egg through to a virtually unmarked egg. Eggs within a clutch can be easily arranged in order of decreasing degree of patterning and there was good reason to suppose that patterning decreases from first laid to last laid egg. When nests were found containing nestlings the following measurements were made. Each nestling was weighed, to the nearest 1g for those weighing less than 300g. and to the nearest 5g. for those weighing more than 300g. using either a 300g. or 1000g. pesola spring balance as appropriate. Wing-length was measured to the nearest 1mm. using a steel rule as described by Svensson (1984). The length of primaries 4 to 9, numbered according to Ashmole, Dorward & Stonehouse (1961), were measured to the nearest 1mm. using a steel rule as described in Petersen & Thompson (1977). Tarsus length and combined head and bill length were both measured to the nearest 0.1mm. using dial callipers. Descriptions were made of each nestling by scoring individual feather tracts as absent, in pin, emerged from pin or completely out of sheath. When not found while nestlings were still small, hatching order was inferred from comparisons of feather tract descriptions. These descriptions allow the status of each nestling to be determined without making assumptions about relative size of nestlings and their status. Small chicks can easily be placed in order of age, chicks doubling in size every few days, during the early period of growth. When eggs failed to hatch the status of the remaining chicks was determined by reference to the degree of patterning on the unhatched eggs. Thus, for example, two chicks hatching from a clutch of three eggs would be assigned as status=1 and status=3 if the intermediately patterned egg was the one that failed to hatch. Unhatched eggs usually remained undamaged in the nest for several weeks and so were generally available for examination. Nestlings were ringed with British Trust for Ornithology issue metal leg rings to allow subsequent identification.

Minimum clutch size was taken to be the maximum number of eggs or nestlings observed in, or believed to have occupied, the nest. The minimum number of young fledged was taken to be the maximum number of nestlings seen in the nest, thirty or more days after hatching. This was considered a reasonable measure of how many nestlings would fledge as there were no recorded instances of brood reduction in the latter stages of the nestling period. In fact all recorded instances of brood reduction took place when chicks were less than ten days old. Determination of laying date was by indirect means as no clutches were discovered before laying was complete. Section 2 of this chapter deals with estimation of laying date. An assessment of the quality of the nestlings from each breeding attempt was also desired. As a measure of the quality of a brood of nestlings, the weight of individual nestlings was scored as either lower, higher or not significantly different from that which would be expected for a typical nestling of that age. Each breeding attempt was then classified with reference to which group, on average, the nestlings were in. Full details are given in section 3 of this chapter.

SECTION II: COMPARISONS OF TECHNIQUES USED TO ESTIMATE THE LAYING DATE OF BUZZARDS BASED ON MEASUREMENTS OF EGGS AND NESTLINGS

INTRODUCTION

An important aspect of bird breeding biology is the date on which egg laying commences. Finding the nests of birds, particularly raptors, is often difficult. Many nests will not be located until they contain a full clutch of eggs or partially grown nestlings. Also, some species may be susceptible to disturbance during the critical egg laying stage and nest visits are best avoided at this time if the outcome of the breeding attempt is not to be unduly influenced. This is particularly so if the location and ease of access make nest visits necessarily lengthy procedures. Consequently it is, more often than not, necessary to make indirect estimates of laying date.

There are two main options available for estimating laying dates that would be expected to yield reasonable results. The hatching date of eggs, and hence the laying date for species with known incubation periods, can be estimated from measurements of egg density. Changes in the density of eggs during incubation, due to water loss, can be calibrated for a given species and the curve of the relationship between egg density and days to hatching used to estimate the number of days to hatching for other clutches (Furness & Furness 1981). Perhaps more commonly, hatching and laying dates are deduced from estimates of the ages of nestlings. Nestling age should be estimated on features that are largely unaffected by the individual condition of nestlings and those not susceptible to fluctuations (Bechard, Zoellick & Nickerson 1984). Thus body weight, for example, is not a useful measure. Wing features have frequently been used to estimate the age of nestling raptors, for example, the red-tailed Hawk (Petersen & Thompson 1977, Bechard *et al* 1984), sparrowhawk (Moss 1979, Newton 1986), great horned owl (Petersen & Thompson 1977), Ural owl (Pietiäinen 1989) and northern harrier (Scharf & Balfour 1971). All these studies used the length of a particular primary feather in their estimations of nestling age.

METHODS

Hatching dates were determined wherever possible by direct observation. Hatching is asynchronous in buzzards with about a two day period between eggs. From the first signs of a chick chipping its egg shell to finally breaking free from the egg takes up to 48 hrs. and for the first day a chick can be identified as having just hatched by its wet or still matted down. Thus in a typical buzzard clutch of two or three eggs a window of opportunity of about one week exists when hatching dates, and hence laying date, can be accurately determined. In 1989 frequent visits were required to determine hatching date as there was no way of predicting when this might occur. In 1990 an analysis of the 1989 egg density data along the lines to be presented below for both years allowed visits to be timed with at least some estimate of when hatching might be expected.

Buzzard eggs are laid at 2 to 3 day intervals. The incubation period for buzzards has been variously quoted as lying between 33 and 38 days and there is evidence that incubation times within a clutch become less with subsequent eggs so that chicks hatch at about 2 day intervals (Mebs 1964, Brown 1976, Tubbs 1974). In this study, eggs were assumed to be laid at three day intervals, incubation is taken to begin with the first egg. The incubation period for the first egg is taken to be 37 days. Second ,third and fourth eggs are taken to have incubation periods of 36, 35 and 34 days respectively leading to 2 day hatching intervals.

RESULTS

ANALYSIS OF EGG MEASUREMENTS

Of the 73 nests from which nest histories were obtained, 25 of these were located during incubation. Of these the hatching dates of 18 individuals from 11 clutches were established by direct observation of partially hatched broods assuming a two day hatching interval. Egg age was plotted against egg density. The age of the egg at the time of measurement was calculated from hatching date. In all cases where the hatching order could be determined it was established that the order conformed to the assumption that the degree of patterning on buzzards eggs within a clutch decreases from the first to last eggs. This assumption was therefore used to establish the status of some eggs in several clutches where the hatching order could not be deduced for all eggs by direct observation, for example when only the first egg in a clutch of three had actually started to hatch. Density was calculated using the equation;-

$$\text{density} = \text{weight} / ((\text{length})(\text{breadth})^2)$$

This is not the true egg density as that is obtained by multiplying the value obtained above by a value relating to egg shape. This value can, however, be considered constant within a species and is therefore not necessary for the purposes of this analysis. While the curve of egg age against density is not linear most of the deviation from linearity comes during the last few days of incubation. If data from this period are excluded a simple linear plot adequately describes the relationship. In the sample analysed no deviation from linearity was apparent. Because of the small sample size it was necessary to use egg measurement data from all eggs in each clutch. Eggs within a given clutch cannot be considered independent of each other and this might have compromised the statistical validity of any relationship found which related egg age to egg density. A jackknifing procedure was therefore used to test the predictive power of the relationship. The linear regression relating egg age to egg density was repeatedly calculated, using least squares method, each time omitting data obtained from all eggs from a particular clutch. The age of eggs in each clutch was then estimated using the relationship derived from all other clutches. Such age estimates were used to make an estimate of the hatching date of each egg. Clutches in which estimated date of hatching differed unacceptably from the known date of hatching were identified. Estimates were considered as unacceptable when they differed by more than two days from the actual value. The three clutches so identified contained eggs nearing the late stages of incubation. All eggs for which measurements had been taken during the last 7 days of incubation were therefore removed from the analysis and the linear regression relating age to egg density recalculated.

The regression curve of egg age (days) with density (g/cm^3) is shown in Figure 3.1 (r^2=0.729, P<0.01, n=14). The age of an egg is obtained from the relationship;-

$$\text{age} = 248.8 - 445.8(\text{density})$$

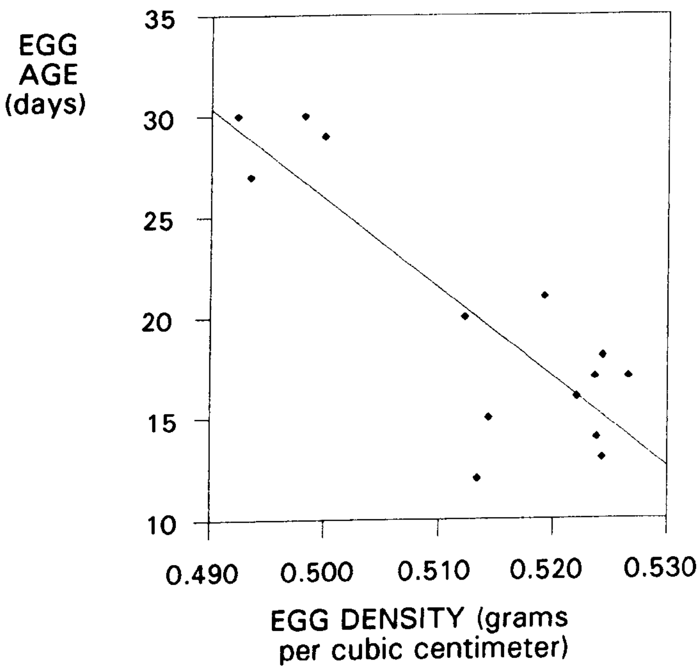

Figure 3.1: Egg age in relation to egg density.
The regression curve of egg age against density was used to predict the age of eggs in order to establish laying dates for clutches which failed to hatch due to embryo death. It was also used in the field to predict hatching dates in advance. Egg age is predicted from the relationship:-.

Age =248.8 - 445.8(density) (r^2=0.729, P<0.01. n =14)

The estimate of laying date used in subsequent analyses is that obtained from the mean estimate of laying date for all eggs in the clutch, each of these having been obtained using relationship;

$$(\text{laying date}) = (\text{date measured}) - \text{age} - 3\ (\text{status}) + 3$$

The error in estimation of laying dates, expressed as the number of days deviation from laying date derived from actual hatching dates, are given in Table 3.1.

Site	Error in estimate based on egg density
A	-1
B	0
C	-2
D	+5
E	+3
F	+40
G	-1
H	0
I	-20
J	-1
K	+3

Table 3.1: Error in days of estimates of laying date from laying date, derived from actual hatching dates, for each of 11 breeding attempts. Estimates are based on measurements of egg density.
Estimates are for laying date of first egg in the clutch. Each estimate is derived as the mean of all estimates made from all measurements of all eggs in the clutch.

ANALYSIS OF NESTLING MEASUREMENTS

Hatching dates of 35 nestlings from 16 broods were established from observations of incompletely hatched clutches. Measurements were obtained from all nestlings at least once and, for the 31 nestlings surviving to fledging, several sets of repeat measurements were obtained in most cases. As an initial means of analysis, nestling age was plotted against each of the biometric measurements in turn. At this stage all measurements of all known age chicks were used. Linear regression curves, using least squares method, were fitted to the linear phase of growth for each relationship. All measurements showed highly significant relationships with nestling age. Wing measurements showed the strongest relationships, weight the weakest, much as expected. Wing-length and length of 5th. primary (P5-length) were chosen for further consideration because wing measurements gave the strongest associations. Other measurements will not be discussed further here. The similarity of the coefficients of determination obtained when considering age and lengths of each of the primary measurements in turn suggested there would be little to choose between them. P5-length was chosen for further consideration however as, in the buzzard, it was found to be the longest of the primary feathers that has a distinctly pointed tip. Primaries to the inside of this one are longer but have much blunter tips and so measurement would be more prone to error. Although it was thought that wing-length may be more prone to measurement error than was primary length, it was included for further consideration as primary measurements were not available from several sites, monitored by other field workers, for which nestling ages would need to be calculated.

Nestling age was plotted separately against P5-length for each of status = 1, status = 2 and status = 3 nestlings (Figure 3.2). The single status = 4 nestling for which data were obtained was included in the status = 3 data set. Data points for which P5-length > 200mm. were excluded as beyond this limit primary growth deviated noticeably from linearity. When data sets had been obtained for a single nest over several visits the data from the visit closest to the mid-point of the nestling growth period was chosen.

Linear regression curves were fitted to each plot. The equations describing these three relationships were;

status=1:
age = 12.3 + 0.130 (P5-length) (r^2=0.953, $P<0.001$, n=16)

status=2:
age = 13.2 + 0.120 (P5-length) (r^2=0.903, $P<0.001$, n=13)

status=3:
age = 13.4 + 0.115 (P5-length) (r^2=0.965, $P<0.001$, n=4)

These three regression curves were compared using analysis of covariance, performed through the SPSS PC+ MANOVA procedure (Norušis/SPSS Inc. 1990). No significant differences were found between either the slopes (manova, $F_{2,27}$=0.35, P=0.705) or between the elevations ($F_{2,29}$=0.10, P=0.904) of these relationships.

A similar analysis was conducted for the wing-length measurements (Figure 3.5). Data points for which (wing-length) < 35mm. or (wing-length > 250mm) were excluded. Beyond these limits wing growth deviated noticeably from linearity. When data sets had been obtained for a single nest over several visits the data from the visit closest to the mid-point of the nestling growth period was chosen. The equations describing these three relationships were:

status=1:
age = 6.17 + 0.109 (wing-length) (r^2=0.960, $P<0.001$, n=21)

status=2:
age = 6.69 + 0.105 (wing-length) (r^2=0.918, $P<0.001$, n=17)

status=3:
age = 5.06 + 0.110 (wing-length) (r^2=0.953, $P<0.001$, n=5)

When these three relationships were compared using an analysis of covariance no significant differences were found either between the slopes (manova, $F_{2,37}$=0.15, P=0.864) or between the elevations (manova, $F_{2,39}$=1.07, P=0.354) of the relationships. Thus in the analysis which follows, data from all categories of nestling status are combined.

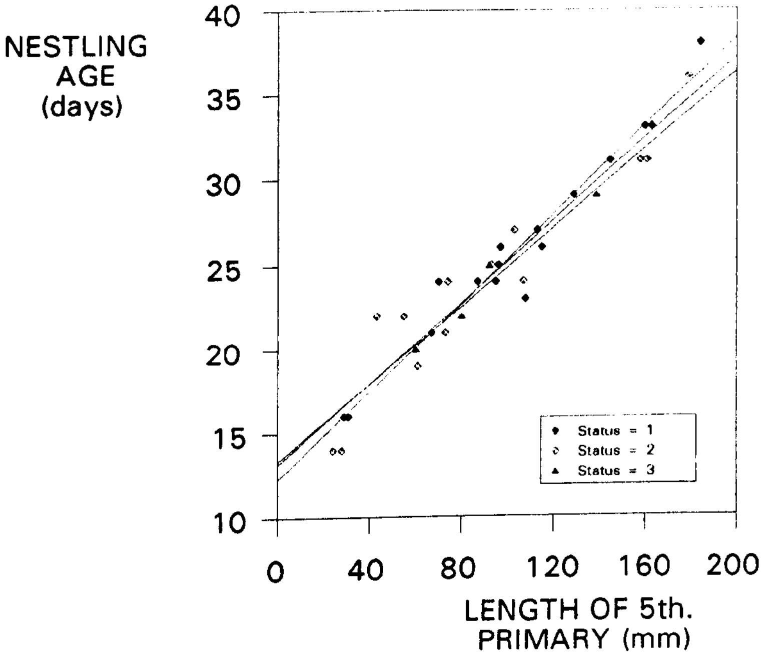

Figure 3.2: Nestling age in relation to length of 5th. primary by nestling status.
The regression curves of nestling age against length of 5th. primary were compared for nestlings of different status. No significant differences were found between the slopes of the curves (manova, $F_{2,27}$=0.35, P=0.705), or the elevations of the curves (manova, $F_{2,29}$=0.10, P=0.904).

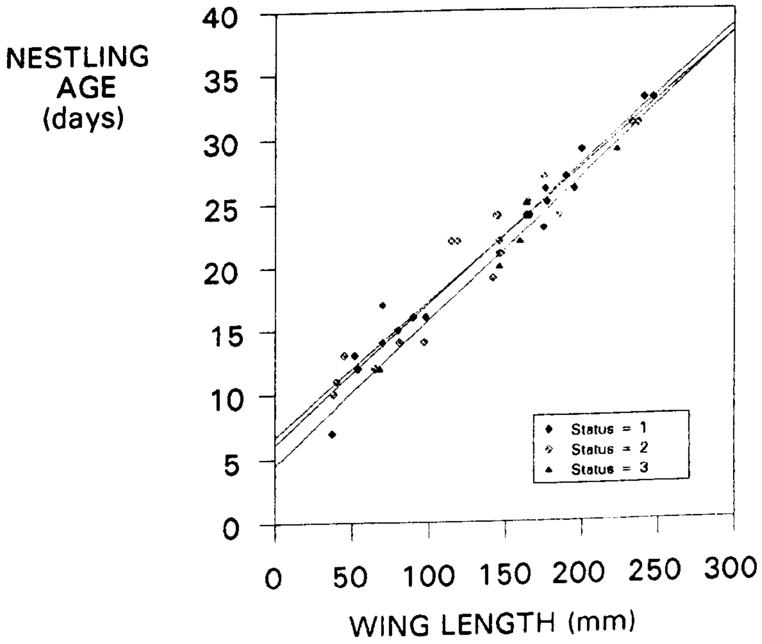

Figure 3.3: Nestling age relation to wing-length by nestling status.
The regression curves of nestling age against wing-length were compared for nestlings of different status. No significant differences were found between the slopes of the curves (manova, $F_{2,37}$=0.15, P=0.864), or the elevations of the curves (manova, $F_{2,39}$=1.07, P=0.354).

The aim of this analysis was to develop a means of estimating the laying date for each breeding attempt rather than a means of ageing individual nestlings. Also nestlings within a single brood are not independent and this may have invalidated subsequent statistical relationships between wing measurements and nestling age. Thus a jackknife procedure was used to test the predictive power of the age to wing measurement relationships obtained, when using this to estimate the laying date for each breeding attempt. This estimate was based on the mean laying date estimate, derived from hatching date estimates for each nestling in a brood.

The linear regression curves relating age to wing-length and age to P5-length were repeatedly calculated each time omitting data obtained from a different brood. The age of nestlings in each brood was then estimated using the relationship derived from all other broods. Cases in which the estimated age at the time of measuring differed unacceptably from the known age were thus identified. Estimates were considered as unacceptable if they differ by more than two days from the actual value. In the case of estimates based on P5-length, estimates which were unacceptably different from the actual age involved those of large nestlings with P5-lengths in excess of 200mm. In the case of estimates based on wing-length, estimates which were unacceptably different from the actual age involved those of nestlings that were either very large with wing-lengths in excess of 250mm. or small nestlings in which the primary feathers were still in pin for which wing-lengths were less than 35mm. The linear regression curve relating age (days) to P5-length (mm.) was calculated omitting all data points for which P5-length > 200mm. but otherwise using all nestlings from all broods ($r^2=0.930$, $P<0.001$, $n=33$). This is shown in Figure 3.4. The age of a nestling is obtained from the relationship;-

$$\text{age} = 12.754 + 0.125(\text{P5-length})$$

The linear regression relating age to wing-length was calculated omitting all data points for which 35mm. < (wing-length) < 250mm. but otherwise using all nestlings from all broods ($r^2=0.962$, $P<0.001$, $n=44$). This is shown in Figure 3.5. The age of a nestling is obtained from the relationship;-

$$\text{age} = 6.302 + 0.106(\text{wing-length})$$

The estimate of laying date taken for a given brood is that given by the mean estimate of laying date obtained from all sets of measurements, from all chicks in that brood. The laying date estimate from each nestling was obtained using the equation;

$$(\text{laying date}) = \text{date} - \text{age} - 35 - 2(\text{status})$$

The error in laying date estimates expressed as the difference in days from the laying date derived from actual hatching dates, calculated both when using data from all nestlings for all visits and when using only data for which P5-length < 200mm. or for which 35mm. < wing-length < 250mm., but otherwise using data from all nestlings for all visits are given in Table 2.

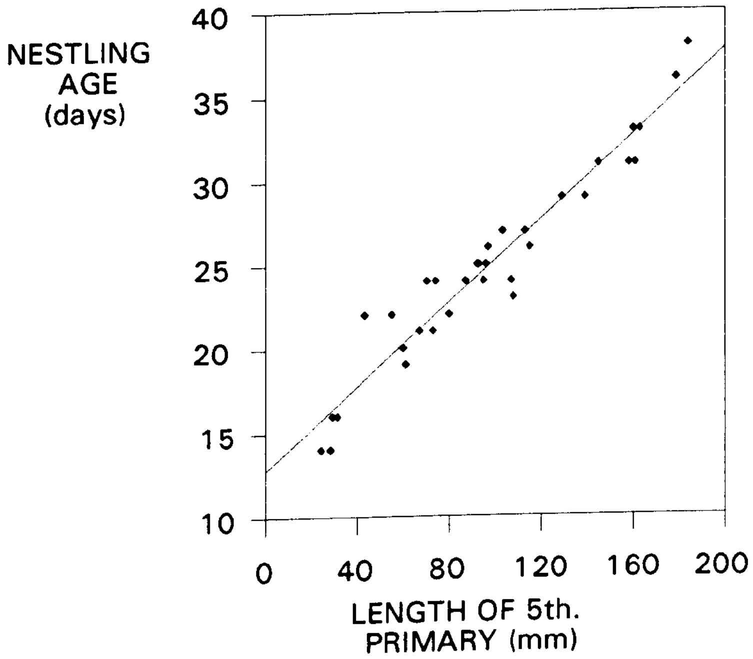

Figure 3.4: Nestling age in relation to length of 5th. primary.
The regression curve of nestling age against length of 5th. primary was used to predict the age of nestlings in cases where hatching had not been observed. Nestling age is predicted from the relationship:-

Age = 12.754 + 0.125(P5_length) ($r^2 = 0.930$, $p < 0.001$, n=33)

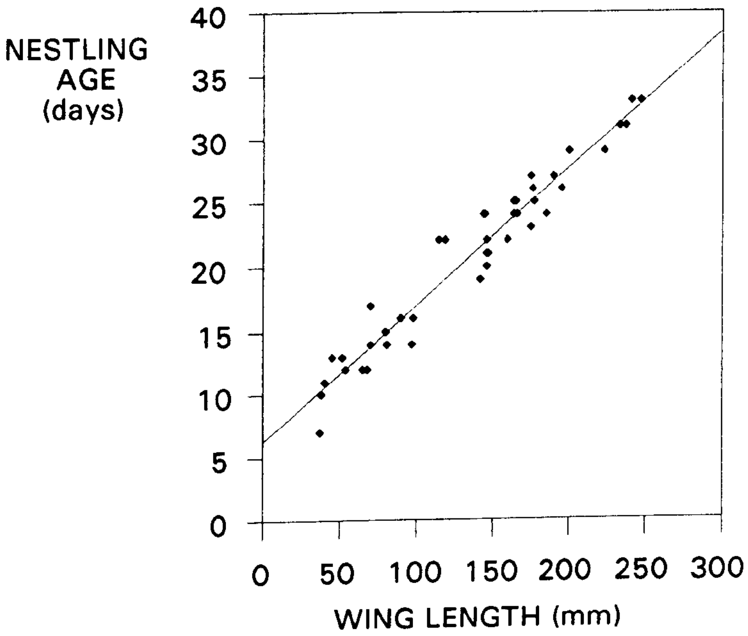

Figure 3.5: Nestling age in relation to wing-length.
The regression curve of nestling age against wing-length was used to predict the age of nestlings in cases where hatching had not been observed and no measurements of 5th. primary were available. Nestling age is predicted from the relationship:-

Age = 6.302 + 0.106(wing-length) (r^2= 0.962, P<0.001, n=44)

Site	Error in estimates based on wing measurements using data from all nestlings for all visits		Error in estimates based on wing measurements using data for which P5-length<200mm. or for which 35mm.<wing-length<250mm. as appropriate but otherwise using data from all nestlings for all visits	
	Error in estimate based on P5-length	Error in estimate based on wing-length	Error in estimate based on P5-length	Error in estimate based on wing-length
A	+1	+1	+2	+1
B	-1	0	0	0
C	0	0	-1	-1
D	0	0	+1	0
E	0	0	+2	0
F	+2	-2	+3	+2
H	**	-2	**	-1
I	-3	-3	-2	-3
M	0	0	+1	0
N	+4	+3	**	**
P	-8	-14	-6	**
G	-2	-2	-1	-2
J	+2	+1	+3	+1
K	**	+1	**	+1
L	+1	0	+2	0
O	**	-4	**	-4
Mean	-0.31	-1.31	0.33	-0.43
Standard Error	0.81	0.95	0.74	0.44

Table 3.2: Error in days of estimates of laying date from laying date, derived from actual hatching dates, for each of 16 breeding attempts.
Estimates are based on measurements of length of 5th. primary and wing-length.
Estimates are for laying date of first egg in the clutch. Each estimate is derived as the mean of all estimates made from all measurements of all nestlings in the brood.
** = no estimate available.

ESTIMATES OF UNKNOWN LAYING DATES

For the 57 nests for which no direct observations of hatching data were obtained it was necessary to estimate laying date using one of the measures discussed here. For some of these there was no choice as to which measure to use. For example, when clutches failed to hatch, only estimates using egg density data could be made, and for several broods where data were supplied by other workers no measurements of primary length were obtained for nestlings. There were however many cases where estimates could be based on two or more criteria. Thus there were 39 cases for which estimates were available using both wing-length and P5-length data, 6 cases in which estimates were available using both P5-length and egg density data and 2 cases in which estimates were available using both wing-length and egg density data. While these estimates can not be compared with actual values for laying date they can be compared amongst themselves. When estimates based on wing-length were compared with those based on P5-length they were found to be in close agreement with a mean difference in estimates of 0.91 days (n=39). In 31 cases the difference in laying date estimate was less than 1 day and in only 2 cases was the difference greater than 2 days. When estimates based on P5-length were compared with those based on egg density the mean difference in estimates is 2.7 days (n=6) with no differences of more than 3 days. When estimates based on wing-length were compared with those based on egg density both cases differed by over 13 days.

DISCUSSION

Considering the estimates of laying date based on egg density measurements (Table 3.1), the three estimates that differ unacceptably from the laying date, derived from actual hatching dates, were those from sites for which measurements of eggs were obtained during the final week of incubation. The large error in the estimates for these sites is therefore expected, the rate of water loss increasing during this period causing the age against density curve to deviate from linearity and there was a possibility that early signs of shell chipping had gone unrecorded. If these cases are ignored then the estimates of laying date would be suitable for many purposes. This would, for example, be the case in the present study where laying dates for different pairs, spread over a six week period between late March and early May, are being compared. The problem, however, is if estimates of laying date are to be made using egg densities alone, how can eggs in the final stages of incubation be identified? It may be possible in some cases to detect movement and vocalisations from within the egg but recourse to such methods can be unreliable. This problem can be partly overcome by fitting a non linear curve to the data and so allow for increased rate of change in density towards the late stages of incubation (Furness & Furness 1981). For this to be meaningful, however, a much larger sample size than obtained in the current study would be needed. This is likely to be difficult to obtain for a population of free living buzzards. Caution was therefore necessary when using estimates of laying date derived from this method in subsequent analysis. The method was, however, useful in estimating the expected hatching dates of eggs in order that the window of opportunity during which partially hatched broods will be found can be targeted for a visit. In the current study this method was successfully employed in the second year using a relationship derived from the first years data. One effect of this was to reduce the number of visits required during this critical period, and hence reduce the potential disturbance to the birds.

Considering the estimates of laying date made using both P5-length and wing-length, both are seen to provide accurate estimates with a mean error of the laying date estimate from that derived from the actual hatching date being -0.31 ± 0.81 days and -1.31 ± 0.95 days (Mean ± S.E.) for estimates based on P5-length and wing length respectively. When the errors in these estimates for individual nests are considered, looking first at estimates based on all measurements of nestlings regardless of size (see Table 3.1) in both cases several sites (14,15,16) are seen to have unacceptably large errors (F, N & L for P5-

length, H & K for wing-length). In these three cases measurements used included those made of large nestlings with wing-length > 250mm. or P5 > 200mm. The analysis had previously identified measurements of this magnitude as unsuitable and so normally they would have been excluded. For these sites, when such measurements are dropped from the analysis (see Table 3.2) some estimates are lost as all measurements were outside the limits. Of the estimates remaining there is little improvement probably because these estimates are now being made on single measurements of a single nestling from that brood, rather than being made using measurements from several nestlings in a brood over several visits. Eliminating large and small nestlings from the data sets for the other sites caused little overall changes in the accuracy of estimates as they had included only a minority of such cases. The mean error of the laying date estimate from that derived from the actual hatching date using only measurements from nestlings within this reduced sample being -0.33 ± 0.74 days and -0.43 ± 0.44 days (Mean ± S.E.) respectively.

The high level of agreement between estimates based on these two measures, both when considering those sites for which laying dates were known, and when considering sites of unknown laying date, simply reflects the fact that much of the total wing-length is composed of the length of the primary forming the point of the wing. It does, however, indicate that if estimates of laying date or chick age have been made using either of these two measurements valid comparisons can still be made amongst them. This was important in this study where wing-lengths only were available for some broods where data from the Cowal peninsula in 1989 had been gathered by other workers. There was no detectable difference between the accuracy of estimate made using the two measures and so it is largely a matter of personal preference as to which one to use.

SECTION III: THE USE OF NESTLING WEIGHT IN RELATION TO AGE TO CLASSIFY BROOD QUALITY

INTRODUCTION

It has been demonstrated that the nestling period can be important in contributing to differences in breeding success observed between different habitats. For the sparrowhawk *Accipiter nisus* Moss (1979) suggested that differences in growth rates between contrasting habitats were related to food supply. In the carrion crow *Corvus corone* Richner (1989) found nestling growth to be habitat specific and that the weight attained immediately prior to fledging was related to subsequent fledgling survival. Both these studies show that growth rates were unaffected by brood size. It would therefore seem that measurement of nestling growth may provide a useful indication of home range quality.

Estimation of growth rates used in the studies referred to above were based on daily measurements of individuals, growth rate referring to the linear regression coefficient for the linear phase of growth seen during the middle of the nestling period. It was not feasible to obtain such a degree of detail in this study and for many breeding attempts it was only possible to obtain one set of nestling measurements from the linear growth phase of each nestling period. Instead of growth rate, the weight of each nestling in a brood was compared with that which would be expected for an average nestling of the same age from the study population and these data used to classify the overall "quality" of each brood. The main purpose of this analysis was to arrive at a means of assigning breeding attempts to a small number of brood quality classes which would serve as a grouping variable for use with a discriminant analysis (Chapter 9).

METHODS

All statistical procedures described in this chapter were performed using SPSS PC+ (Norušis/SPSS Inc. 1990). Standard regressions were performed between weight and age for all nestlings. Where necessary nestling age was estimated based on the methods described in section 2 of this chapter. Rather than base nestling age on a single wing-length or primary measurement, the age of each individual was estimated in relation to the laying date for the brood from which it came which was in turn derived from the mean estimate obtained using data from all siblings. The intention of this procedure was to reduce errors due to individual variation. Separate regression curves were fitted for nestlings of six different classes of status and sibling count . The six classes were :-

1) Nestlings in current brood of 1.
2) Status 1 nestlings in current brood of 2.
3) Status 1 nestlings in current brood of 3 or 4.
4) Status 2 nestlings in current brood of 2.
5) Status 2 nestlings in current brood of 3 or 4.
6) Status 3 or 4 nestlings.

Only measurements of nestlings taken when they were between the ages of 7 and 30 days were used. During this time, weight increase was found to be approximately linear. When several visits had been made to an individual nest during this period only one set of measurements was used, this being the set obtained nearest to the middle of the nestling period (15-20 days old). These regression curves were used to obtain an expected weight for each nestling for comparison with its observed weight. Nestlings were then classified as either heavy for age or light for age, as appropriate, if their observed weight was outside the 95% confidence intervals for the estimated weight for a nestling of similar age. The number of nestlings classified as either heavy for age or light for age was then scored for each nest. This was then used to assign nests to one of three groups;- those containing a predominance of heavy nestlings, those containing a predominance of light nestlings and those in which no nestlings differed significantly in weight from that which would be expected for their age.

RESULTS

Details of the linear regression curves relating nestling weight to nestling age, for each class of nestling status and sibling count, are summarised in Table 3.3.

Nestling Status and Sibling Count	Sample Size (n)	Coefficient of Determination (r^2)	Constant (a)	Regression Coefficient (b)	Standard Error of the Estimate
Nestlings in brood of 1	17	0.8789	-17.57	30.01	62.850
Status 1 nestlings in broods of 2	40	0.8405	11.46	27.29	77.083
Status 1 nestlings in broods of 3 or 4	15	0.9289	-80.76	34.59	46.859
Status 2 nestlings in broods of 2	33	0.7603	64.75	23.77	95.089
Status 2 nestlings in broods of 3 or 4	18	0.8412	42.19	27.07	56.793
Status 3 or 4 nestlings	22	0.9025	-73.01	32.99	59.372
All nestlings	145	0.8615	-25.38	30.26	76.370

Table 3.3: Regression equations derived to estimate expected weight of nestlings from age. Separate regression equations were constructed separately for each class of nestling status and sibling count as well as for all nestlings combined. Regression equations are of the form WEIGHT = a + b(AGE).

These regression curves were compared using an analysis of covariance performed through the SPSS PC+ MANOVA procedure. No significant differences were found between the slopes of the curves (manova, $F_{5,133}$=1.31, P=0.263) or their elevations (manova, $F_{5,138}$=0.48, P=0.079). Data from the six classes were therefore combined. The regression curve relating nestling weight to nestling age is given in Figure 3.6.

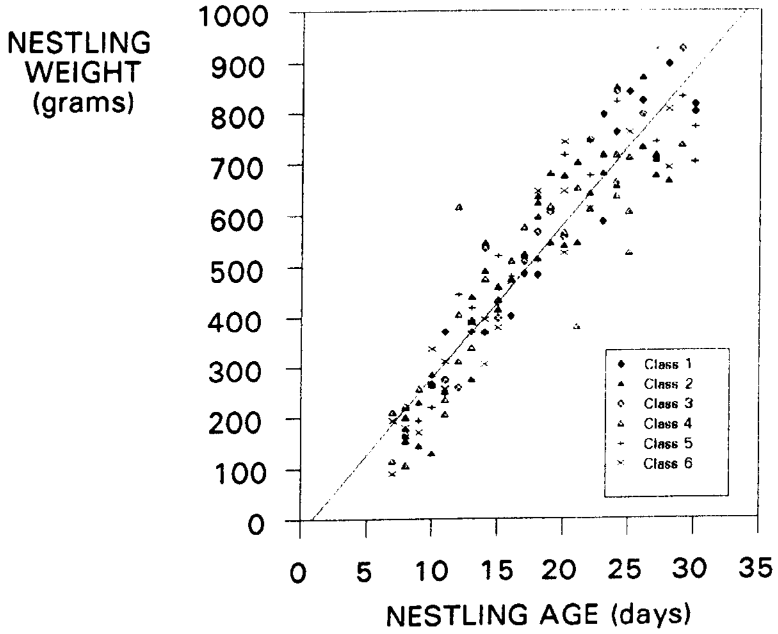

Figure 3.6: Nestling weight in relation to age.
The regression curves of nestling weight against nestling age were used to predict the expected weight for each nestling based on the population average, given its age for the purpose of comparison with its actual weight.
Nestlings were assigned to one of six classes:-

1) Nestlings in current brood of 1,
2) Status 1 nestlings in current brood of 2,
3) Status 1 nestlings in current brood of 3 or 4,
4) Status 2 nestlings in current brood of 2,
5) Status 2 nestlings in current brood of 3 or 4,
6) Status 3 or 4 nestlings.

The linear regression curve shown is based on data from all nestling classes combined. No significant differences were found between either the slopes (manova, $F_{5,133}=1.31$, $P=0.263$) or the elevations (manova, $F_{5,138}=0.48$, $P=0.079$) of the individual regression curves for the six classes of nestling status and sibling count.

When nestling weights were predicted for individuals, using regression equations based only on data obtained for other individuals of similar status and sibling count (like nestlings), 66 nestlings were identified as significantly above or below the sample average weight for their age. Of the 43 nests to which these nestlings belonged, 20 contained, on average, nestlings above the sample average weight for their age and 17 contained on average nestlings below the sample average weight for their age. The remaining 6 nests contained equal numbers of nestlings from these two classes.

When nestling weights were predicted for individuals, using regression equations based on all other individuals (all nestlings), 89 nestlings were identified as significantly above or below the sample average weight for their age. Of the 49 nests to which these nestlings belonged, 16 contained, on average, nestlings above the sample average weight for age and 23 nests contained, on average, nestlings below the sample average weight for age. The remaining 8 nests contained equal numbers of nestlings from these two classes.

Classification of individual nestlings was compared between the case where they were assigned to class based on data from like nestlings with the case where they were assigned on data from all nestlings. When basing classification on the all nestling regression equation, 4 individuals were classified as below average weight for age whereas they had been classified as above average weight for age when using the like nestlings regression equations. Another 4 individuals were not classified as significantly above or below average weight for their age by the all nestling regression equation whereas they had been found to be significantly above (2 cases) or below (2 cases) average weight for age when using the like nestling regression equations. When, however, nests were classified by whether, on average, they contained nestlings that were of significantly lower or higher weight for age than the sample average only one of these cases affected the overall classification of the nest. There were, however, 24 cases not identified as significantly above or below the average weight for their age by the regression equations based on like nestlings which were so identified by the regression equation based on all nestlings. These did result in a change in classification of 3 nests overall.

DISCUSSION

The aim of this analysis was to provide a means of categorising breeding attempts according to brood quality for use in subsequent analyses. Analysis presented in Chapter 5 uses this classification to compare the brood quality between different nest site situations and analysis presented in Chapter 9 uses it in relation to habitat. It was therefore important to obtain a classification which could identify reasonable samples of low and high weight for age broods. In these chapters weight predictions are based on the combined data set. Discussion of whether or not this method produced a useful measure of brood quality will be more appropriate later in this thesis.

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CHAPTER 4: BUZZARD BREEDING PERFORMANCE THROUGHOUT BRITAIN

CONTENTS:

INTRODUCTION

The main aim of monitoring breeding performance in the buzzards was to provide an assessment of the performance of each pair in order to relate this to the habitat contained within each home range. However, a number of other studies of buzzards from around Britain have published details of breeding performance and it is worth comparing these data between themselves and with the mid-Argyll study. In the first part of this chapter details of overall breeding performance of the buzzards in mid-Argyll is presented. In the second part of this chapter studies from throughout Britain are compared using published data. The aim of this treatment is to identify where any regional differences in breeding performance may exist and consider whether or not these differences may reflect broad differences in habitat between these areas.

BREEDING PERFORMANCE OF BUZZARDS IN MID-ARGYLL

LAYING DATE

The date on which the first egg was laid could be estimated for 33 breeding attempts for 1989 and 37 for 1990. As no direct observations of laying dates were obtained laying dates were estimated using the methods described in Chapter 3. Estimates based on actual observations of hatching date were used whenever possible. Estimates based on primary measurements were favoured over those based on wing measurements which in turn were favoured over those based on egg density. Of the three nests for which no estimate of laying date was obtained in two cases this was because the entire clutch was infertile while the other involved an inaccessible nest for which no nestling biometrics were obtained. Table 4.1 gives details of the number of estimates based on each method. In both years the median laying date was 14th. April with a range between 2nd. April and 7th. May.

Method used to estimate laying date	Number of breeding attempts
From direct observation of hatching	16
From nestlings aged using measurements of primary 5	34
From nestlings aged using measurements of wing-length	16
From eggs aged using density	4

Table 4.1: Criteria used to estimate laying dates.
Full details of these four methods are discussed fully in Chapter 3. Methods are listed in order of preference in which they were adopted to estimate laying dates when several criteria were available.

CLUTCH SIZE

An estimation of minimum clutch size was obtained for 34 breeding attempts in 1989 and 39 in 1990. On average each pair of buzzards in mid-Argyll produced a clutch of 2.2 eggs (median=2), with a range of 1 to 4. Details of clutch sizes in each year are given in Table 4.2. No significant difference was found between the median clutch size between years (Mann-Whitney, z=-0.0705, P=0.9438, n=73).

Year	Clutch size			
	1	2	3	4
1989	4	19	10	1
1990	2	26	10	1

Table 4.2: Minimum initial clutch size found in buzzard nests in mid-Argyll for 1989 & 1990. No significant difference was found in clutch size between years (M-W, z=-0.0705, P=0.9438, n=73).

BROOD SIZE

The initial brood size was estimated for 73 breeding attempts including 6 nests in which no eggs hatched. Results from some studies express average brood size calculated on all breeding attempts while others quote average brood size calculated on only those that successfully hatch at least one young. On average each pair of buzzard in mid-Argyll produced 2.0 young. If pairs which failed to hatch any young are excluded the average brood size was 2.1. Details of initial brood sizes for each year are given in Table 4.3. No significant difference was found between the median initial brood size between years for pairs which hatched at least one young (Mann-Whitney, z=-0.6640, P=0.5067, n=67).

Year	Brood size				
	0	1	2	3	4
1989	2	5	17	9	1
1990	4	5	23	6	1

Table 4.3: Initial brood sizes found in buzzard nests in mid-Argyll in 1989 & 1990. There was no significant difference in the median initial brood size between years for pairs which hatch at least one young (M-W, z=-0.6640, P=0.5067, n=67.

FLEDGING SUCCESS

The number of nestlings reared to fledging were estimated for 73 breeding attempts. Results from some studies express the average number of nestlings fledged calculated on all breeding attempts while other quote the average number fledging from successful breeding attempts. On average buzzards in mid-Argyll fledged 1.8 young per pair. If only pairs rearing at least one young to fledging are considered on average 2.0 young fledged per nest. Details of the number of young fledged in each year, from nests in which at least one nestling had hatched is given in Table 4.4. No significant difference was found between the median number of young fledged per nest between years for nests in which at least one nestling had hatched (Mann-Whitney, $z=-0.5738$, $P=0.5661$, $n=67$).

Year	Number of young fledged				
	0	1	2	3	4
89	1	10	13	7	1
90	0	7	21	7	0

Table 4.4: Number of young fledged from buzzard nests in mid-Argyll for 1989 & 1990. Data are for nests in which at least one nestling had hatched. There was no significant difference in the number of young fledged from nests in which at least one young had hatched, between years (M-W, $z=-0.5738$, $P=0.5661$, $n=67$).

BREEDING FAILURE

All six cases of complete nest failure occurred during the egg stage. Of these, one clutch was predated, one clutch of developing eggs was abandoned and the remainder contained infertile eggs. A further 10 eggs failed to hatch and in all cases where the reason could be determined, no embryo had developed. Overall 21 eggs from a total of 164 known to have been laid failed to hatch.

Out of a total of 143 nestlings hatched 131 were reared to fledging. All losses were of nestlings less than ten days old and there were no records of more than one nestling lost from any one nest. The number of nests from which nestlings were lost were 1,8,2 and 1 from broods with initial sizes of 1,2,3 and 4 respectively. There was, therefore, no significant differences in the proportions of nests from each initial brood size class from which nestlings were lost ($\chi^2_3=1.25$, $P>0.7$).

COMPARISON WITH OTHER STUDIES

LAYING DATE

Many published studies give data on median, or sometimes mean laying date or give details from which these parameters can be derived. Campbell (1947) gives 15th. to 25th. April as the peak laying time for buzzards in Argyll, and a similar peak was found in Kintyre, south Argyll, with an earliest laying date of 27th. March and a latest laying date of 5th. May (Maguire 1979). The median laying date from the Kintyre study can be derived as 20th. April. Elsewhere in Britain the situation is similar. In south-west England, peak laying dates have been given as 15th. to 25th. April (Pring 1947) and 9th. to 20th. April (Ryves 1946, Dare 1961), the latter corresponding to the 10th. to 20th. April found for Speyside nest record cards (Tubbs 1972). In the English Lake District, peak laying was reported as 19th. to 29th. April (Coombes 1946) and Holdsworth (1971) gives the median laying date as 21st. April with a range from 8th. April to 9th. May for North Yorkshire.

CLUTCH SIZE

It is possible to derive data detailing the proportions of clutches of various size from data published in a number of British studies. Here I use published data from studies in Speyside, (Picozzi & Weir 1974), Kintyre, Argyll (Maguire 1979), the Lake District (Coombes 1946), Sedburgh, North Yorkshire (Holdsworth 1971), Snowdonia, north Wales (Dare 1989, pre publication draft), the New Forest, Hampshire (Tubbs & Tubbs 1985), Devon and Somerset (Mayo 1948) and south west England (Pring 1947). The data for mid-Argyll from this study is also included for comparison. In some cases these data were collected during a few years of intensive study (Speyside, Kintyre, Snowdonia, mid-Argyll) while in others it is the result of many years of continued study (Lake District, Sedburgh, New Forest, Devon & Somerset and south-west England). It is also apparent that some of these studies will contain data from repeated observations from single sites although whether or not the same individuals were involved is undetermined. These data are given in Table 4.5. From all but one study it was not possible to separate data on a yearly basis and so it is given here for all years combined.

Location	Clutch size					
	1	2	3	4	5	6
mid-Argyll	6	45	20	2	0	0
Speyside	0	20	35	17	0	0
Kintyre	6	29	50	4	0	0
Lake District	1	8	50	1	0	0
Sedburgh	1	10	34	10	1	0
N.Wales	13	42	33	0	0	0
New Forest	14	48	12	0	0	0
Devon & Somerset	1	15	38	4	2	0
S.W.England	1	17	34	3	2	1

Table 4.5: Proportion of nests containing clutches of various sizes from nine British studies. Mid-Argyll (this study), Speyside (Picozzi & Weir 1974), Kintyre, Argyll (Maguire 1979), the English Lake District (Coombes 1946), Sedburgh, North Yorkshire (Holdsworth 1971), Snowdonia, north Wales (Dare 1989, pre publication draft), the New Forest, Hampshire (Tubbs & Tubbs 1985), Devon and Somerset (Mayo 1948), south-west England (Pring 1947)

A Kruskal-Wallis one way analysis of variance by ranks (Siegel & Castellan 1988) was used to compare the median clutch size between the studies. A highly significant difference was found under the null hypothesis that; there is no difference between the median clutch sizes found in the nine studies ($K_{[\text{corrected for ties}]} = 144.9630$, $P<0.0005$), and so a multiple comparisons test was appropriate (Siegel & Castellan 1988). The significance level for multiple comparisons was constrained to $\alpha=0.05$. Table 4.6 gives the results of the multiple comparisons test between these studies.

Location	Mid Argyll	Devon & Som	South West Eng	New For	North Wales	Sed	Lake Dist	Kin
Speyside	SP>Ar	SP=De	SW=Sp	Sp>NF	Sp>NW	Sp=Se	Sp=LD	Sp=Ki
Kintyre	Ki>Ar	Ki=De	Ki=SW	Ki>NF	Ki>NW	Ki=Se	Ki=LD	
Lake District	LD>Ar	LD=De	LD=SW	LD>NF	LD>NW	LD=Se		
Sedburgh	Se>Ar	Se=De	Se=SW	Se>NF	Se>NW			
North Wales	NW=Ar	NW<De	NW<SW	NW=NF				
New Forest	NF=Ar	NF<De	NF<SW					
SW England	SW>Ar	SW=De						
Devon and Somerset	De>Ar							

Table 4.6: Results of multiple comparison test comparing clutch size data given in Table 4.5. Inequalities indicate where differences lie with multiple significance level constrained to $\alpha<0.05$.

BROOD SIZE

As was the case for clutch size, it is possible to derive data from some other British studies for brood size. Here brood size refers to the initial number of young hatching in a nest. In some studies it is not indicated whether or not counts of young were made early in the nestling period. These were not included as they may have underestimate how many young had hatched when losses had occurred before counts were made. In the case of four British studies data comparable to that obtained for mid-Argyll could be derived from published work. These data, details of which are given in Table 4.7 were obtained from the studies in Speyside (Picozzi & Weir 1974), Sedburgh (Holdsworth 1971), Kintyre (Maguire 1979) and from the New Forest (Tubbs 1967). It was not possible to determine the number of nests in which eggs were laid but no young had hatched for all the studies used and consequently data tabulated includes only breeding attempts in which at least one young was hatched.

Location	Number of young hatched				
	1	2	3	4	5
mid-Argyll	10	40	15	2	0
Speyside	3	26	30	14	0
Kintyre	11	30	35	2	0
Sedburgh	18	27	24	5	1
New Forest	44	29	0	0	0

Table 4.7: Proportion of nests containing broods of various size from five British studies. Mid-Argyll (this study), Speyside (Picozzi & Weir 1974), Sedburgh (Holdsworth 1971), Kintyre (Maguire 1979) New Forest (Tubbs 1967)

A Kruskal-Wallis one way analysis of variance by ranks was used to compare the median clutch size between the studies. A highly significant difference was found under the null hypothesis that; there is no difference between the median brood sizes found in the five studies ($K_{[\text{corrected for ties}]}=97.4619$, $P<0.0005$), and so a multiple comparisons test, with multiple significance level constrained to $\alpha=0.05$, was used to investigate where these differences lay. Table 4.8 gives the results of the multiple comparisons test between these studies.

Location	mid-Argyll	New Forest	Sedburgh	Kintyre
Speyside	SP>Ar	Sp>NF	Sp>Se	Sp=Ki
Kintyre	Ki=Ar	Ki>NF	Ki=Se	
Sedburgh	Se=Ar	Se>NF		
New Forest	NF<Ar			

Table 4.8: Results of multiple comparison test comparing brood size data given in Table 4.7. Inequalities indicate where differences lie with multiple significance level constrained to $\alpha<0.05$.

NUMBER OF YOUNG FLEDGED

As was the case for clutch size and brood size it is possible to derive data from some other British studies for the number of young actually fledged. In the case of three studies, data comparable to that obtained for mid-Argyll could be derived from published work. These data were obtained from the studies in Speyside (Picozzi & Weir 1974), Snowdonia (Dare 1989 pre-publication draft) the New Forest

(Tubbs & Tubbs 1985). Data presented in Table 4.9 gives details of number of young fledged from all nests that hatched at least one young, including those failing between hatching and fledging.

Location	Number of young fledged				
	0	1	2	3	4
Speyside	65	5	36	28	11
North Wales	25	108	50	5	0
New Forest	63	143	122	7	0
mid-Argyll	7	17	34	14	1

Table 4.9: Proportion of nests fledging various numbers of young for four British studies. Mid-Argyll (this study), Speyside (Picozzi & Weir 1974), Snowdonia (Dare 1989 pre-publication draft) the New Forest (Tubbs & Tubbs 1985).

A Kruskal-Wallis one way analysis of variance by ranks was used to compare the median number of young fledged between the studies. A highly significant difference was found under the null hypothesis that; there is no difference between the median number of young fledged found in the four studies ($K_{\text{[corrected for ties]}} = 22.8377$, $P<0.0005$), and so a multiple comparisons test, with multiple significance level constrained to $\alpha=0.05$, was used to investigate where these differences lie. Table 4.10 gives the results of the multiple comparisons test between these studies.

Location	mid-Argyll	North Wales	New Forest
Speyside	Sp<Ar [Sp>Ar]	Sp=NW [Sp>NW]	Sp=NF [Sp>NF]
New Forest	NF<Ar [NF<Ar]	NF=NW [NF=NW]	
North Wales	NW<Ar [NW<Ar]		

Table 4.10: Results of multiple comparison test comparing data on number of young fledged given in Table 4.8. Inequalities indicate where these differences lie with multiple significance level constrained to $\alpha<0.05$. Inequalities in parentheses indicate where differences lie when nests failing during the egg stage are excluded.

BREEDING FAILURE

It is apparent from the published studies that failure of eggs to hatch is one of the principal causes of breeding failure, although often this refers to complete clutch failure rather than failure of individual eggs. Egg failure in mid-Argyll was 12.8%, none of which was attributed to human predation, and this compares favourably with other studies. An overall egg failure rate of 25% was reported for Speyside although 50% of these losses were due to human persecution (Picozzi and Weir 1974). This was enough to account for the higher overall loss. In Kintyre 12.4% of eggs failed, with 18% (2 clutches) of these losses due to human predation (Maguire 1979). A failure rate of between 6.3% and 25% was reported for the New Forest, due mainly to predation by crows. Dare (1961) reported a failure rate of nearly 30% of clutches for Dartmoor. Holdsworth(1971) gives a 75% success rate for eggs from Sedburgh but this excludes nests where total egg failure occurred and so a failure rate greater than 25% is implied. Tubbs (1972) found that, for Britain as a whole, about 16% of clutches failed completely.

DISCUSSION

With a median laying date of 14th. April and a range in laying dates from 2nd. April to 5th. May, buzzards in mid-Argyll showed constancy with the other studies for which this was reported. Brown (1976) remarked that variation throughout Britain is less than that which might be expected. It was not possible from the data available to test the significance of observed differences in median laying date between these studies as few studies give details of individual laying dates, however reported peaks in laying remain remarkably consistent between them. What does emerge from all these data however is the wide range in laying date within all populations studied, of up to seven weeks. This suggests that local factors acting upon individual pairs may be as important as the broad differences in climate, latitude, and general location.

The median clutch size for all the studies considered was, not surprisingly, either 2 or 3. Median clutch size of 3 was found for Speyside, Kintyre, North Yorkshire, the English Lake District, Devon and Somerset, and the south-west of England while median size of 2 was found for mid-Argyll, Snowdonia and the New Forest. The analysis presented above shows that this difference is significant, with the result of the multiple comparison test dividing the studies neatly into these two groups. This indicates that buzzards in some areas are producing larger clutches than other areas. Several factors may be contributing to this. Tubbs' analysis of nest record cards (Tubbs 1972) suggested that clutch size may increase with latitude, although Brown (1976) pointed out that this may well have been an artefact of the uneven distribution of nest records available at the time as this analysis had included a large sample from the New Forest in the south where clutch size was low and a large sample from the Speyside where clutch size was high. The present analysis did not detect any such trend. In fact the three areas identified as having low median clutch size are distributed evenly over the full latitudinal range considered as are those with high clutch size, and two geographically close areas, Kintyre and mid-Argyll had significantly different median clutch size. It may well be, therefore, that broad environmental differences between areas, such as climatic gradients and day length, which relate to latitude are not as important as immediate environmental factors such as vegetation cover, topography and local climate.

Not surprisingly, the number of young hatched showed a similar pattern to clutch size except that only Speyside showed significantly greater median brood size than mid-Argyll, whereas several studies had shown greater median clutch sizes. This reflects the particularly low egg loss, natural or otherwise, found in mid-Argyll. Much of the differences in egg failure seen between studies can be accounted for by the differing levels of human persecution. The earlier studies, which have particularly high egg failure rates, also span periods when organo-chlorines were used in pesticide sprays and sheep-dip. In some areas such as the New Forest and Dartmoor avian prey was commonly taken, while in mountainous areas sheep carrion was eaten. Both of these prey habits are believed to have led to high levels of contamination in other species (e.g. Lockie, Ratcliffe & Balharry 1969, Newton 1979). While similar effects were not reported for buzzards it may be that these chemicals could have had local impacts on some populations rendered vulnerable by local feeding habits. Buzzards in mid-Argyll also exhibit a high fledging success. When considering all breeding attempts where eggs were known to have been laid, the median number of young fledged from mid-Argyll nests was significantly greater than all the other studies used in the comparison. If, however, only nests where clutches that successfully hatched at least one young are considered the differences between areas is more akin to that seen for clutch size. Consequently it appears to be the low failure rate during the early stages of breeding in mid-Argyll that accounts for the high average fledging success found.

When differences are found in the overall breeding performance of separate populations of a species, ecologists will generally look for differences in environmental factors such as land use and prey availability to provide an explanation (e.g. Dare 1989, Moss 1979). In raptors, environmental factors such as climate, altitude, topography, land use and prey abundance have all been put forward to explain such differences. One would expect that the effects of habitat seen at the population level represent the average effect of local conditions on each individual in that population. This suggests that the same parameters of breeding performance that differ between populations in response to habitat will also differ at the level of individual buzzard pairs. Thus breeding performance will be correlated with the quality of individual home ranges although one might expect that this effect will be modified by individual bird quality. A number of raptor studies have therefore sought to relate these same environmental factors to differences in the breeding performance of individuals within a single population (e.g. Kuusela 1981, Newton, Marquiss & Moss 1979, Newton, Davis & Davis 1981. Marquiss, Ratcliffe & Roxburgh 1985). The wide variation in laying date apparent in all the buzzard studies may well reflect differences in home range quality between pairs. Differences in breeding output from buzzards in these various studies are seen to stem largely from the size of the clutches they are producing. No pattern is apparent that might lead us to suspect that buzzards from these areas differ in their ability to rear young once they have hatched. A number of studies have failed to detect differential nestling survival in broods of different sizes (Picozzi & Weir 1974, Dare 1989), although often sample sizes make this difficult to test.

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CHAPTER 5: BUZZARD NEST SITE SELECTION IN MID-ARGYLL

CONTENTS:

SECTION I: NEST SITE HABITS

INTRODUCTION

When investigating distribution and breeding performance of a species such as the buzzard the availability of potential nest sites in any given area is an important consideration. Buzzard nests can be sizeable structures and it is possible that otherwise favourable habitat is rendered unacceptable by the absence of suitable structures on which to site a nest. In the context of this study, this is an important consideration as the ultimate aim is to relate breeding performance and distribution to land use and vegetation cover. If, however, these factors are being influenced by nest site availability this must be considered in any subsequent analysis. The aim of this section is to investigate factors which may be important in nest site selection and to address the question of whether or not it is possible that buzzard distribution in mid-Argyll is limited by availability of potential nest sites.

METHODS

Descriptions were made of all active nest sites found during the two years of the study. Typically buzzards in mid-Argyll nested in one of three situations; in trees, on crags or on banks. In this context crag sites refer to nests situated upon ledges on open rock faces overlooking the surrounding landscape. Often the actual nest ledge was vegetated and a few trees may have been rooted into the face of the cliff but generally these crags exhibited much exposed rock. Bank sites refer to nests situated on the well vegetated faces of gullies, generally formed by a water course. Sometimes these banks were steep but they still showed little in the way of exposed rock. Photographic examples of typical sites are given in Figures 5.1 to 5.4.

The following data were recorded for bank and crag nests:

Aspect of nest,
Angle, extent and vegetation cover of slope above nest,
Angle, extent and vegetation cover of slope below nest,
Length and width of nest ledge,
Vegetation cover on nest ledge,
Subjective concealment of nest ledge.

If these were within a gully the following was recorded:

Tree, shrub, and ground cover of gully,
Orientation, depth and width of gully.

The following data were recorded for tree nests:

Tree species,
Whether dominant, co-dominant, intermediate or supressed,
Whether in plantation, woodland, park land, small stand or an isolated tree,
If on slope, the aspect and angle of the slope,
Diameter at breast height, height and height to canopy of the tree,
Height of nest above ground,
Whether or not branches capable of supporting a nest were below the level of the nest.

RESULTS

The proportions of nest site habits found in this study are given in Table 5.1. While many old nests were also found during the two years of the study, only the 73 sites in which breeding attempts were actually made are included so as to reduce bias due to the differential ease with which nests in different situations can be found. This table includes three instances of individual tree nests used in two consecutive years. These include two cases of nests in scots pine and one case in oak. There was no significant difference between the proportions of each nest site situation used between the two years (χ^2_2=0.19, P>0.9, n=73).

Nest situation	Number of nests in 1989	Number of sites in 1990	Number of sites overall
Tree	23	27	50
Crag	7	7	14
Bank	4	5	9

Table 5.1: Buzzard nest site habits in mid-Argyll.
Data are given for 1989, 1990 and both years combined. There was no significant difference in nest site habit selection between years (χ^2_2=0.19, P>0.9, n=73).

Buzzard nests were recorded as being sited in nine different tree species, details of which are given in Table 5.2. These data imply that oak and spruce are the most important species. These data do not, however, permit one to interpret this as a true preference as undoubtedly within the study area these two species represent the greatest proportion by far of available trees capable of supporting buzzard nests. birch is also common in the study area, probably more so than oak, however many birch stands support only small trees, or there are other more substantial trees close by. The general impression obtained during nest finding was that tree nesting buzzards tended to choose conifers when these were present in preference to broad-leaved species. When they choose broad-leaved trees the nests were generally located in one of the larger trees present regardless of species, however if no substantial trees were present buzzards in mid-Argyll would build their nests in very small trees indeed.

Tree Species	Number of nests (both years combined)
Oak *Quercus spp.*	19
Spruce *Picea spp.*	12
Birch *Betula spp.*	4
Scots Pine *Pinus sylvestris*	4
Ash *Fraxinus spp.*	3
Larch *Larix decidua*	2
Cypress *Chamaecyparis spp.*	2
Douglas Fir *Pseudotsuga menziesii*	2
Rowan *Sorbus aucuparia*	1
Beech *Fagus sylvatica*	1

Table 5.2: Proportions of nest sites occurring in trees of different species used by tree nesting buzzards in mid-Argyll.

The availability of apparently suitable trees appeared to have no bearing upon whether or not crag or bank nests were used. In many instances clusters of old nests, assumed to be alternative sites within a single territory, included both tree sites and crag or bank sites, while in only a few instances where buzzards were nesting on crags did it appear that there were no trees capable of supporting a nest and in many cases tree nests from previous years were found in the immediate vicinity. While it is possible that predecessors were responsible for the tree nests in such cases, and the choice of nesting habit is largely due to individual preferences, the behaviour of depositing fresh vegetation at unused alternative nest sites indicated that these other nests were recognised as such by the then current occupier. It is probable that crag and bank nests are used more frequently than these data suggest and the same probably holds true for nests situated in conifers within mature forestry plantation blocks. Within the study area, of those buzzard pairs for which the active nest was not found, a disproportionate number were suspected of nesting in such situations. When buzzards were nesting in open woodland the nature of this habitat within the study area meant that one could be reasonably confident that all other alternatives had been checked. This assumption could not always be made in well vegetated gullies or mature forestry.

Because buzzards in mid-Argyll nest in such a wide variety of situations it is not possible to arrive at a common scale on which sites can be compared. For example, it is not meaningful to compare heights above ground of bank nests with tree nests or to compare tree nests in mature woodland with nests in isolated trees amidst sheepwalk. Statistical descriptions of nest location are, therefore, largely precluded, general descriptions of nest sites being more appropriate.

Nests were located on crags ranging in height from five to over fifty metres, with the actual nest ledge at heights from two to forty metres. The face below the nest ledge was invariably vertical, while that above was more variable. Nests generally occupied ledges which they would fill completely.

Nests were located on vegetated banks from three metres to thirty metres high. One invariable characteristic of all these sites was the presence of an overhang or vertical face immediately below the nest although in some cases this was only a few metres high. The nest was often supported by the base of a young tree or bush growing out from the face of the bank. While nests were often built into the back of the bank, the slope above the nest did not seem critical ranging from twenty to ninety degrees. Most bank nests were well hidden by vegetation from below but open from above.

Because of the variety of trees used and the variety of situations in which they were found nesting, no generalisations can be made other than to say that buzzards were prepared to build their nests in whatever locations were available. When, for example, no tall trees were available buzzards were found nesting as low as two metres above the ground in small birch trees. Not surprisingly, no nests were found in such situations in mature oak woodland although such sites were clearly available. Statistics such as mean height above ground and measures relating to size of tree, therefore, would be clearly misleading in this case.

Figure 5.1: Buzzard nest site in oak tree. Glen Lochy, May 1990.
This photograph was taken in late May and the first nestling was to hatch within a week of this photograph having been taken. This illustrates the lateness of the seasons in Argyll and just how exposed nest contents might be to the elements in such sites in this part of the country.

Figure 5.2: Buzzard nest site in conifer. Glen Lochy, May 1989. Conifer trees appeared to be chosen in preference to deciduous species when both were available.

Figure 5.3: Buzzard nest site on well vegetated bank in wooded gu y. Glen Euchar, May 1989. The use of bank nests was not related to the availability of alternative tree sites. Often a single home range would contain old nest sites in both habits.

Figure 5.4: Nestling buzzard, close to fledging at a crag nest site. Cowal peninsula, July 1989. This particular nest ledge was only about five metres above the base of the crag and alternative tree sites were available.

DISCUSSION

The choice of nest sites used by buzzards has been described from a number of areas of Britain and shows considerable local differences. Along with this study, those in Kintyre, north Wales and North Yorkshire record the crag nesting habit as common (Maguire 1979, Dare 1989, Holdsworth 1971). It would appear that, where crag nesting is established, buzzards will often nest in this type of situation whether or not tree sites are available as alternatives. Often, the alternative nest sites within a given buzzard home range will include both types. In north Wales Dare (1989) found crag nesting to be more prevalent amongst pairs in rugged mountainous terrain. The bank nesting habit appears to be less widely spread. Bank nesting was recorded by Maguire (1979) for Kintyre in much the same proportion as found in mid-Argyll but Dare (1989) recorded only a single instance of a buzzard nesting on a steep bank. Away from mountainous areas tree nesting appears to be the rule. Tubbs (1974) and Dare (1961) make no reference to nest sites other than trees although, presumably, bank sites similar to those used in mid-Argyll would be available in both the New forest and Dartmoor. All these studies suggest that tree nesting buzzards show a preference for conifers. In Speyside scots pine *Pinus sylvestris* appeared to be favoured over birch *Betula spp.* and despite its scarcity in Kintyre a substantial number of buzzards there nested in scots pine. A preference for scots pine is also suggested by the New Forest data. This tree species was rare in mid-Argyll and would have been available to only a few buzzard pairs. Thus the four cases in which they did nest in scots pine is, perhaps, a significant proportion. A substantial number of buzzards in mid-Argyll did, however, nest in conifers of other species. In home ranges encompassing tracts of mature forestry plantation, conifers were undoubtedly the commonest potential nest sites present, but even when deciduous species predominated experience showed that the most likely trees in which to find active buzzard nests were any conifers present. This preference, for conifers in general, was also suggested in the Dartmoor study (Dare 1961) and also from a study in Denmark (Joensen 1968).

A number of raptor studies have attempted to determine what features of a location make it suitable as a nest site by comparison of actual nest sites with randomly chosen locations. These type of approach use a discriminant function analysis to separate the two groups and take differences between the two sets of sites to be indicative of features chosen by the birds (e.g. Andrew & Mosher 1982, Morris, Penak, Lemon & Bird 1982, Rich 1986, Speiser & Bosakowski 1987, Speiser & Bosakowski 1988, Jedrzejewski, Jedrzejewska & Keller 1988). Collection of data described above was originally designed with this type of analysis in mind, however, further consideration of this approach, suggests that this technique would be flawed in this study. A discriminant function analysis seeks to produce a function, based on a group of key variables, which can be used to separate two or more real categories. Invariably any two sets of data will have some differences between them and if enough variables are included the nature of this approach means that a discriminant function will be found. Thus there must be good reason to believe that the two or more groups being compared are truly separate. So, in the case of comparing buzzard nest sites with random sites such an approach would only be meaningful if there is good reason to believe that the two groups are real entities. The assumption, that the random sites, not coinciding with actual nest sites are not suitable as nest sites is unrealistic. In fact, the random selection could contain many sites which may be perfectly suitable but are not occupied for any one of a number of reasons. Birds may be excluded from using potentially suitable sites for reasons other than their physical characteristics; for example, when birds show territorial behaviour, unless nest sites are limiting the population, more sites may be present in an area from which other birds are excluded than could possibly be used by the territory owners. This is almost certainly the case for birds such as buzzards where it is difficult to believe, considering the wide choice of sites described above, that nest sites are limiting their distribution. Such an analysis also implies that areas without birds are without potential nest sites. This in turn assumes that the population is at the maximum carrying capacity of the habitat. It is well established that buzzards show some degree of faithfulness to their sites either alternating between actual nests from year to year or building new nests within clusters of old nests, often in adjacent trees. There is, therefore, an element of chance involved in that suitable nest sites, perhaps superior to that already in use within a territory, have simply not been explored by the resident birds.

The general descriptions of nest sites used here, similar to those used in many of the British studies (e.g. Picozzi & Weir 1974, Tubbs 1974, Dare 1989, Fryer 1986), were therefore more useful than attempting to apply this statistical approach in deciding whether or not nest site availability could influence buzzard distribution in mid-Argyll. The general conclusion to come from this consideration is that the adaptability of buzzards in the region, with regards to nest site selection, means that few potential buzzard home ranges would remain unoccupied for the want of an acceptable nest site.

SECTION II: BREEDING PERFORMANCE AND NEST HABIT

INTRODUCTION

In this section the breeding performance is considered in relation to nest site habit. Of particular interest is the choice by many buzzards in mid-Argyll of vegetated banks as sites for nests. Bank sites would appear to be more vulnerable to ground predators than either tree or crag sites while all sites would appear to be equally vulnerable to aerial predators, principally hooded crow (*Corvus corone corax*). It has already been established that bank sites are not only used when suitable tree sites are unavailable, suggesting that some other advantage is to be gained by this nesting behaviour. One hypothesis is that buzzards occupying high quality home ranges are able to reach a body condition conducive to breeding early in the season and that by nesting in the shelter of well vegetated banks they are able to take advantage of their condition. In Argyll most deciduous trees will not be in leaf until the latter stages of incubation or the early nestling period for early laying birds. If this is the case then one might predict that bank nesting buzzards will produce earlier clutches and have a higher breeding performance than those nesting in other nest site habits.

METHODS

The parameters of breeding performance described in the previous chapter were each compared between different nest site habits. Thus, laying date, clutch size, initial brood size, brood quality and fledging success were each compared between nest sites situated on banks, in coniferous trees, in deciduous trees and on crags. For the purpose of this analysis, nests in larch trees were grouped with those in deciduous trees. Each comparison was made using a Kruskal-Wallis one way analysis of variance, performed using SPSS PC+ (Norušis/SPSS.Inc 1990). Significant results were further evaluated using a multiple comparisons test (Siegel & Castellan 1988). Significance levels for the multiple comparisons test were constrained to $\alpha = 0.05$.

RESULTS

Median laying date, clutch size, initial brood size, number of young fledged and median brood quality ranking are given in Table 5.3.

Breeding Parameter	Nest Site Situation			
	Bank (n=9)	Coniferous Trees (n=20)	Deciduous Trees (n=30)	Crag (n=14)
Median Laying Date	9	14	14	25
Average Clutch Size	2.59 (2)	2.01 (2)	2.01 (2)	2.17 (2)
Average Initial Brood Size	2.38 (2)	1.90 (2)	2.19 (2)	2.00 (2)
Average Number Fledged	2.13 (2)	1.84 (2)	2.11 (2)	1.25 (1)
Average Brood Quality Rank	2.06 (2)	1.53 (1)	2.07 (2)	1.80 (2)

Table 5.3: Breeding performance in relation to nest site situation.
Laying date is given in relation to April 1st = day one. Brood quality rank is based on 1= brood containing nestlings of low weight for age, 2 = brood containing nestlings all of expected weight for age and 3 = brood containing nestlings of high weight for age. Values in parentheses refer to median values where average values are given.

A significant difference was found between the laying dates at nests in the four nest site habits (Kruskal-Wallis one way anova, $K_{[\text{corrected for ties}]}$=11.6358, P=0.0087, n=70). The multiple comparisons test indicated that clutches laid in bank nests were produced significantly earlier than those laid in other nest habits. No significant differences were found between the median clutch size found in nests of different nest site habit (Kruskal-Wallis one way anova, $K_{[\text{corrected for ties}]}$=5.5552, P=0.1354, n=73).

No significant differences were found between the initial brood size in nests of different nest site habit (Kruskal-Wallis one way anova, $K_{[\text{corrected for ties}]}$=4.6501, P=0.1354, n=67).

No significant differences were found between the median brood quality rank in nests of different nest site habit (Kruskal-Wallis one way anova, $K_{[\text{corrected for ties}]}$=6.9829, P=0.0724, n=67).

A significant difference was found between the fledging success from nests of different nest site habit (Kruskal-Wallis one way anova, $K_{[\text{corrected for ties}]}$=8.9430, P=0.0301, n=67). The multiple comparison test indicated that significantly fewer young fledged from nests on crags than from those in other nest site habits.

DISCUSSION

The results showed that on average buzzards nesting on vegetated banks produced earlier clutches than those using other nest site habits. This would be expected if they are adopting this behaviour in order to gain protection from adverse climatic conditions early in the breeding season. The advantages of early breeding were discussed in earlier chapters. Bank nesting would, therefore, allow buzzards occupying high quality home ranges, which enables them to achieve a high body condition early in the year, to take advantage of their ability to start breeding early in the season without incurring high energy costs associated with unfavourable weather conditions in exposed sites. This might well outweigh any costs associated with increased predation risk. This may explain why bank nesting is not as widely reported from areas such as south-west England, the New Forest and Wales where the seasons are more advanced.

There was no measurable difference in clutch size, initial brood size or brood quality between the different nest site habits although fledging success was found to be lower from crag sites. Although the sample of crag sites is small these tended to occur at higher altitudes in the bleaker part of the study area where no other alternative nest site habits were available. It is, therefore, possible that crag sites were associated with home ranges of poorer quality.

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CHAPTER 6: HABITAT AND LAND USE DATABASE

CONTENTS:

INTRODUCTION

The overall aims of this project are to determine how buzzard habitat use, distribution and breeding performance are influenced by biological, physical and cultural aspects of their environment. Most habitat data can be represented in a map format (vegetation cover, topography, climate etc.). Maps may be available in published form, for example Ordnance survey maps, or will be derived from fieldwork, for example a vegetation survey. Studies of animal distribution in relation to habitat have generally relied upon extracting data sets manually from these maps.

With such an approach, decisions that may well influence the success of subsequent analysis, for example, to what distance from an animal's home range will habitat variables be measured?, or to what level of precision should these be measured?, need to be made at the beginning. These decisions are often made in an arbitrary manner, as perhaps we do not become aware of our requirements until analysis is underway. This may leave no other option than to go back to the original maps and repeat the laborious task of manual extraction again. A consequence of this is that studies have been limited in the amount of habitat data that can be considered. It was, however, inevitable that for this study, a large quantity of data would need to be handled, given the size of the study area and complexity of the landscape.

GEOGRAPHIC INFORMATION SYSTEMS

Recently ecologists have become aware of the potential power of Geographical Information Systems (GIS) for handling such data. This study used the **Horizon** GIS system (Laser-Scan Ltd. 1991) to handle the habitat data. **Horizon** was run on a Digital 3100 workstation, running **Dec windows** and supported by the Glasgow University VMS/VAX-cluster host. Data were stored on the Glasgow University Ingress (Version 6.2) database . The data are handled by the user in the form of map features. It is, therefore, in effect the raw data that is stored in the computer database. The user effort goes into the data capture (digitising of raw map data) and preparation of these data in readiness for extraction. The extraction of data is made in the form of map-feature related queries and is itself fast, accurate, versatile and repeatable.

DATA FORMATS

The **Horizon** system can handle many "layers" of map data and "knows" where all map features, in all layers, are in relation to each other. Data are presented in the form of maps on the computer screen. The system can handle map data in both raster and vector formats. A map is said to be of raster format when it is composed of an array of equal sized cells or picture elements, generally referred to as pixels, each of which has associated with it a particular value and has its position defined by matrix row and matrix column. A typical example of raster format is a satellite derived image where each distinct pixel value is displayed as a different colour. A map is said to be of vector format when it is composed of features that are points, lines or polygons enclosing areas, or any combination of these. Each feature has its position defined on a pair of Cartesian axes. A typical example of vector format are the Ordnance survey maps composed of points, for example public telephone boxes, lines, for example roads, and polygons, for example woodland, whilst a vegetation map produced by field survey is composed totally of polygons each representing a different vegetation category.

HABITAT DATA INCORPORATED INTO THE GIS

Habitat data were included in the GIS on two main criteria. Firstly there should be reason to believe it to be of biological significance and, secondly, it should be available for the entire study area and also potentially available for any area of interest where predictions concerning buzzard distribution or breeding performance may be required.

BIOLOGICAL ASPECTS OF HABITAT

Clearly the vegetation covering the landscape is a key element in describing an animal's habitat. Two techniques to quantify this were considered. The first involved the mapping of vegetation cover of the study area by interpretation of aerial photographs supported by field survey, the second involved interpretation of satellite imagery. The first option was not considered feasible, for such an extensive tract of land, if precision and accuracy were not to be compromised, and the satellite option was chosen as being the most likely to yield consistent results across the entire study area. A vegetation cover interpretation of aerial photographs was however undertaken by a co-worker for part of the study area. These data were made available and, therefore, included in the GIS for the purpose of cross reference to the satellite derived classification.

Another very important aspect of the biological environment of a predatory species is clearly the availability of prey. Prey availability data were not, however, included in the habitat database as no methods were found which would allow this to be determined for the entire study region. This was one of the main criterion for inclusion of data in the database the main purpose of which was to provide data for predictive models. Such models require that data should be available for areas where predictions may need to be made.

PHYSICAL ASPECTS OF HABITAT

Topography has been shown to have an influence on the distribution and breeding performance of animal species. Many species exhibit altitudinal limits to their local distribution. The aspect of the land, its slope and its ruggedness can be expected to have a marked effect on climate and micro-climate, making otherwise suitable areas of ground inhospitable. When considering predatory species the impact of these factors in controlling the distribution and abundance of their prey will also be important.

Topography was described by constructing a digital terrain model of the study area from which GIS data layers representing altitude, slope, aspect and a land ruggedness index were derived.

Prevailing climatic conditions are known to influence bird distributions. At the extreme, otherwise suitable habitat may be rendered inhospitable by adverse climate. High temperatures, above a certain threshold have been shown to have an adverse effect on the nestling growth of some raptors (e.g. Beecham & Kochert 1975, Mosher & White 1976, Tomback & Murphy 1981) as have low temperatures (Hiraldo, Veiga & Máñez 1990). High rainfall has also been shown to have an adverse effect on nestling growth (Hiraldo, Veiga & Máñez 1990).

The underlying geology of the landscape may well influence the productivity of the land through its contribution to the nutrient content of the soil. This in turn will influence the type and quality of vegetation cover. If a high correlation were to be found between geology and vegetation cover then, when considered along with, for example, topography, it may allow modelling of the vegetation cover that was previously found in an area but has since been replaced by man made vegetation such as forestry plantations or agricultural grassland. Similarly it may be useful in predicting which semi-natural vegetation communities might come to replace land currently under one of these land use regimes, for example when agricultural land is abandoned or neglected.

CULTURAL ASPECTS OF HABITAT

In the past, populations of most, if not all, British raptors have been detrimentally influenced by human activity. Much of the potential range of British buzzards remains unoccupied and direct persecution is implicated (Cadbury, Elliot & Harbard 1988). Many raptorial birds are known to be sensitive to human disturbance even when this is not malicious, as in the case of recreational activities or misguided casual interest (Ratcliffe 1990). While it is not possible to derive a direct measure of human disturbance, it is possible to map cultural artefacts such as human habitation and road systems. The intensity of human activity in the vicinity of a birds territory will be related to both of these measures.

COMPILATION OF HABITAT DATABASE

Compilation of the habitat database to be described below was the result of equal efforts between myself and Mr. C.J.Thomas who was conducting a sympatric study of ravens in mid-Argyll. Both parties contributed to all aspects of data capture and preparation described in this chapter.

DATA CAPTURE

With the exception of the satellite imagery, in which data are obtained in a digital format, all other data sets were derived from data obtained in map format. Initial data capture from such sources was done using digitising facilities at Glasgow University Topographic Science Department and the **Mapdata** software package. The output from **Mapdata** was converted into Laser-Scan internal feature format (IFF) using a customised conversion program (Ibbs 1990 unpublished).

VEGETATION COVER

The vegetation cover classification used for this study was derived by processing satellite imagery of the study area produced by the NASA Landsat 5 thematic mapper. Of four images available for the study area from the past decade, each offering at least partial cover of the study area, two were clear of snow or cloud cover. Both were obtained for analysis. One of these, produced in June 1987, gave coverage for about 70% of the study area. This was processed prior to the acquisition of a May 1990 image, which was not available initially. Image processing was undertaken at the NERC image processing facilities at Environmental Information Centre, ITE, Monkswood, Cambridge, England, and at NERC Computing Service, British Geological Survey, Edinburgh, Scotland. The satellite images were processed using International Imaging Systems, Inc., System 600 Digital Image Processing Software (IIS 1989) running on a Model M75 processor and VAX host central processor.

The Landsat 5 platform has a circumpolar orbital path at an altitude of just over 700km. and obtains a complete sweep of the earth approximately every 16 days. The intensity of reflected radiation from the earth's surface is recorded in seven distinct wave bands in the visible and near infrared part of the spectrum. Different wavelengths are appropriate for different applications. For the mapping of surface vegetation cover, wave bands 3, 4, and 5 were selected (on advice of personnel at Monkswood). From these wavelength data, system 600 produces a false colour raster image with a 30m.x 30m. pixel representation. An example of this unclassified image is given in Figure 6.2.

The aim here was to produce a land cover classification which reflected the principal upland vegetation types. There are two principal approaches to classification of satellite imagery, referred to as supervised and unsupervised classification. A supervised classification is one in which classification statistics are derived from training areas on the image for which the vegetation cover has been determined by field survey. An unsupervised classification is one in which the classification statistics are based on a cluster analysis of pixel values. The unsupervised approach is considered most likely to produce meaningful results for a mountainous landscape with a heterogeneous vegetation cover such as that found in the study area (Jones & Wyatt 1988) although, acting on advice from personnel at Monkswood, a supervised classification was also undertaken. The land cover classification used in this thesis was based on an unsupervised classification of the May 1990 image. A supervised classification was not attempted on this image as experience gained from using the two techniques to produce a classification of the May 1987 image had indicated that only an unsupervised classification was likely to produce meaningful results for the type of landscape being considered. The supervised classification had failed to produce a classification which could subsequently be equated with actual vegetation cover.

Classification of the satellite image

The system 600 software contains many image processing functions, which can be used to derive a classification of an image and "massage" it to the finished product. The classification of any particular image is only likely to use a small subset of these functions and is unlikely to follow exactly the same route as the classification of a different image. In the discussion that follows, routines with prefix **cpu** are executed on the VAX host, central processing unit, routines with prefix **M75** are executed using the M75 image processor working on a user defined 512 pixel x 512 pixel sub-area of the main image, and routines with the qualifier **virtual** attached to the **M75** prefix are executed using the M75 image processor to work through the entire image taking 512 pixel x 512 pixel sub-areas for consideration in a sequential manner. The following procedure was used to produce the classification of the May 1990 image:

The unclassified image was geometrically corrected and aligned using the **cpu cpwarp** routine. This routine does a rubber sheet warp, and the transformation is determined by a "least squares best fit of bivariate legendre polynomial using nearest neighbour resampling" (IIS 1989). This process used a control point file produced using the routine **m75 gcp virtual display**. This file contained 21 control points which were used by **cpu cpwarp** to align the May 1990 image, using the rubber sheet warp, to the June 1987 image which had been previously corrected and aligned by personnel at Monkswood and was known to have good agreement with the British National Grid. The transformation indicated above was the default (from five options) when using a control point file of the size produced here.

A filtering process was now used to 'smooth' the image. The routine **cpu convolve** was used to reassign the wave band intensity values of each pixel, in the warped image. The new value is derived from a 5 cell x 5 cell matrix, centred on the target pixel, the values of each matrix cell being determined by the product of the intensity value of that cell and a weighting constant. The weighting constant is derived from the Gaussian transformation. This caused the wave band values of each pixel to "migrate" towards those in its neighbourhood. This process is useful in removing noise from the unclassified image while retaining the integrity of boundaries between groups of pixels of distinct character (IIS 1989).

Prior to classification of the whole image, the routine **M75 cluster_class** was used to produce some initial classifications of sub-areas of the image and **M75 level_slice** was used to investigate, in some detail, the distribution of wave band intensities present in the transformed image. A 512 pixel x 512 pixel sub-area (representing 15.36km. x 15.36km. on the ground) was chosen to be representative of the image as a whole. This sub-area was chosen because field work had shown that it contained representatives of all the main topographic and vegetation cover features found in the whole study area.

By way of initial analysis the routine **M75 cluster_class** was used to produce an initial classification for this sub-area. This routine uses a cluster analysis approach to place pixels into classes dependent on their reflectance intensities. This routine allows the user to set the starting number of classes that is to be used in the clustering process. The routine was carried out repeatedly each time using a different number of starting classes in the range 16 to 50 classes, but otherwise system defaults were accepted for all command qualifiers. The ultimate aim was to produce a classification which would distinguish at least the principal upland vegetation cover types, and so ultimately about 10 categories were needed. Using the unsupervised approach a single vegetation cover type may correspond to several classes because the classification is also sensitive to variations in sunlight intensity caused by the topography of the landscape. For example an area of heather moor on a south-facing slope may well be classified separately from heather moor on a north-facing slope and in fact its 'reflectance signature' may be more similar to a completely different vegetation cover type. When a low number of initial classes were specified many areas of vegetation were misclassified. while some of the derived classes clearly contained several vegetation cover types that it was desirable to separate. Classifications containing twenty or more classes produced results that appeared to be consistent.

This initial examination also highlighted another important problem. Areas that were subjected to shade when the image had been produced could be determined in many cases from visual examination of the image combined with personal knowledge of the study area. These areas together with areas of shallow water were confused in all initial classification, regardless of the number of classes, with areas of mature conifer plantation. This problem was addressed using the **M75 level_slice** routine. The intensity of reflected radiation in each wave band for a particular pixel will have an integer value of between 0 and 255 inclusive and the **M75 level_slice** routine allows all pixels with intensities lying between 0 and a user specified upper limit to be highlighted. It was found that. in all wave bands, areas of mature forestry reflected at very low intensities, similar to that of areas under shade and of shallow water. It was further determined that the lower 8.6% of the pixel intensity range in wave band 3 contained 100% of the pixels corresponding to mature forestry, just 100% of the pixels corresponding to shallow water and about 50% of the pixels corresponding to areas under shade. The lower 15.7% of the pixel intensity range in wave band 4 contained, just 100% of pixels corresponding to areas of shade, 100% of pixels corresponding to shallow water, but no pixels corresponding to mature forestry. The lower 19.6% of pixel intensity values in wave band 5 contained, just 100% of pixels corresponding to shade, 100% of pixels corresponding to shallow water and 100% of pixels corresponding to mature forestry.

Using the knowledge obtained in this initial investigation the routine **cpu scale** was used to further process the unclassified image before attempting a classification of the whole. The aim of this processing was to avoid subsequent problems with misclassification of areas under shade or of shallow water. In the **cpu scale** routine the user is able to specify a low clip and high clip values for each of the wave bands independently. All values in the intensity range below the low clip value are reset to zero and all values in the intensity range above the high clip value are reset to 255. The remaining values are reset using a scaling algorithm to stretch the histogram of pixel intensity values over the full range. Low clip values were specified as 0.086. 0.157. and 0.196 for wave bands 3. 4. and 5 respectively. as determined by **M75 level_slice** percentages given above. System default values were accepted for all other command qualifiers.

A sub-area corresponding to that used in the initial investigation was now extracted from the scaled, unclassified image. The routine **M75 cluster_class** was used to produce several classifications each containing a different number of classes and command qualifier options. The classification preparation statistics of each classification were saved as output. These classification statistics were then applied to a selection of other sub-areas using the routine **M75 virtual mdclassify**. These other sub-areas were chosen to represent a variety of landscape character. Best classifications were obtained using the command qualifier **extrema=yes** which has the effect of preserving classes lying in the tails of the pixel intensity histogram. This option causes many classes to be lost during early iterations of the clustering routine and so a high initial number of classes was specified to compensate for this. This routine was repeated using a number of other sub-areas in order to find which one gave classification preparation statistics that were most universally applicable across the whole image.

The routine **M75 virtual mdclassify** was then used to classify the whole image. The classification preparation statistics specified were those derived from a twenty one category classification. **M75 virtual mdclassify** is a minimum distance classifier, that is each pixel in the unclassified image is assigned to the class with the closest reflectance intensity in all wave bands to its own. Only pixels lying within a given distance of a class mean are classified, the remainder being assigned to class = 0. The command qualifier **tolerance=5** caused all pixels lying within = ± 5 s.d. of a class mean to be classified and reduced the number of unclassified pixels corresponding to land to zero. Sea remained largely unclassified although shallow water was classified. Increasing the tolerance from the system default of +/_ 2 s.d. does not alter the classification of those pixels that would have been classified anyway but causes further pixels to be classified with decreased statistical confidence. This approach was considered not to compromise the classification as it was seen to invariably place formerly unclassified pixels, lying within otherwise homogeneous blocks of pixels, into the expected category, and to place formerly unclassified pixels lying between two different homogeneous blocks of pixels into either one or the other of the two neighbouring categories but not into a third category.

The classified image so produced did, however, still contain isolated pixels unlike those surrounding them. In some cases these pixels may have represented true vegetation features while in other cases they may have been artefacts of the classification process or due to noise in the unclassified image that subsequent processing had failed to deal with. On balance the latter scenario probably occurred much more frequently as it was unlikely that true vegetation features would correspond exactly to a pixel, most vegetation features, even relatively small ones, would be expected to affect the values of several adjacent pixels. These pixels were reclassified using the routine **M75 virtual mode_filter**. This filtering process considers each pixel in turn as the centre of a 3 pixel x 3 pixel matrix and reassigns its value to equal the modal value for its neighbourhood (matrix). The command qualifier **isolated** was used so that only pixels with values unique to their neighbourhood were affected, thus causing only mild filtering of the classified image. An example from the twenty one category classification is given in Figure 6.3.

The now classified image was converted from **IIS system 600** format into **IIS system 500** format to facilitate importation of data by Laser-scan Ltd. **Lamps** software (Laser-Scan Ltd.) (subsequent releases of Lamps software now support direct importation of IIS system 600 format data).

The **Lamps** module **DTI Convert** (Laser-Scan 1990) was used to convert the classified **IIS system 500** format data into Laser-Scan **dti** format. In this format the image was available for processing using **Lamps** software and was incorporated as a data layer in the **Horizon** GIS.

Equating the satellite classification with the vegetation survey

The classification procedure described above produced a classification of vegetation cover which, based on personal familiarity with the study area, appeared to provide a meaningful description of the actual vegetation cover. The final classification had been accepted on the grounds that distinct features of vegetation such as forestry plantations, enclosed fields and in some cases homogeneous stands of other vegetation types were clearly distinguishable, and conversely that they did not appear in places where they should not have. There is however a need to quantify what exactly each class in the image represents. No single approach can be used to achieve this and it is necessary to draw on several levels of investigation. There are two main problems to be overcome in determining what each class represents.

Firstly when considering upland vegetation one is attempting to divide a continuum of vegetation communities into distinct classes. This is not a problem with classes representing for example forestry plantations or agricultural land in which vegetation communities are relatively simple being made up of a small number of species, and patches of which tend to have distinct boundaries. It becomes more of a problem when dealing with the semi-natural open hill ground where vegetation communities that need to be separated, for example blanket bog from upland grassland or heather moorland, may actually contain many of the same component species, generally do not exhibit distinct boundaries, and may themselves describe a distinctive amalgamation of contributing vegetation types. So, for example, heather stands, while being the dominant feature of heather moorland are also a major component of blanket bog, and occur frequently in both upland perennial grassland and wet heath. Where a classification of vegetation cover derived from satellite imagery differs from one using vegetation survey methods is that, to take the current example, heather stands will be classified as heather wherever they occur. When using vegetation survey methods the heather will be considered in conjunction with surrounding vegetation types to derive an overall description. Thus an area of vegetation cover one might describe simply as blanket bog using vegetation survey methods may be depicted in the satellite derived classification as patches of deciduous grasses, patches of perennial grasses and patches of heather.

The second problem to be overcome is that of locating oneself on the ground. The satellite image is evidently locating pixels on the ground with very high accuracy, however, this can not be matched by workers in the field navigating with maps and compass. This is a problem when it comes to collecting 'ground truth' and was one of the reasons that a supervised classification of the satellite image was believed to have failed to produce consistent results. This means that ground truth obtained prior to classification will often be difficult to interpret. Also, because of the difficulty of locating oneself with the required degree of accuracy, any vegetation descriptions that turn out to have been made close to a class boundary on the classified image must be ignored to avoid assigning a description to the wrong class. Warren, Johnson, Goran & Diersing (1990) describe a procedure for the automated selection of field sample sites for ground truthing of satellite derived classifications, using GIS, which avoids problems of subjective biases in selecting sample points. This, however, requires global positioning system (GPS) technology to be available to workers in the field and such a system was beyond the resources of the current study.

Vegetation maps, derived from an interpretation of 1:24000 scale aerial photographs were made available for part of the study area. The photographs had been taken during a Scotland wide survey undertaken on behalf of the Scottish Development Department in June and October 1988. The interpretation of these photographs was undertaken by Dr. P.Haworth, University of Glasgow, who was assisted in the field by Dr. D.Horsfield of the Nature Conservancy Council Scotland upland vegetation unit. Prior to the analysis given below, for parts of two regions, south-east Mull and north-Lorn, this interpretation had been backed up by ground survey. It is from these two regions that comparisons were based. These vegetation maps, in the form of vegetation polygons superimposed onto Ordnance Survey 1:50000 scale Landranger maps were digitised using **Mapdata** software and incorporated into the **Horizon** GIS. The class descriptions used in subsequent analysis were derived from a visual interpretation of the classified image coupled with a comparison of the classified image with the vegetation classification using GIS and correspondence analysis.

Forestry plantations are clearly distinguishable on the classified satellite image as, indeed, they were in the unclassified image. Two distinct classes were seen to correspond with post-thicket tree stands and pre-thicket tree stands respectively, the latter characterised by a dense herb layer and young birch scrub amongst the young conifers.

Improved and semi-improved pasture were also clearly distinguishable. Being areas of relatively homogeneous vegetation this agricultural grassland stands out as distinct blocks in the satellite derived image. Boundaries match well with field boundaries as depicted on Ordnance Survey 1:25000 pathfinder maps and the vegetation survey maps.

Water fell into two classes. These classes corresponded to deep and shallow water.

Areas of mature trees other than forest plantation, such as deciduous and mixed woodland were not consistently classified. This is most probably a consequence of using a satellite image produced at the beginning of May as this had not been a problem when considering the June 1987 image. At this time of year, in Argyll, most broadleaf species are still in leaf bud and so the classification of woodland areas is subject to influence from the herb layer below the trees.

A number of classes were considered to be unclassified. These corresponded to areas of shade, small patches of unique land cover types or perhaps very rare land cover types not included in the original area processed. The presence of these classes had already been acknowledged prior to accepting the classified image as it was considered that if some patches of land cover could not be confidently classified they would be better treated as unknown vegetation cover than risk misclassification.

CORRESPONDENCE ANALYSIS OF VEGETATION SURVEY AND SATELLITE CLASSIFICATION

The remaining classes, corresponding to the open hill ground, required a more detailed approach using the GIS. The satellite derived classification was displayed on the monitor with the vegetation map overlaid within the **Horizon** GIS and a grid, with cell size representing a 200m.x200m. square, superimposed. Working systematically through the open hill vegetation categories of the vegetation survey map, polygons representing homogenous vegetation stands were identified. In each polygon of the vegetation map the point corresponding to the centre of each grid square was queried on the satellite classification. Grid squares separated from the boundary of the vegetation polygon by less than a complete grid square were not sampled so as to reduce error due to mapping inaccuracies and the subjective nature of where to represent class boundaries inherent in vegetation survey techniques. This procedure produced a sample of 2,702 control points for which classes in the twenty one class classification of the satellite image could be linked to open hill vegetation categories identified in the vegetation survey. This sample represented control points from fourteen of the twenty one classes in the satellite derived classification. Classes not represented in the sample include those representing water bodies and those representing forestry plantations and woodland, none of which were sampled from the vegetation survey map. Three control points were removed from the sample because they were known to correspond to areas of shade or misclassification. The vegetation survey classification had sought to differentiate major land cover types. Within the area sampled, four open hill vegetation categories had been mapped. These corresponded to upland perennial grassland, heather moorland, blanket bog and wet heath.

The table of correspondence between the satellite derived classification with the vegetation survey classification is given in Table 6.1. This was used to identify potential groups of satellite derived classes that could be merged into meaningful open hill ground vegetation cover categories. This table must be interpreted whilst bearing in mind the differences between the two methods. The largest source of disagreement between the two is likely to arise from problems in determining the boundaries between categories during field survey. There are two factors that will affect this. Firstly the position at which the boundary is designated on the ground is a subjective decision, as in most cases, with the exception of forest edges or enclosed fields, no true boundary exists on the ground, one vegetation type merging into another. Secondly errors will undoubtedly arise in transcribing these boundaries onto maps. Consequently problems will arise due to edge effects when comparing the two classifications although avoidance of sampling near to vegetation boundaries will have reduced this to some degree. Another source of disagreement between the two methods is encountered when patchy vegetation is considered. Generally the vegetation survey will describe small patches of dissimilar vegetation cover as belonging to the principle category whilst the Landsat classification may distinguish these as separate patches as the area represented by each pixel is largely considered in isolation.

Landsat Class	Blanket Bog	Heather Moorland	Upland Perennial Grassland	Wet Heath
A	33	5	15	0
B	239	74	35	4
C	59	25	81	81
D	0	0	13	0
E	41	15	41	0
F	255	65	111	32
G	80	22	80	126
H	0	0	46	0
I	73	13	122	6
J	54	1	4	86
K	50	25	95	40
L	29	8	49	73
M	8	8	103	8
N	11	0	67	188

Table 6.1: Correspondence table of open ground categories from the vegetation classification produced from interpretation of aerial photographs with classes from the initial twenty one class satellite classification. While there were twenty one classes in the initial satellite classification only fourteen of these corresponded with areas of open "hill ground". Tabulated values are frequencies of landsat classes (A to N) corresponding to each of the vegetation categories (Blanket Bog, Heather Moorland, Upland Perennial Grassland, Wet Heath) in the sample of 2699 control points.

Categories D and H were already known to represent agricultural grassland but, in a small number of instances, these two categories corresponded to upland perennial grassland from the vegetation survey. This will be explained in part by the factors referred to above, but also it would not be surprising if some particularly rich patches of perennial grassland were classified as agricultural grassland which they might closely resemble. This is especially likely in some parts of mid-Argyll where the agricultural grassland may be of particularly poor quality. These two categories were therefore excluded from the following analysis.

A correspondence analysis was used to investigate interactions between the vegetation survey categories and the satellite classification categories. This was performed using the SPSS PC+ ANACOR procedure, which allows one to examine relationships between two nominal variables graphically in multidimensional space (SPSS Inc. 1990). The resulting plot is given in Figure 6.1. A canonical normalisation was specified to enable relationships between the satellite derived classes (labelled A to N) and the vegetation survey categories (named) to be investigated. The correspondence of each satellite class to each vegetation survey category is represented by their proximity in the plot. This two dimensional plot explains 98.3% of the total "inertia". Dimension 1 explains 67.8% of this and dimension 2 explains a further 30.5%.

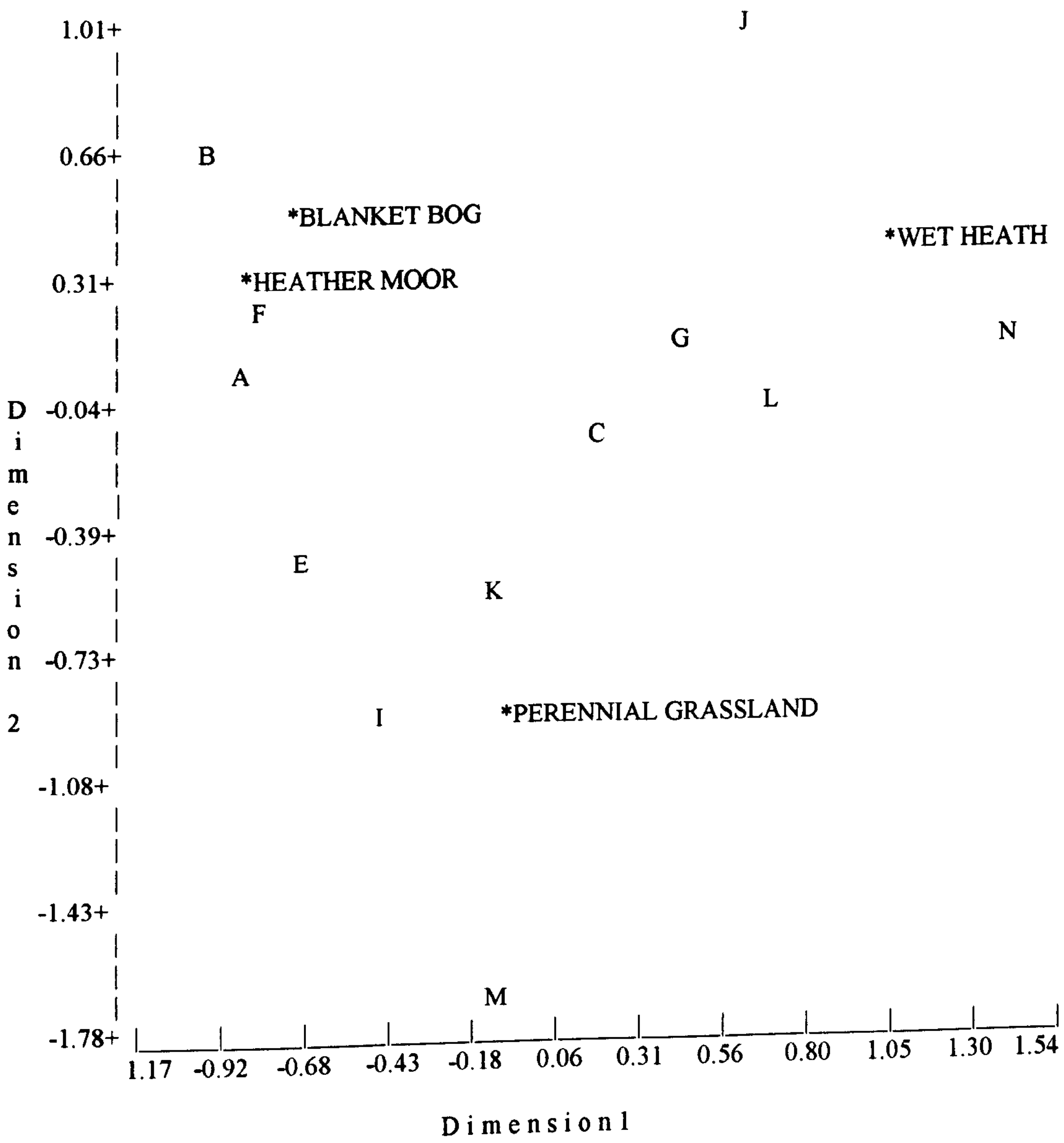


Figure 6.1: Correspondence analysis plot showing relationships between vegetation classification as produced by interpretation of aerial photographs and classes produced by satellite image analysis.
The plot gives a graphical representation of the relationship between classes produced by the two classification techniques. Capital letters refer to satellite categories. The plot was obtained through the SPSS PC+ ANACOR procedure using canonical normalisation.

The correspondence plot was used in conjunction with inspection of the satellite image to assign the twelve classes currently under consideration to the four open hill ground vegetation categories. The statistical approach represented in Figure 6.1 is useful for identifying potential satellite categories which could be merged. It does, however, not describe the spatial relationships between categories that can be identified from the satellite image, for example, when two classes regularly occur intermingled or when two classes rarely occur in the same area. There was therefore considerable recourse to inspection of the unmerged satellite classification when deciding which classes to merge in order to produce the final classification.

From the correspondence plot, upland perennial grassland appears to be associated with the satellite classes E, I, M and K. When these were considered on the satellite classification, classes E, I and M were seen to regularly occur together over large tracts of land. Class K, however, more often than not occurred in isolation from these and was more often associated with classes C and F.

Wet heath appears to be associated with satellite classes J, N, G and L. Again these were seen to occur together in large tracts of land on the satellite classification.

Blanket bog and heather moorland are clearly not well separated by the statistical approach as both occupy much the same space in the correspondence plot. The satellite classes A, B and F are all closely associated with both. This is not surprising as heather stands are a major component of blanket bog and heavy grazing pressure in mid-Argyll means that heather moorland is of a generally poor quality. When the GIS was used to overlay the vegetation maps from the vegetation survey over the satellite classification it was apparent that class B was the dominant class within areas identified as heather moorland, and that the boundaries of the two tended to coincide. Class F often occurred in areas where no heather moorland was indicated. Class A was comparatively rare but tended to occur intermingled with class F more often than with class B.

Problem classes from the point of view of the statistical consideration were therefore class C, which lies equidistant from the four vegetation categories and class K which appears to be associated with perennial grasslands statistically while occurring spatially intermingled with classes assigned to blanket bog. It is probable that both of these classes are of an intermediate nature somewhere between the two extremes of blanket bog and perennial grassland and in the vegetation survey may be classified alternatively as one or the other. Neither class tended to occur in the proximity of those assigned to wet heath. Both classes are here assigned to the blanket bog category due to their spatial proximity to class F.

The classes from the initial satellite classification were assigned to the four open hill ground vegetation categories as indicated in Table 6.2.

Satellite Classes	Description
B	Heather Moorland
A C F K	Blanket Bog
E I M	Upland Perennial Grassland
G J L N	Wet Heath

Table 6.2: Classes from initial twenty one class classification of the satellite image representing each of four open hill ground vegetation categories used in subsequent analyses.

The vegetation survey maps could not be used in this way to investigate the classification of the remaining classes. Forestry plantations had not been mapped as such, but taken to be as depicted on Ordnance Survey 1:50,000 scale maps. Each forestry block had been classified as to the major plantation category but no attempt had been made to subdivide these blocks further. Similarly deciduous and mixed woodlands had been taken to be as shown on the Ordnance Survey 1:50,000 scale maps. Agricultural grassland had been mapped using boundaries taken to follow those marked on Ordnance Survey 1:50,000 scale maps and 1:25,000 scale maps. Thus following the procedure used to determine open hill classes would merely duplicate the criterion already applied to identify these classes in the initial acceptance of the satellite image derived classification. In the case of forestry plantations and agricultural grasslands this is not considered a problem. As described above these are clearly distinguishable as such on the satellite image derived classification.

In the case of the deciduous and mixed woodland the satellite image derived classification could not be relied upon. Whilst pixels identified as corresponding to mixed woodland were frequently found to have been classified along with mature forestry this was not always the case, especially for the more open woodland, and there was no clear pattern of misclassification that may have allowed the problem to be tackled in some other way. Consequently it was accepted that the best representation of the distribution of both broadleaf and mixed woodland would be that which could be obtained from Ordnance Survey maps. The module **ITOGRID** from the **Lamps Matrix** software (Laser-Scan Ltd 1989) was used to incorporate details of woodland, digitised from Ordnance Survey 1:50,000 scale Landranger maps, directly into the satellite derived classification. The same process was also used to reclassify water. Water, which had been classified into deep water, shallow water and exposed mud at low tide by the satellite image processing, was reclassified into sea and freshwater using **ITOGRID**. An example from the twelve class classification is given in Figure 6.4.

DETAILS OF VEGETATION COVER CLASSIFICATION

The final vegetation classification therefore contains the following categories:-

Pre-thicket forestry.

Young forestry plantations before canopy closure. Characterised by lush herb layer and shrub birch with much open space between lines of planting.

Post-thicket forestry.

Forestry plantations after canopy closure and through to mature tree stands. Characterised by sparse or near absent herb or shrub layer. The only open areas are rides between stands.

Broad-leaved woodland.

Corresponds to deciduous woodland as marked on 1:50,000 scale Ordnance Survey Landranger series maps. In mid-Argyll oak and birch are the dominant species.

Mixed woodland.

Corresponds to mixed deciduous and coniferous woodland as marked on 1:50,000 scale Ordnance Survey Landranger series maps. In mid-Argyll this will often refer to the under-planting with plantation species of broad-leaved woodland. This leads to a patchwork, with broad-leaved species persisting along gullies and areas where conifers fail to take hold.

Agricultural grassland.

Corresponds to that part of the land, enclosed from the open hill ground, that is maintained through cultivation by ploughing, reseeding and fertilising.

Upland grassland.

Characterised by perennial grasses such as *Festuca ovina and Agrostis tenuis* with *Pteridium aquilinum* commonly present as an invasive species.

Blanket Bog.

Characterised by species such as *Eriophorum angustifolium*, *Tricophorum cespitosum*, and *Molinia caerulea* with a carpet of moss, principally *Sphagnum spp*.

Wet heath.

Over large tracts of land in mid-Argyll, the very wet climate combined with high grazing pressure by sheep and deer causes blanket bog to degrade to *Molinia* dominated heath with a very much reduced dwarf shrub component.

Heather moorland.

Characterised by cover species such as *Calluna vulgaris*, *Vaccinium myrtillus* and *Nardus stricta*.

Freshwater.

Corresponds to freshwater bodies as marked on 1:50,000 scale Ordnance Survey Landranger series maps.

Sea.

Corresponds to below the high tide line as marked on 1:50,000 scale Ordnance Survey Landranger series maps.

Unclassified.

Areas corresponding to pixels representing rare land cover categories that image processing failed to classify, urban areas and areas filtered out during processing as they were subject to shade.

TOPOGRAPHY

A digital representation of the topography of the landscape was incorporated into the GIS by means of a Digital Terrain Model (DTM). A DTM is a digital representation of a geographical area, the data consisting of a regular matrix of heights.

Initial data capture was made using Ordinance Survey 1:50000 scale Landranger maps for reference. Water bodies, coastline and all 50 metre contour lines, were digitised. An example of these data is given in Figure 6.5. These data were then processed using the modules **Triang**, **Trider**, and **Trigrid** from the **Lamps Dtmcreate** software (Laser-Scan Ltd. 1989) to produce a DTM of the entire area. A detailed explanation of the algorithms used to construct the DTM is not appropriate here. A full explanation of this is given in Laser-Scan Ltd.(1989).

The module **Triang** creates a Delaunay triangulation from the digitised input data (Laser-Scan Ltd. 1989). Prior to input, coastline features were coded so they would be considered as one metre high cliffs by **Triang**, and so complying with the recommended procedure in the **Dtmcreate** documentation. Accordingly the **assign cliff_fc** subcommand was used but otherwise system defaults were accepted.

The module **Trider** creates slope derivatives using output files from **Triang** (Laser-Scan Ltd. 1989). System defaults were accepted for all command qualifiers.

The module **Trigrid** creates a digital terrain image (DTI.) taking as input the various files output by **Triang** and **Trider**. The command qualifier **sidelength** was used to specify several pixel resolutions to be used in the resulting DTIs, but otherwise system defaults were accepted. The resulting DTM's were displayed in **Horizon** GIS for comparison. Pixel resolutions of 100m. x 100m., 200m. x 200m. and 500m. x 500m. were evaluated visually. A pixel resolution representing 100m x 100m was chosen to provide a reasonable representation of the complexity of the landscape while still being large enough to smooth out inherent artefacts of the digitising process.

This DTM was incorporated into the **Horizon** GIS for further processing with the **Terrain** application which was used to derive three further data layers which, together with altitude, adequately describe the topography of the landscape. Each will be described separately.

Altitude

The DTM produced was essentially a raster altitude map with a 100 x 100 metre pixel representation. Altitude was represented to the nearest metre. The value of each pixel approximates to the mean altitude of the area of land represented by that pixel. An example of these data is given in Figure 6.6.

Slope

Within the **Terrain** application of **Horizon** the **Slopes** function was used to generate slope data. The resulting output represented slope, measured to the nearest degree from the horizontal, in raster format, with a 100 x 100 metre pixel resolution. The value of each pixel approximates to the mean slope of the area of land represented by that pixel. An example of these data is given in Figure 6.7.

Aspect

Within the **Terrain** application of **Horizon** the **Aspect** function was used to generate aspect data. The resulting output represented aspect, measured to the nearest degree from north, in raster format, with a 100 x 100 metre pixel resolution. The value of each pixel approximates to the mean aspect of the area of land represented by that pixel. An example of these data is given in Figure 6.8.

Ruggedness

Within the **Terrain** application of **Horizon** the **Heights** function was used to generate data representing the altitude differences within the neighbourhood of each pixel. The command qualifier **disable average** was used in order that the calculated value for each pixel in the output was the maximum altitude difference found between cells in a 3 x 3 pixel matrix centred on that pixel. This output therefore consisted of altitude differences, measured to the nearest metre, in raster format, with a 100 x 100 metre pixel resolution. This output was taken as providing measure of local altitudinal range or an index of land ruggedness. An example of these data is given in Figure 6.9.

CULTURE

All individual habitations and all classified roadways were digitised using Ordnance Survey 1:50000 scale Landranger maps for reference. It was not feasible to distinguish occupied habitations from unoccupied habitations. This was not considered a problem as unoccupied and derelict buildings are often still associated with human activity, for example housing for livestock or storage for fodder. An example of these data is given in Figure 6.10.

CLIMATIC CONDITIONS

Climatic conditions as represented by the Assessment of Climatic Conditions in Scotland series maps (McCaulay Institute for Soil Science 1970) was considered to be at the level of complexity required for the current work. While of obvious importance climatic data were not included within the database. At a local level climate is strongly linked to altitude and maritime influence. Consequently climatic maps are largely secondary derivations of other data sets already included in the database. When altitude and proximity of coast were controlled for, the maps under consideration depicted no variation in climatic conditions across the study areas. Thus, had they been included, data would have been duplicated. It therefore follows that were such data required for analysis it could be derived from data already entered in the database.

GEOLOGY

Data capture was made using British Geological Survey 1:250000 scale map sheets (Tiree and Argyll) for reference. Although included in the GIS these data were not considered in subsequent analyses.

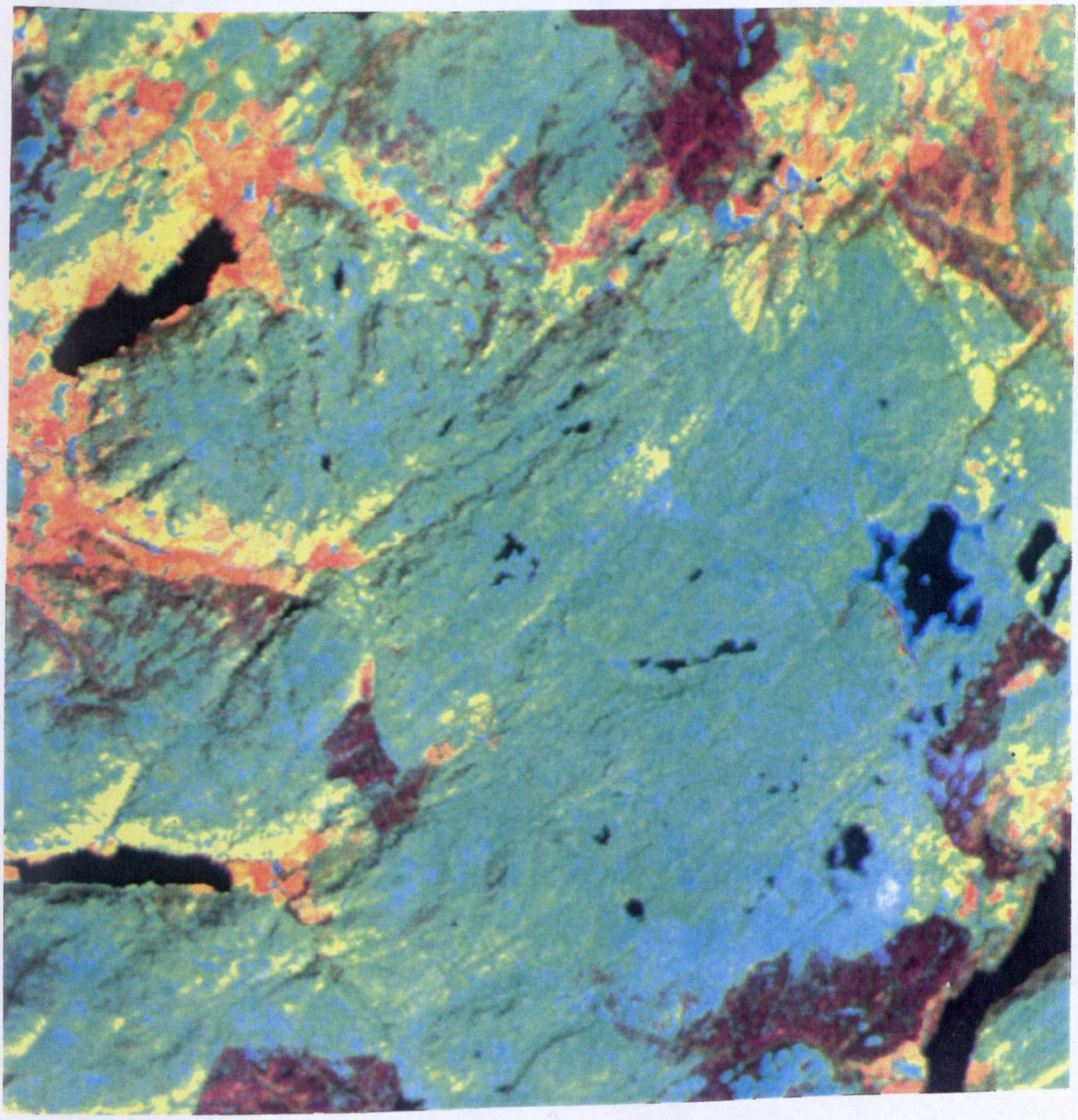


Figure 6.2: An example from the unclassified satellite image from which the vegetation cover classification used in the study was derived. This example is centred on the north-Lorn study area.
The image was produced from data acquired by Landsat on 2nd.May 1990. Certain landscape features such as forestry plantation blocks (deep red), improved agricultural land (orange) and water (black) are clearly discernible at this early stage of processing.

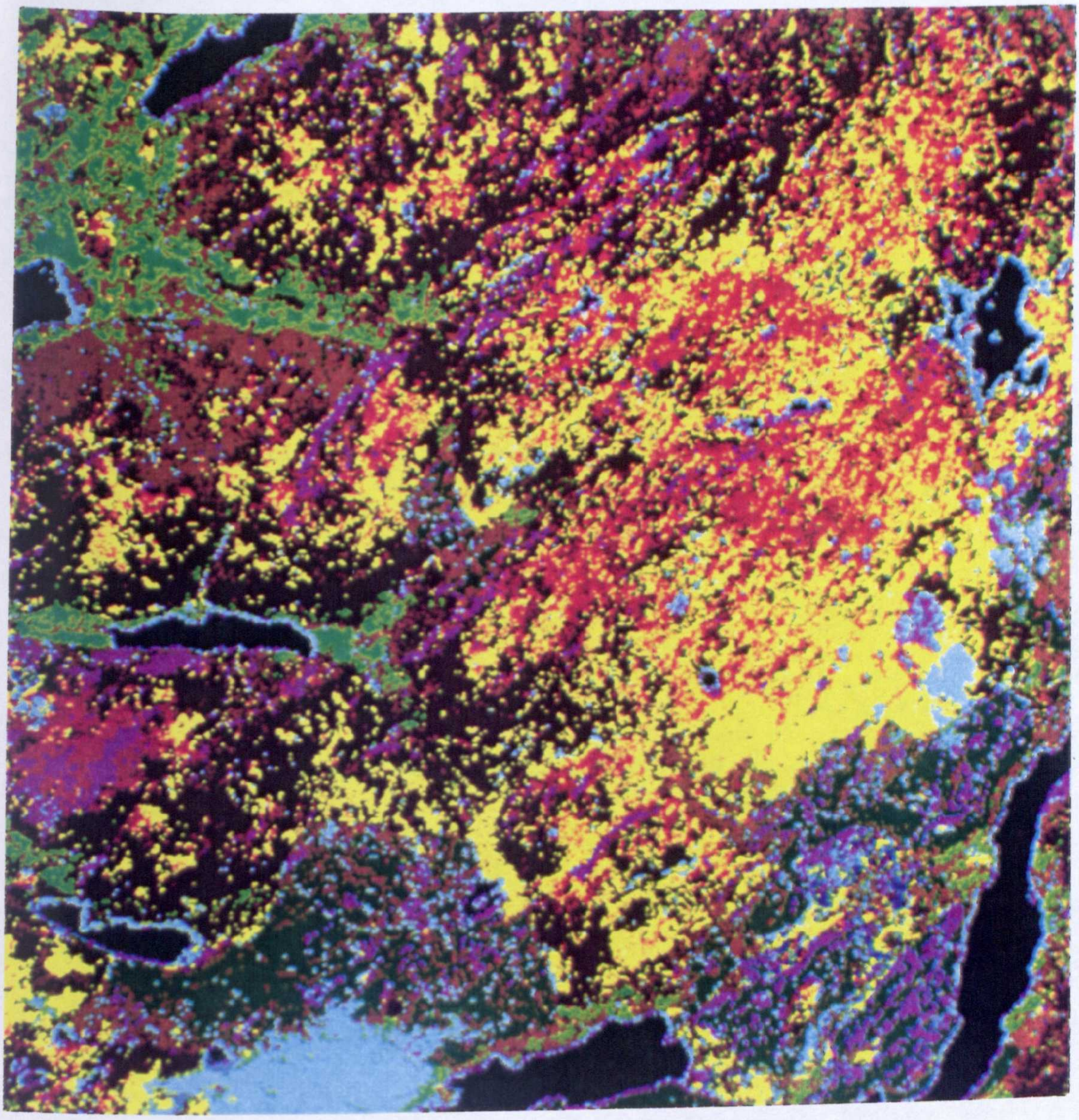
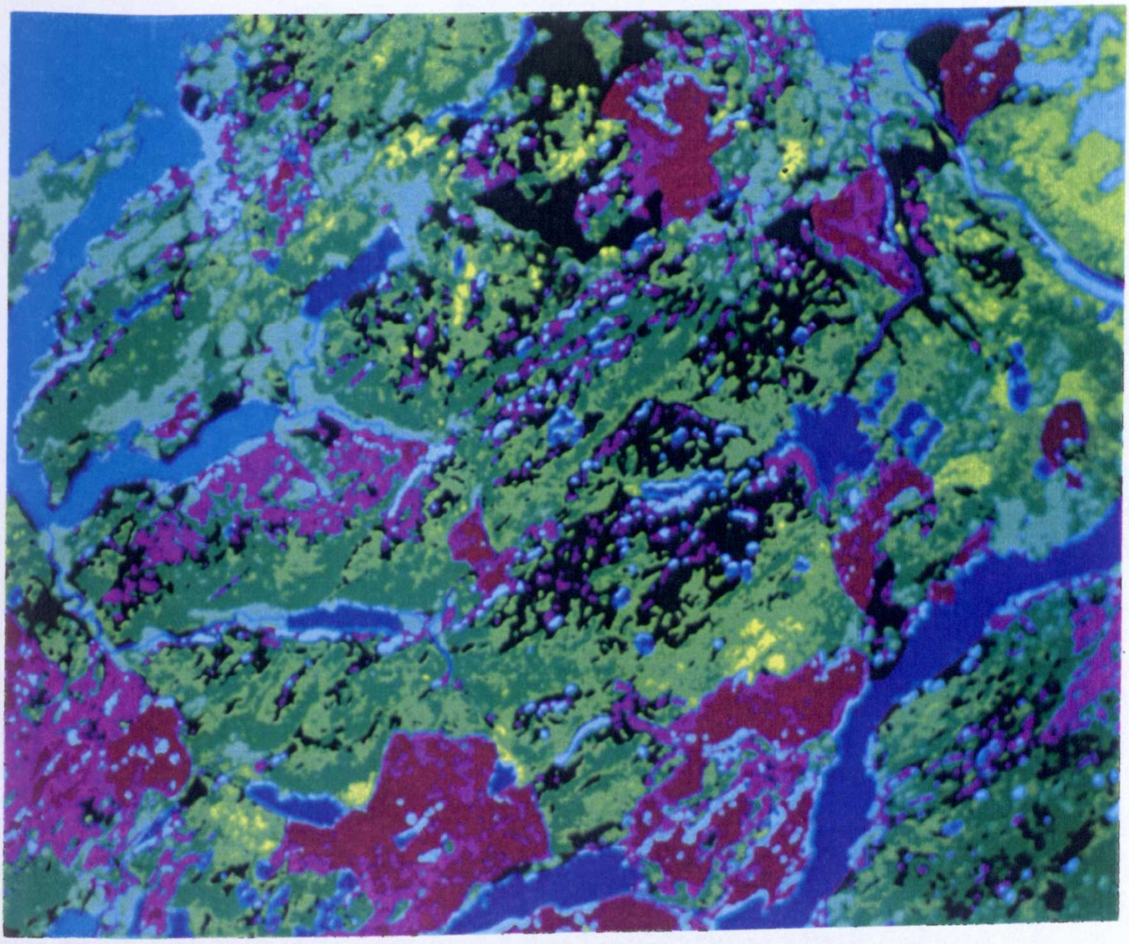


Figure 6.3: An example from the twenty one class vegetation cover classification produced by initial processing of the satellite image shown in Figure 6.2. At this stage of processing several classes may still correspond to a particular vegetation cover category.



Key to vegetation classification. See pages 110-111 for full descriptions.

- ⬜ **Unclassified**
- 🟥 **Mature Forestry Plantation**
- 🟪 **Pre-thicket Stage Forestry Plantation**
- ⬛ **Heather Moorland**
- 🟩 **Blanket Bog**
- 🟨 **Wet Heath**
- 🟦 **Agricultural Grassland**
- 🟩 **Upland Perennial Grassland**
- ⬛ **Broad-leaved Woodland**
- ⬛ **Mixed Woodland**
- 🟦 **Salt Water**
- 🟦 **Fresh Water Bodies**

Figure 6.4: An example from the twelve class vegetation cover classification produced by merging of classes from the twenty one class classification shown in Figure 6.3.

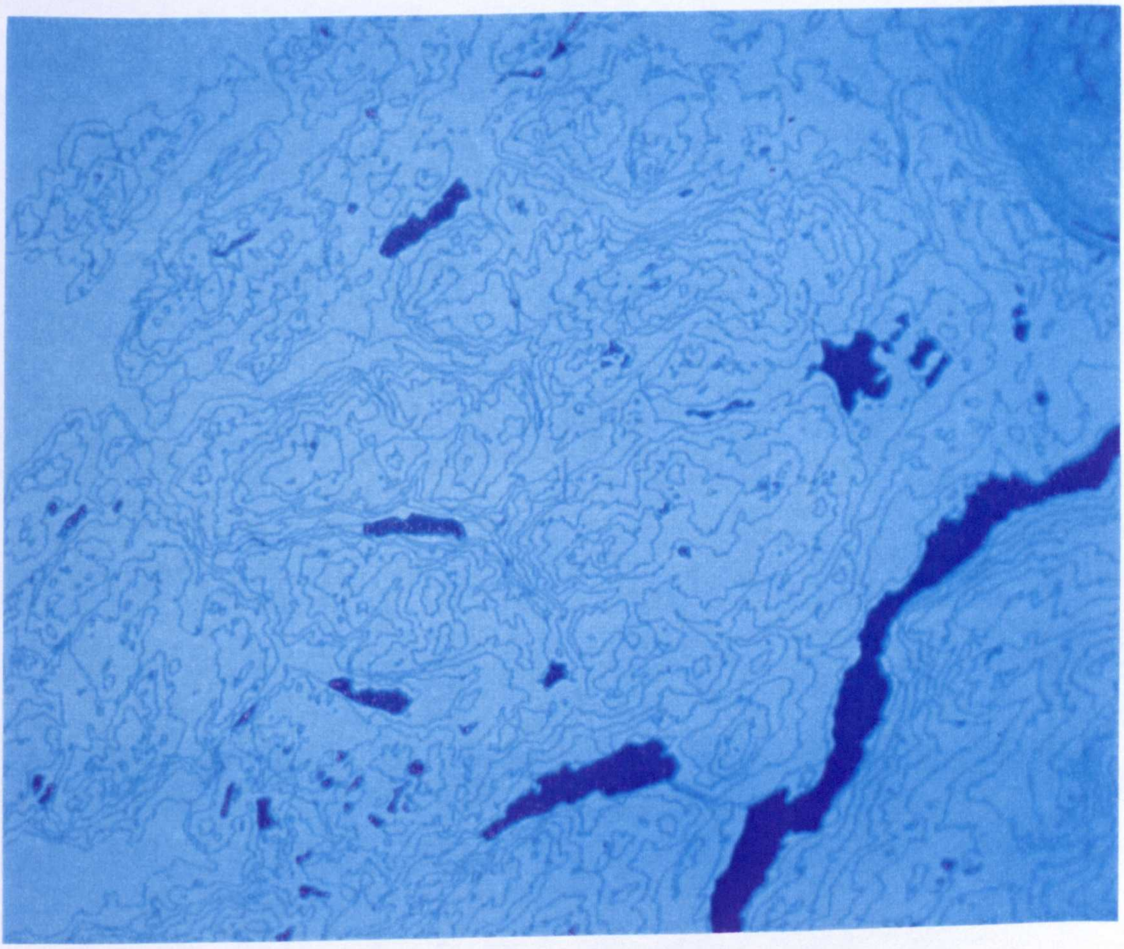
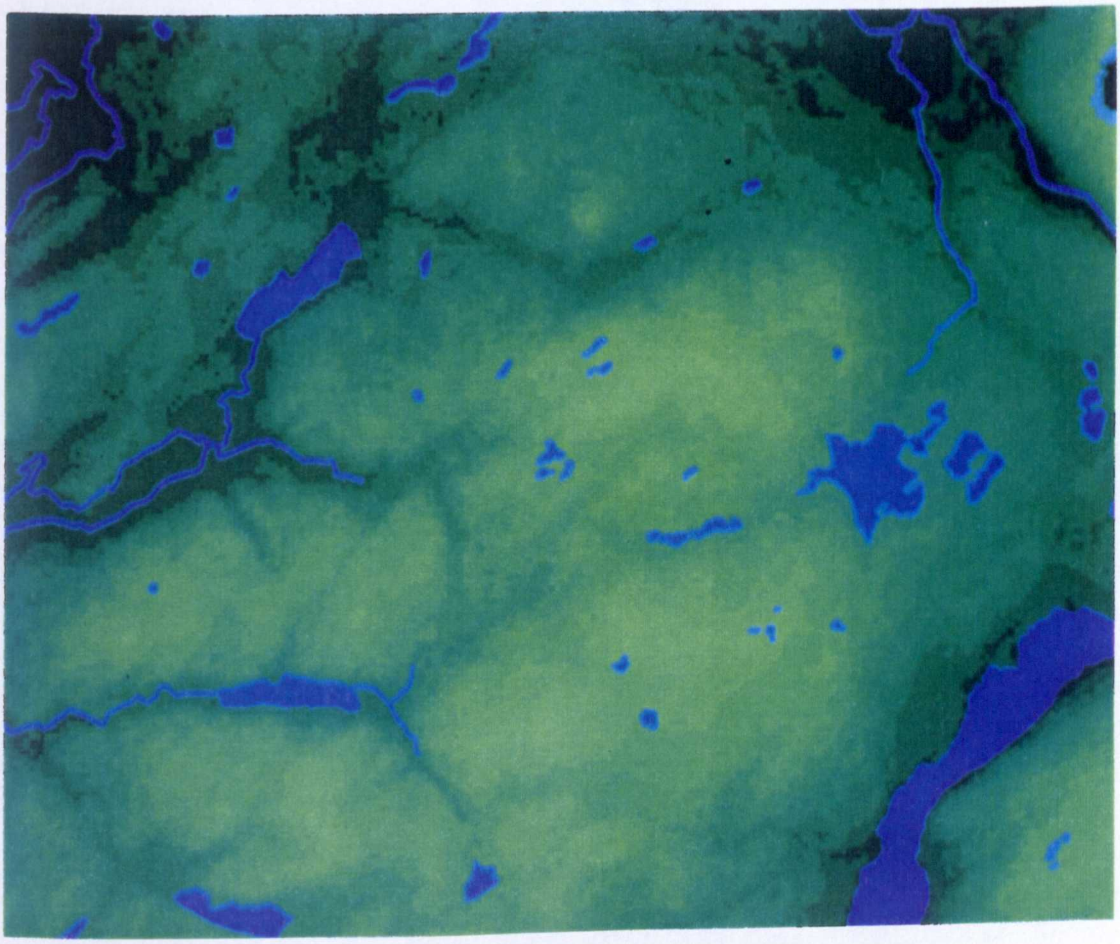


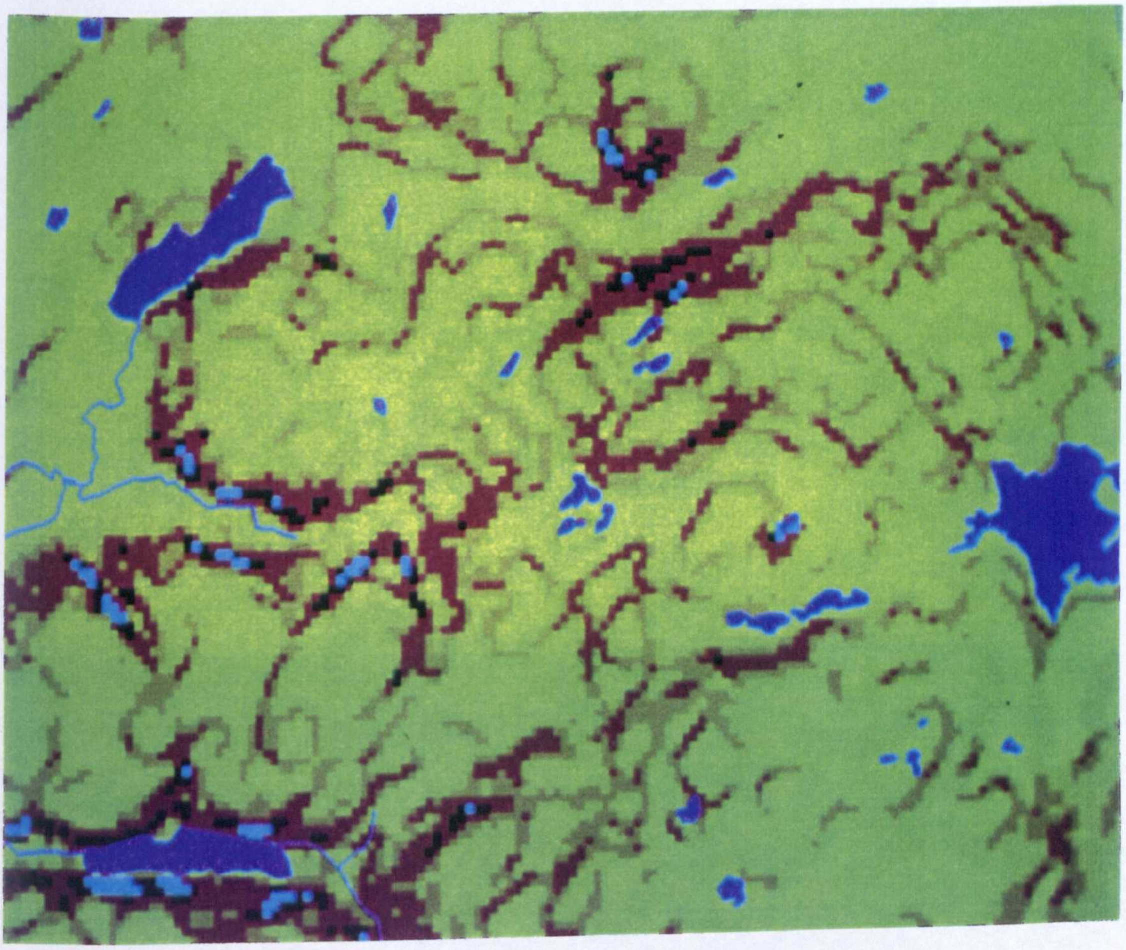
Figure 6.5: An example from the vector data set used in the development of the digital terrain model (DTM) of mid-Argyll. See pages 111-112 for full details.
These data were captured with reference to Ordnance Survey 1:50,000 Landranger maps, using the Mapdata software package and incorporated into the Horizon GIS. Data includes 50m. contours, rivers, fresh water bodies and coastline.



Key to altitude classification.

	Altitude Range in Metres
🟦	< 50m.
🟩	51m. - 100m.
🟩	101m. - 150m.
🟩	151m. - 200m.
🟩	201m. - 250m.
🟩	> 250m.

Figure 6.6: An example from the raster altitude data produced within the Horizon GIS from the DTM of mid-Argyll.
Pixel values represent altitude to the nearest metre. The pixel resolution corresponds to 100m. x 100m. Here pixel values are displayed so as to represent 50m. altitude zones (0m.,1m.-50m.,51m.-100m.,...).

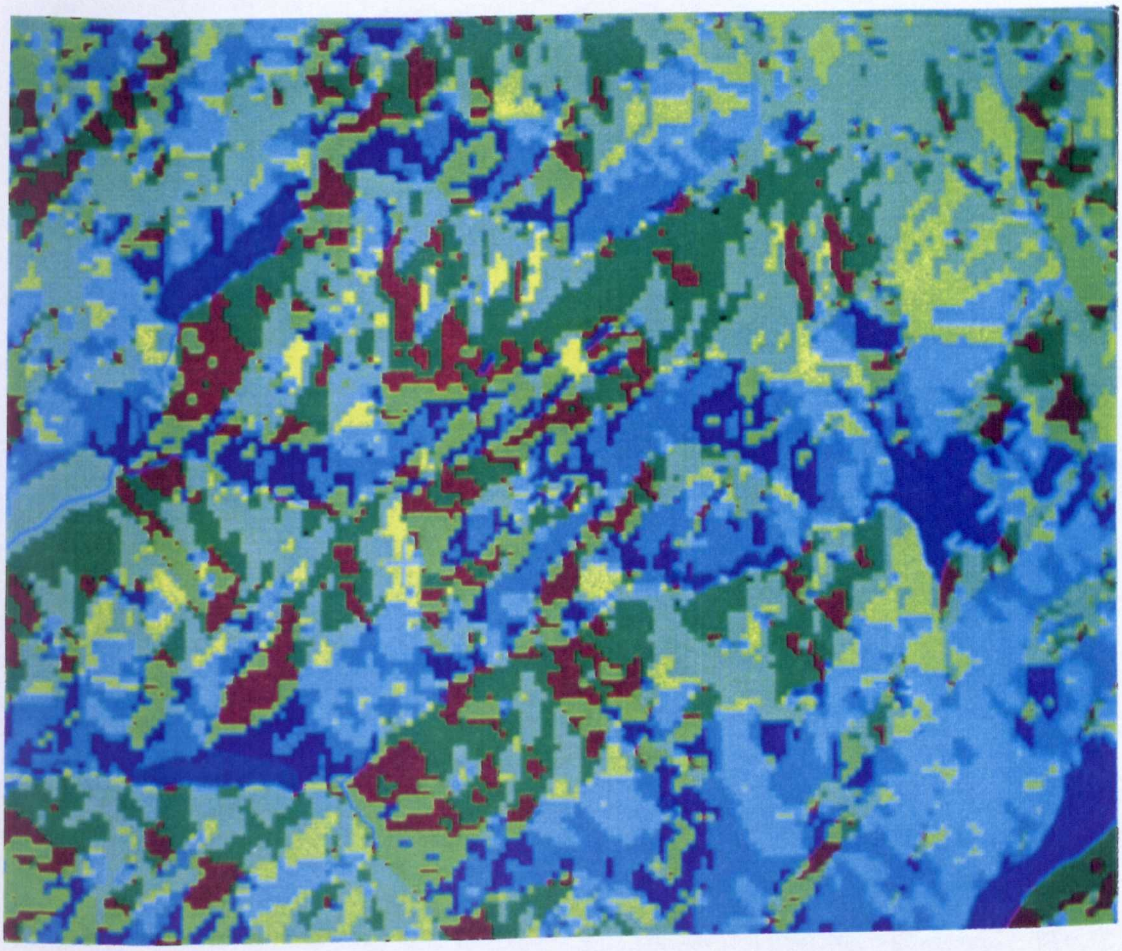


Key to slope classification.

Slope in Degrees

🟩	**0°**
🟩	**1° - 5°**
▨	**5° - 10°**
🟥	**10° - 15°**
🟥	**15° - 20°**
⬛	**20° - 25°**
🟦	**>25°**

Figure 6.7: An example from the raster slopes data produced within the Horizon GIS from the DTM of mid-Argyll.
Pixel values represent slope, measured to the nearest degree from the horizontal. The pixel resolution corresponds to 100m. x 100m. Here pixels values are displayed to represent 5° increments in slope (0°,1°-5°,6°-10°,...).

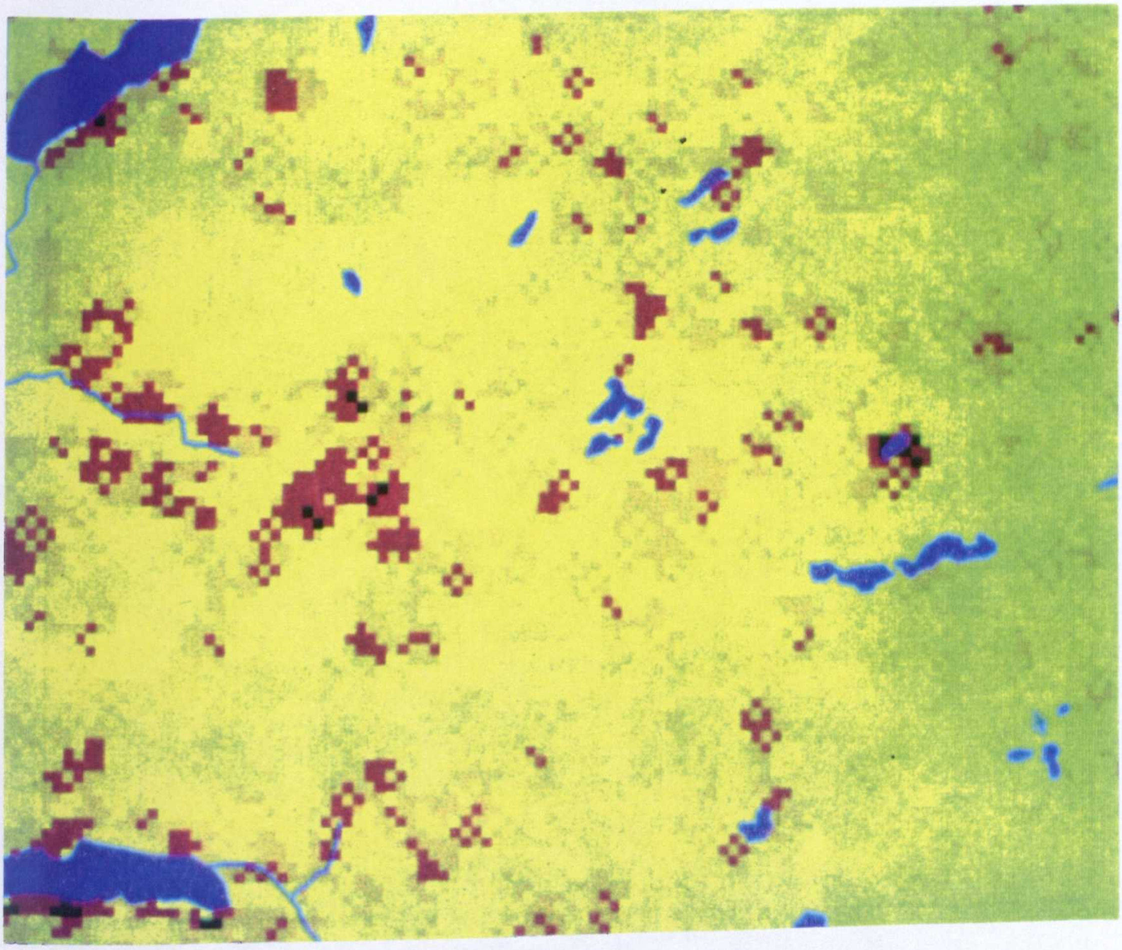


Key to aspect classification.

Aspect in Degrees from North

🟥	**No Aspect**
🟩	**1° - 45°**
🟦	**46° - 90°**
🟦	**91° - 135°**
☐	**136° - 180°**
🟨	**181° - 225°**
🟦	**226° - 270°**
🟩	**271° - 315°**
⬛	**316° - 360°**

Figure 6.8: An example from the raster aspect data produced within the Horizon GIS from the DTM of mid-Argyll.



Key to land ruggedness classification.

Altitude Range (Ruggedness) in Metres

🟩 **0m.**
🟩 **1m. - 5m.**
🟩 **6m. - 10m.**
🟥 **11m. - 15m.**
🟪 **16m. - 20m.**
🟦 **> 20m.**

Figure 6.9: An example from the raster ruggedness data produced within the Horizon GIS from the DTM of mid-Argyll.
Pixel values represent neighbourhood altitude range to the nearest metre. The pixel resolution corresponds to 100m. x 100m. Here pixel values are displayed so as to represent 5m. altitude range zones (0m.,1m.-5m.,6m.-10m.,...).

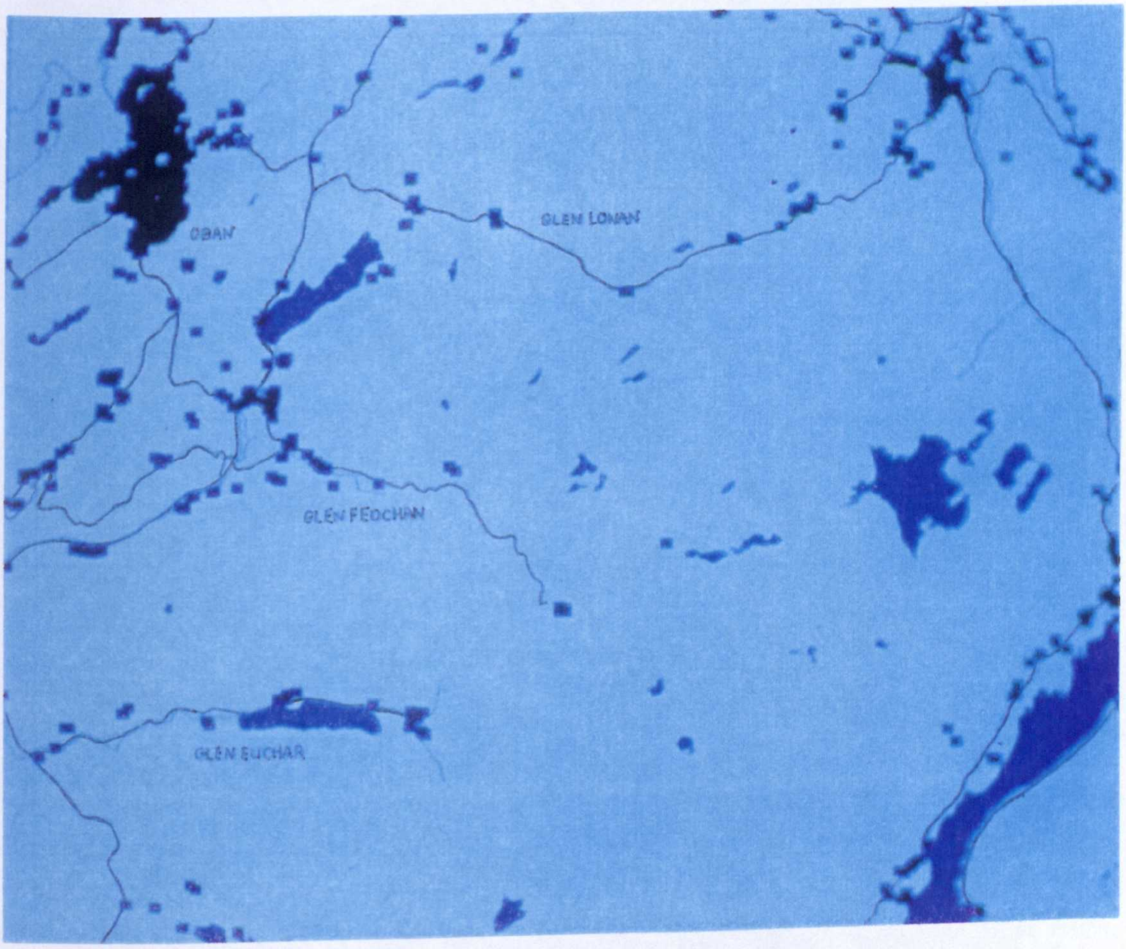


Figure 6.10: An example from the cultural artefacts data set.
These data were captured with reference to Ordnance Survey 1:50,000 Landranger maps, using the Mapdata software package and incorporated into the Horizon GIS. Data includes human habitation (■) and roads (—).

DATA EXTRACTION FROM THE HABITAT DATABASE USING GIS

TYPE OF INFORMATION EXTRACTED FROM GIS

Like most such systems the **Horizon** GIS makes easy the querying of data held on the underlying database in the format of map oriented questions using menu options. For the purpose of this study the type of query asked of the system generally fell into one of the following categories:

1/ The distances between points, for example, what is the distance from a buzzard nest site to that of its nearest neighbour?

2/ Counts of features within a region of interest, for example; how many human habitations lie within a given radius from a buzzard's nest site?

3/ Measurements of linear features within a region of interest, for example; What is the length of coastline within a given radius from a buzzard's nest site?

4/ Measurements of areas of cover types within a region of interest, for example; What is the area covered by each of the vegetation cover categories within a given radius from a buzzard's nest site.

Most of these queries could be worked through interactively on the computer display using the menu options, particularly the first two, and in some instances this was the method employed. Most data extraction, however, required that the same chain of command options be repeated many times over, and also some queries were, by necessity, mechanically very complex and so user error would be expected during interactive use. Therefore an automated mechanism for data extraction was appropriate.

DATA HANDLING

The **Horizon** GIS uses command macros written in the **Lites2** command macro language to run its procedures. **Lites2** itself is a part of the **Lamps** computer mapping software (Laser-Scan Ltd 1989 & 1990). This allows the user to run command macros written in the **Lites2** command language under **Horizon**. More importantly in the context of this study it means that any data layers created or manipulated by one system can be displayed and queried by the other system. Simple command macros and those requiring user interaction were run under **Horizon**. However, most jobs required many hours of processing time and these were executed in VMS batch mode, under **Lites2**.

EXTRACTING DATA FROM VECTOR AND RASTER FORMATS.

The querying of data presented in vector format could be achieved in a relatively straight forward manner. Counts of features, measurements of the lengths of features or distances between features, displayed by **Horizon** or **Lites2**, can be obtained directly by a short series of commands either using the menu system or written into a short command macro. Command macros used in this study and written in the **Lites2** command macro language are given in Appendices 1a & 1b.

Area data was stored in raster format. In this format there are two options for data extraction available using Laser-Scan Ltd. software. The simplest method is to construct simple command macros that will use pixel counts to report the area of each cover type. So, for example one can obtain the total number of each pixel type in a given region. This region would be defined with reference to the pixel matrix, for example. a count of pixels in a pattern of x columns and y rows centred on the point of interest, such as a nest site, referenced to the British National Grid. This method provides a simple solution when the region of interest and hence the number of pixels to be counted is small, and was used to describe habitat in the analysis which follows in Chapter 7 of this thesis where only a description of a relatively small area was required. An example of a command macro to do this type of data extraction, one of several, is given in Appendix 2.

When the region of interest becomes large, however. this approach becomes cumbersome. Also, of relevance to this study, data in raster format cannot be queried other than as to the value of each pixel. Data describing, for example, the distance between features, the size of individual patches of a given cover type, or the length of boundaries of homogenous patches cannot be obtained. The solution is to convert between the two data formats. This facility is offered by the **Vectorise** module of the **Lamps Matrix** software(Laser-Scan Ltd 1989) and was the method employed in the extraction of vegetation cover and topographic data for analyses which follow in chapters 8 and 9. Using this approach interactive data extraction is no longer appropriate and these procedures were always executed in batch mode. The chain of command procedures written to extract area and boundary length data for within a single radius centred on a single point of interest (e.g. a buzzard nest site) are given in Appendix 3a to 3e.

In this study it was required that this process was repeated for a number of radii for each point of interest, for example a nest site, for many such points and for five different data layers, these being the satellite produced vegetation cover and the four topographic layers. A command procedure was therefore written which itself writes the necessary command procedures using the command macros, given in Appendices 3a to 3e, required to execute the data extraction for a series of points of interest (e.g. buzzard nest sites). It does this in response to user answers to prompts including the data layer to be considered and radii of interest. Details are given in Appendix 4.

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CHAPTER 7: HABITAT UTILISATION BY BUZZARDS IN MID-ARGYLL

CONTENTS:

INTRODUCTION

Buzzards are known to take a wide range of prey, and show much adaptability in their foraging techniques. Consequently, they are able to find prey in a variety of habitat types. For self maintenance, food items such as invertebrates and carrion may be usefully exploited. However, when a pair of buzzards are feeding a brood of young, or when a male is supplying an incubating female with food, this must be obtained in economically transportable packages, small vertebrates being the obvious choice. A shift in diet between seasons has been found in several studies (e.g. Pinowski & Ryszkowski 1962, Dare 1961). A shift in prey requirements may well lead in turn to a shift in the relative importance of different habitat types between seasons and such changes in habitat use between seasons has also been suggested (e.g. Tubbs 1974, Weir & Picozzi 1983).

One approach to studying habitat use by animals is to follow the movements of individuals over a period of time. Studies of raptors along these lines invariably involve marking of individuals with wing-tags or radio transmitters to enable contact and recognition to be maintained (e.g. Wakely 1978, Bechard 1982, Watson 1986). This is not always feasible, nor indeed may be the following of individuals, especially when working in broken or difficult terrain. Also such studies, by their very nature, are necessarily biased towards the idiosyncrasies of a small number of individual animals.

A second approach to this problem is to make use of single observations of many birds without following their movements. This technique has been widely applied in studies of habitat utilisation and bird abundance. Examples include many studies of migratory raptors during the winter, especially in North America, but it has rarely been applied to raptors on their breeding grounds where the habitat has generally been described in relation to territory or home range. Many raptors however wander widely, at least outside the nesting season, and during the nesting season foraging ranges frequently are not limited to a defended territory. Studies using point observations have variously made use of raptor sightings made from vehicles whilst driving along standard routes (Andersen, Rongstead & Mytton 1985, Bauer 1982, Bohall & Collopy 1984, Craig, Craig & Powers 1989, Enderson 1965, Johnson & Enderson 1972) or made during systematic foot searches (Jorgensen 1986, Barnard 1987). Analysis of point observations have successfully described habitat utilisation differences between species (Barnard 1987, Bohall &

Collopy 1984, Schell 1968. Sferra 1984), between the sexes within a species (Koplin 1973. Steinson, Crawford & Lauthner 1981) as well as habitat utilisation by individual species.

Neu, Byres and Peek (1974) describe a technique for analysis of utilisation-availability data. In this type of analysis, usage is considered to be selective if components of the habitat are used disproportionately to their availability. This technique has been applied in habitat selection by large mammals in a number of studies (Byres, Steinhorst and Krausman 1984, Krausman 1978, Neu *et al* 1974) and more recently in a number of studies of bird habitat selection (Alldredge & Ratti 1992, Kilbride, Crawford, Blakely & Williams 1992). It is used here in the analysis of buzzard habitat selection. Several other methods for looking at habitat utilisation in relation to availability have been described (e.g. Johnson 1980, Alldredge & Ratti 1986). However, the method of Neu *et al* (1974) is most appropriate here as it does not rely on repeated observations of known individuals (Alldredge and Ratti 1992).

The aim of this analysis was to try and identify the habitat types selected by buzzards in the pre-nesting and nesting seasons. Both a foot survey and a vehicle survey were conducted in order to provide two independent assessments of habitat utilisation, and to allow a comparison of the two approaches to be made.

METHODS

FOOT SURVEY OF BUZZARDS

The foot survey took place between mid-March and mid-June 1990. Three observers were involved in the collection of the foot survey data analysed here, Mr. C.J.Thomas (mid-March to mid May), Mr. M.Green (1 week in mid-March) and myself (mid- March to mid-June). Data collection was ceased in mid-June, when nest visits became the principle fieldwork activity, so as to avoid bias associated with buzzards in the immediate vicinity of their nest sites. All sightings of buzzards made during routine fieldwork were logged with details recorded for date, location and the bird's activity. Observers also kept a log of all 1km grid squares, referenced to the British National Grid, visited during fieldwork. The vegetation cover in each grid square was described using the classified satellite image. Sample counts of pixels representing each cover type present were made in each grid square. The product of the count for each cover type and number of visits to each grid square was summed across all grid squares sampled to provide an index of observer effort in each habitat. The vegetation cover type that was associated with each buzzard observation was also described using the classified satellite image. A buzzard was taken to be over the cover type, represented by the modal pixel type, after the removal of water categories, in a pattern approximating to a 100 metre radius circle, centred on the grid reference recorded for that observation. Buzzard observations were classified into four categories of activity; perched, those engaged in hunting flight, non-hunting aerial activity and other or undetermined activities. Buzzards spend much of their hunting time perched in positions that give them a good overall view of their surroundings, consequently the perched category would have consisted largely of observations of this activity as well as resting birds. Hunting flight includes buzzards actively quartering the ground, usually at low altitude. Non-hunting activity includes mainly buzzards soaring at high altitude. The last category includes buzzards for which activity did not fall into any of the other categories or for which the bird was only seen after it had been flushed by the observer and its activity immediately prior to this was not identified.

VEHICLE SURVEY OF BUZZARDS

The vehicle survey ran from mid January to mid June 1990. Two observers were involved in the collection of road survey data analysed here, Mr. C.J.Thomas (mid-March to mid-May) and myself (mid-January to mid-June). During routine vehicle journeys around the study area all sightings of buzzards were recorded as for the foot survey. Observers also kept a log detailing all routes taken. The vegetation cover of each road section passed through was described using the classified satellite image. Sample counts of pixels representing the vegetation cover types were obtained using a pixel matrix approximating to a 100m. radius on the ground made at 500m. intervals, along each road section. The product of the total count of each cover type and number of journeys made for each road section was summed across all road sections to give an index of observer effort in each habitat.

ANALYSIS

The data presented here were collected between mid-January and early June 1990. The study was split into two periods divided by the median laying date (14th.April) to allow for any change in buzzard activity that may have been associated with the onset of the nesting season. Foot survey data and vehicle survey data are treated separately and so offer two independent assessments of habitat utilisation. Analysis follows the technique of Neu *et al* (1974) (see also Byres *et al* 1984). For each combination of season and survey method, the distribution of overall buzzard activity between habitat types was first considered. A Chi-square goodness-of-fit test was used to test the null hypothesis that buzzards were observed in all habitat types with relative frequencies in accordance with the proportion of the total area sampled that each habitat represented. Examination of Bonferroni probability statements for the 95% family of simultaneous confidence intervals were used to determine where any differences between the observed frequencies and those expected under the null hypothesis were to be found. This method involves constructing confidence intervals for the true proportion of utilisation, P, from the observed proportion of utilisation, p_i, for each category of habitat, using the Bonferroni inequality, i.e.

$$p_i - Z_{\alpha/2k}\sqrt{p_i(1-p_i)/n} \le P \le p_i + Z_{\alpha/2k}\sqrt{p_i(1-p_i)/n}$$

where $Z_{\alpha/2k}$ is the upper standard normal table value corresponding to a probability tail area of $\alpha/2k$; k is the number of habitat categories and α is the level of significance. If the expected proportion of usage for each category does not lie within the confidence interval for that category, then the expected and actual utilisation are significantly different.

In each case the analysis was first done using all vegetation cover types, and then repeated after first removing habitats with impaired visibility, that is forestry and woodland categories. Where necessary, in order to overcome concerns regarding low expected frequencies, habitats were combined.

In such cases all forestry was combined into a single forestry category and all woodland was combined into a single woodland category. Wet heath, blanket bog and moorland were combined into a single heath category. Agricultural grassland and upland perennial grassland always remained separate. For each combination of season and survey method the distribution of specific buzzard activities was then considered. For each of the identified bird activity categories in turn, a Chi-squared goodness-of-fit test was used to test the null hypothesis that buzzards were observed engaged in the activity in question, in all of the habitat types, in the same proportions as overall activity. In each case the analysis was first done using all habitats, and then repeated after removing data from habitats with impaired visibility. When necessary vegetation cover types were combined as described above. Examination of Bonferroni probability statements for the 95% family of simultaneous confidence intervals were used to determine where any differences between the observed frequencies and those expected under the null hypothesis were to be found.

In some cases generally accepted criteria to be met when applying the Chi-squared goodness-of-fit test are violated. It is however probable that these criteria are too conservative (Siegel & Castellan 1988). Where the criterion concerning expected frequency values are violated, that is they have values of less than five, this is acknowledged in the text (as E<5=x%), and a second analysis using combined categories presented. However, the Bonferroni probability statements hold without reference to the initial significance of the Chi-squared goodness-of-fit test or whether or not it has been conducted (Byres *et al* 1984) and so, violation of this criterion for application of the Chi-square goodness-of-fit test to proceed, does not affect any conclusions that may be drawn from consideration of Bonferroni probability statements. It is used principally as a guide as to whether further investigation is warranted.

RESULTS

Foot Survey

Observer effort and season

During the foot survey 1045 km. were walked in 433 observer hours. This produced a sample of 173 buzzard contacts after filtering out ambiguous and unreliable records and those recorded as being within the immediate vicinity of a nest site. Details of observer effort during the foot survey broken down by habitat and between the periods prior to and during the nesting season are given in Appendix 5.

A highly significant difference was found between the observed and expected values under the null hypothesis that; observer effort in each habitat type was the same in both the pre-nesting season and the nesting season ($\chi^2_8=548$, $P<0.0005$). Subsequent analysis of data from the two periods were therefore always treated separately.

The distribution of general buzzard activity, prior to the nesting season, in relation to habitat

The null hypothesis tested in each case was that; prior to the nesting season, buzzards were observed in each habitat with a frequency in accordance to the proportion of that habitat type in the total habitat sampled. Details of the frequencies with which buzzards were observed during the foot survey, broken down by habitat, activity and between the periods prior to and during the nesting season are given in Appendix 7.

When considering all habitats, a highly significant difference was found between the observed frequencies of buzzard observations and those expected under the null hypothesis ($\chi^2_8=32.24$, $P<0.0005$, $E<5=44\%$). Examination of 95% family of confidence intervals indicated that buzzards were observed less in wet heath and more in upland perennial grassland than would be expected under the null hypothesis. When habitats with impaired visibility were excluded, again, a highly significant difference was found ($\chi^2_5=27.19$, $P<0.0005$). Examination of the 95% family of confidence intervals indicated that buzzards were observed less in wet heath and more in upland perennial grassland than would be expected under the null hypothesis. This statement remained true when the 99% family of confidence intervals were considered. When habitats were combined, in order to overcome concerns regarding small expected frequencies, and all habitats considered, a highly significant difference was found ($\chi^2_4=27.19$, P<0.0005). Examination of 95% family of confidence intervals indicated that buzzards were observed less in heath and more in upland perennial grassland than would be expected under the null hypothesis.

The distribution of general buzzard activity, during the nesting season, in relation to habitat

The null hypothesis tested in each case was that; during the nesting season, buzzards were observed in each habitat with a frequency in accordance to the proportion of that habitat type found in the total habitat sampled.

When considering all habitats, a highly significant difference was found between the observed frequencies and those expected under the null hypothesis (χ^2_8=114.13, P<0.0005). Examination of the 95% family of confidence intervals indicated that buzzards were observed less in blanket bog and wet heath, and more in upland perennial grassland than would be expected under the null hypothesis. When habitats with impaired visibility were excluded, a significant difference was still found (χ^2_4=117.05, P<0.0005). Examination of 95% family of confidence intervals indicated that buzzards were observed less in wet heath, and more in upland perennial grassland than would be expected under the null hypothesis. This statement remained true when the 99% family of confidence intervals were considered.

Specific buzzard activities and season

During the period prior to the nesting season 75 buzzard observations were made. Of these, 8.0% involved perched birds, 18.7% involved buzzards actively hunting, 64.0% involved buzzards seen in non-hunting aerial activity and 9.3% involved birds seen pursuing other or undetermined activities. During the nesting period 98 buzzard observations were made. Of these, 8.2% involved perched birds, 4.0% involved birds engaged in active hunting, 71.4% involved birds engaged in non-hunting aerial activity and 16.3% involved birds pursuing other or undetermined activity. A significant difference was found between the observed frequencies and expected frequencies under the null hypothesis; buzzards were observed engaged in different activities in the same relative proportions prior to and during the nesting period (χ^2_2=7.02, P<0.05) (excludes undetermined activities). Examination of contributions to the Chi-squared statistic indicates a decrease in the relative frequency with which birds were seen hunting from the pre-nesting to nesting season.

The distribution of specific buzzard activity, in relation to habitat, prior to the nesting season

The null hypothesis tested in each case was; prior to the nesting season, buzzards were observed engaged in the activity in question, in each habitat, with a frequency in accordance to the proportion of total observations represented by those in that habitat.

Only in the case of non-hunting aerial activity was the sample size considered sufficient to meet criteria for further analysis, and then only after habitat categories had been combined. When considering all habitats, no significant difference was found between observed frequencies and frequencies expected under the null hypothesis (χ^2_4=4.28, P>0.3). When the analysis was repeated after excluding habitats with impaired visibility, again, no significant differences were found (χ^2_2=1.99, P> 0.3).

The distribution of specific buzzard activity, in relation to habitat, during the nesting season

The null hypothesis tested in each case was; during the nesting season, buzzards were observed engaged in the activity in question, in all habitat types, in the same proportions as overall activity.

Only in the case of non-hunting aerial activity was the sample size considered sufficient to meet criteria for further analysis, and then only after habitat categories had been combined. No significant difference was found between observed frequencies and frequencies expected under the null hypothesis (χ^2_4=7.72, P>0.1). However, examination of 95% family of confidence intervals suggests that buzzards were observed less in forestry than would be expected under the null hypothesis (the forestry category had contributed 79% of the total to the chi-square statistic). When the analysis was repeated after excluding habitats with impaired visibility, no significant differences were found (χ^2_2=0.57, P>0.7).

VEHICLE SURVEY

Observer effort and season

During the vehicle survey a total of approximately 10,000 km. were covered during 210 observer hours. This produced a sample of 199 buzzard contacts after filtering out ambiguous and unreliable records. Details of observer effort during the vehicle survey, broken down by habitat and between the periods prior to and during the nesting season are given in Appendix 6.

A highly significant difference was found between the observed and expected values under the null hypothesis; observer effort in each habitat type was the same in both the pre-nesting season and the nesting season (χ^2_8=7044, P<0.0005). Subsequent analysis of data from the two periods was therefore always treated separately.

The distribution of general buzzard activity, prior to the nesting season, in relation to habitat

The null hypothesis tested in each case was that; prior to the nesting season, buzzards were observed in each habitat with a frequency in accordance to the proportion of that habitat type present in the total habitat sampled. Details of the frequencies with which buzzards were observed during the vehicle survey, broken down by habitat, activity and between the periods prior to and during the nesting season are given in Appendix 8.

When considering all habitats a highly significant difference was found between the observed frequency of buzzard observations and those expected under the null hypothesis (χ^2_8=46.96, P<0.0005). Examination of 95% family of confidence intervals indicated that buzzards were observed less in blanket bog and agricultural grasslands and more in upland perennial grassland and broad-leaved woodland than would be expected under the null hypothesis. When habitats with impaired visibility were excluded, again, a highly significant difference was found (χ^2_4=25.07, P<0.0005), and examination of the 95% family of confidence intervals indicated that buzzards were observed more in upland perennial grassland than expected under the null hypothesis.

The distribution of general buzzard activity, during the nesting season, in relation to habitat

The null hypothesis tested in each case was that; during the nesting season, buzzards were observed in each habitat with a frequency in accordance to the proportion of that habitat type in the total habitat sampled.

When considering all habitats, no significant difference was found between the observed frequencies and those expected under the null hypothesis (χ^2_8=2.80, P>0.925, E<5=44%). When habitats with impaired visibility were excluded, again, no significant difference was found (χ^2_4=1.74, P>0.7, E<5=40%). When combined habitats were considered, in order to overcome concerns regarding small expected frequencies, no significant difference was found either when considering all habitats (χ^2_4=2.39, P>0.6) or those with unimpaired visibility (χ^2_2=1.39, P>0.4).

Specific buzzard activities and season

During the period prior to the nesting season 152 buzzard observations were made. Of these, 27.0% involved perched birds, 17.1% involved buzzards actively hunting, 52.0% involved buzzards seen in non-hunting aerial activity and 3.9% involved birds seen pursuing other or undetermined activities. During the nesting period 47 buzzard observations were made. Of these, 12.8% involved perched birds, 25.5% involved birds engaged in active hunting, 61.7% involved birds engaged in non-hunting aerial activity. No significant difference was found between the distribution of activity categories amongst habitats between the two periods (χ^2_2=4.88, P>0.075) (excludes undetermined activities).

The distribution of specific buzzard activity, in relation to habitat, prior to the nesting season

The null hypothesis tested in each case was that; prior to the nesting season, buzzards were observed engaged in the activity in question, in all habitats, in the same proportions as overall activity. Three analyses were possible, that is observations involving perched birds, observations involving hunting birds and observations involving birds engaged in non-hunting aerial activity.

1/ OBSERVATIONS INVOLVING PERCHED BUZZARDS.

When considering perched birds and all habitats a significant difference was found between observed frequencies and those expected under the null hypothesis (χ^2_8=19.37, P<0.025, E<5=78%). Examination of the 95% family of confidence intervals indicated that buzzards were observed less in broad-leaved woodland than expected under the null hypothesis. When combined habitats were considered, in order to overcome concerns regarding small expected frequencies, again, a significant difference was found (χ^2_4=13.09, P<0.025). Examination of the 95% family of confidence intervals indicated that buzzards were observed less in woodland than expected under the null hypothesis. When habitats with impaired visibility were excluded, no significant differences were found either when considering, all habitats (χ^2_4=6.41, P>0.15, E<5=60%), or combined habitats (χ^2_2=3.43, P>0.15). However, in both cases, examination of the 95% family of confidence intervals, indicated that buzzards were observed less in agricultural grassland than expected under the null hypothesis.

2/ OBSERVATIONS INVOLVING HUNTING BUZZARDS

Analysis of buzzard hunting activity was only possible after habitat categories had been combined and then only when considering all habitats. No significant difference was found between observed frequencies and those expected under the null hypothesis (χ^2_4=2.98, P>0.2).

3/ OBSERVATIONS INVOLVING NON-HUNTING BUZZARDS.

When considering non-hunting aerial activity, for all habitats, no significant difference was found between observed frequencies and those expected under the null hypothesis (χ^2_8=10.12, P>0.2). When habitats with impaired visibility were excluded, again, no significant difference was found (χ^2_8=1.29, P>0.7).

The distribution of specific buzzard activity, in relation to habitat, during the nesting season

The null hypothesis tested in each case was that; during the nesting season, buzzards were observed engaged in the activity in question, in all habitats, in the same proportions as overall activity.

Criteria for analysis were only met for observations of buzzards engaged in non-hunting aerial activity and then only after habitat categories were combined. When considering all habitats, no significant difference was found between observed frequencies and frequencies expected under the null hypothesis (χ^2_4=1.28, P>0.85, E<5=44%). When habitats with impaired visibility were excluded, again, no significant difference was found (χ^2_8=1.04, P>0.5).

DISCUSSION

Both foot survey and vehicle survey data indicate positive selection for upland perennial grassland and negative selection for heath and bog. In the case of foot survey this was true of both the period prior to nesting and the nesting period. This was only apparent from vehicle survey during the period prior to nesting; however vehicle observations of buzzards during the nesting period were comparatively few. It is, therefore, reasonable to suggest that no shift in habitat utilisation was found between seasons. For the pre-nesting period, analysis of vehicle observation data suggests that, in addition, agricultural grassland was selected against whilst broad-leaved woodland was positively selected. No such preferences were apparent from the foot observation data. Dealing first with the lower than expected utilisation of agricultural grassland during the pre-nesting period it should be noted that this habitat is very much confined to the flat floors of the glens. Roads too follow the glen floors leading to a higher observer effort in agricultural grassland from vehicle counts as compared to foot surveys. It may well be that a higher observer effort in this habitat, coupled with an overall larger sample size for the pre-nesting season road survey as compared to the foot survey facilitated the detection of this habitat preference. Much the same may be argued for the positive selection of broad-leaved woodland identified during the same period.

Two potential problems, which would affect the interpretation of these results, must be considered. Both of these concern the possibility of differential observer detection rates of birds between habitats. The first problem relates to restricted visibility in certain habitats and the second relates to disproportionate detection of buzzards engaged in different activities. Clearly, visibility in mature forestry and woodland may be lower than in the more open habitats. If birds were under recorded in, for example, woodland, then any analysis suggesting buzzards were showing negatively selection for woodland would need to be viewed with caution. Visibility bias is likely to be a less serious problem when conducting foot surveys as compared to vehicle surveys as observers move much slower, are less likely to be distracted and may locate birds by hearing their own calls or the alarm calls and behaviour of other species. In the results presented above, buzzards appear to show positive selection for broad-leaved woodland and so such a bias would not have favoured the conclusion. Such bias, however, may have favoured conclusions regarding positive selection of open habitats. This does not seem to have been the case. Whenever open habitats were considered, independently of those with impaired visibility, the outcome regarding conclusions about habitat preferences were not affected.

The second problem concerning the disproportionate detection of buzzards engaged in different activities would be important if buzzard activity or hunting technique were related to the habitat they were in. Clearly, a buzzard perched in a bush is less likely to be detected than one hovering low over the ground. Whilst many raptor studies have failed to detect such a shift in behaviour (e.g. Wakely 1978, Bechard 1982, Janes 1985) this has not always been the case (Lein & Webber 1979). There is some evidence from the foot survey data that buzzards engaged in non-hunting aerial activities less over forestry than would be predicted by their overall use of that habitat. This would be unlikely to bias the results regarding overall habitat use as the likelihood of detecting birds flying high over the ground was, presumably, little affected by vegetation cover. There was also evidence from the vehicle surveys suggesting buzzards engaged in perching activity less in agricultural grassland or broad-leaved woodland than would be predicted by their overall use of those habitats. If buzzards are perching less in these habitats, the bias would tend to favour birds being relatively over recorded there, as birds engaged in the aerial activity categories are less likely to be overlooked. This in turn would lead to the incorrect conclusion that overall these habitats were positively selected. In the case of the agricultural grasslands the reverse was found. Regarding broad-leaved woodland this may be the case although it is more likely that the comparatively low frequency of observations of perched buzzards is due to impaired visibility.

There is, therefore, generally a good agreement between the two survey methods, especially after taking into account inherent biases associated with each. Overall, buzzards in mid-Argyll appear to favour the upland perennial grasslands and broad-leaved woodland but avoid various categories of bog and agricultural grassland. Both surveys sampled buzzard distribution in relation to habitat across much of mid-Argyll, and two factors need to be considered in interpreting the results. The pattern seen will partly reflect buzzard distribution and partly reflect the use of habitat within home ranges. We may, however, expect that overall buzzard distribution will be closely linked to the availability of favoured habitats. Buzzards in the study area do not display the marked territoriality reported for some populations (e.g. Dare 1961, Weir & Picozzi 1983) and were seen foraging over apparently undefended ground, travelling some distance from their nest sites, this situation having also been reported in British buzzards elsewhere (e.g. Tubbs 1974). Consequently few areas within the study area are likely to have been out of reach of buzzards, and most birds would have at least some of each habitat type available to them. Buzzards in mid-Argyll are extremely adaptable in their choice of nest sites. Of the active nest sites found during 1989 and 1990 in the main study area just over 60% were in trees, conifers more so than broad-leaved, just under 40% on the banks of, or on crags within, gullies and several on sloping ground or open crags, with no obvious pattern relating choice of site and what was available (Chapter 5). It is, therefore, difficult to believe that buzzards could not find suitable nest sites in all but the most extensive flat, treeless moorland. Preferences for particular habitat types is therefore unlikely to be a result of their proximity to nesting areas. In fact, were this the case, selection for mature forestry and agricultural grassland might be expected, the first because it provides the most favoured type of nest site, the second because most buzzard nest sites tend to overlook the glen floors.

The habitat selection implied by this study can therefore be regarded as reflecting the buzzards foraging requirements. Buzzards spend most of their day foraging (Brown 1976) and this may involve actively seeking prey from the air or perhaps more often taking up position on a perch providing a suitable vantage point. The suitability of habitats for foraging will, to some extent, depend on prey abundance. For example, buzzards in Sweden select habitats with highest vole densities (Sylven 1978). If prey abundance accounted fully for habitat selection, however, the selection described above would be unexpected. A major prey item in the diet of British buzzards is the rabbit, and whilst the distribution of rabbits in mid-Argyll was found to be localised, they do appear as prey remains at the majority of buzzard nests. Rabbits are markedly more numerous in agricultural grassland of the glen floors than on the open hill ground (Brown & Watson 1964). The other major prey species, probably more important to buzzards in mid-Argyll as a prey base, is the short tailed field vole, for which the relative abundance in different habitats was not known but which again might be expected to be higher in agricultural grassland, particularly the older, neglected, fields and field boundaries. Thus highest prey abundance might well be expected in the agricultural grassland. However, there is considerable evidence that raptor habitat use is not related to prey abundance but to prey availability. For example studies on ferruginous hawk *Buteo regalis*, Swainson's hawk *Buteo swainsoni*, red-tailed hawk *Buteo jamaicensis* and tawny owl *Strix aluco* have shown that these species preferentially hunt over habitat with sparse vegetation cover, providing low prey densities and under utilise habitats with higher prey biomass but with vegetation cover providing shelter (Bechard 1982, Janes 1985, Southern & Lowe 1968, Wakeley 1978). Jorgensen (1986) found that wintering buzzards occurred in grass areas with low vegetation and states that although tall vegetation probably held a greater abundance of prey the hunting techniques of the common buzzard appeared less suited to such a habitat. Consequently measures of prey availability are more appropriate than measures of prey abundance in understanding raptor habitat selection. To determine prey availability would require that hunting success be compared between habitats. In this study so few buzzards were actually observed making successful kills that this could not be determined. Perennial grassland in mid-Argyll is very heavily grazed leading to a short swath and little in the way of shrubby growth, whilst bracken cover does not become important until late June. It therefore represents a habitat with greater visibility for hunting buzzards than the rougher margins of the agricultural grasslands and this may more than outweigh considerations of prey abundance. Unfortunately data were not available to test whether this might change after bracken growth became a dominant feature of many tracts of upland grassland from late June, although many open areas would be likely to remain available.

The habitat selection found on the present study shows a similar pattern to studies elsewhere. In north Wales, Dare (1989) found that the valley floor fields and the highest slopes were visited least by foraging buzzards and that pairs rarely claimed the bleak moorland. Their under utilisation of valley floor fields occurred despite territories containing a higher proportion of farmland than available as a whole over the landscape. In Speyside, Weir and Picozzi (1983) found that heather dominated moorland and some conifer forests where largely unoccupied while broad-leaved woodlands were favoured. They did, however, find that, during the winter, buzzards deserted much of the valley side habitat in favour of the valley floors. This apparent difference may be due to a greater availability of rabbits there compared with mid-Argyll.

Given that buzzards favour the perennial grasslands over both bog and agricultural grassland we can consider possible effects of land use change. The two principle land uses in mid-Argyll are sheep farming and forestry. Grazing by sheep does much to maintain the upland grassland preventing the establishment of dwarf shrubs. Land use practises that reduce the number of sheep on the hill may lead to a return to a more luxuriant vegetation, which whilst possibly making the habitat more suitable for other species, such as golden eagle which take larger prey, may reduce prey availability to buzzards. Any increase in the area under agricultural improvement would also be detrimental as this was found to be an unfavoured habitat. With regard to forestry, mature forestry does offer nest sites, perhaps in areas where previously they were sparse. However, other habitat will be lost to one which does not provide readily available prey, even although, in the early stages, there may be a large increase in prey species abundance. Much concern has been expressed over the loss of blanket bog to forestry (e.g. Thompson, Stroud & Pienkowski 1988), but buzzards are unlikely to be adversely affected by such a change. If, however, forestry replaced upland perennial grassland then any benefits to buzzards would almost certainly be outweighed by the loss of suitable foraging habitat.

The distribution of the buzzard in Britain has been well catalogued (Moore 1957, Sharrock 1976, Taylor, Hudson & Horne 1988) and it has been found that after population recovery during the first half of this century little further expansion has been recorded but rather a consolidation within its current range. It has been suggested that further expansion is hampered largely by continued persecution (Cadbury, Elliot & Harbard 1988). If, however, the habitat preferences described here are considered it is apparent that much of the former range of the buzzard, which included most of the British Isles prior to extensive persecution up to early this century, is no longer favourable or at best of marginal suitability. Even in the east of Scotland where it has been suggested that buzzards should occur the extensive heather dominated moorland is seen to be a less favoured habitat.

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CHAPTER 8: THE DISTRIBUTION OF BUZZARDS IN RELATION TO HABITAT

CONTENTS:

INTRODUCTION

A knowledge of the distribution of animal species is important for land management and conservation related applications (Aspinall & Veitch 1991). Such data are often not available for certain species or in particular regions, for example much of upland Britain (Haworth & Thompson 1990). In situations such as the British uplands, or in other remote regions, the collection of such baseline data as the distribution of animal species may not be feasible given limitations of resources, time scales required, and practical difficulties associated with the need to survey vast areas for sparsely distributed species. These data are however essential, providing baseline reference from which to monitor changes in animal populations and for assessing the likely impact of foreseen habitat changes. Consequently ways other than direct observational mapping of distributions have become important in providing this basic framework on which to build subsequent work.

The principal approach to predicting animal distributions is to look at the distribution of suitable habitat for the species in question, which has previously been identified as such by studies of ecological relationships between the species and its environment (e.g. Dubuc, Krohn & Owen 1990, Haworth & Thompson 1990, Lawton & Wooddroffe 1991). Increasingly, remote sensing and GIS are being used for such studies to increase the data handling capacity and hence the size and complexity of the information which can be incorporated. In many regions of the world remote sensing may be the only practical solution to monitoring habitat. Thus a number of studies have successfully used classifications of land cover based on satellite imagery to map the distribution of habitat suitable for animal species (e.g. Laperriere, Lent, Gassaway & Nodler 1980, Lyon 1983, Huber & Casler 1990, Avery & Haines-Young 1990). In some cases GIS have been used to manipulate these data (e.g. Palmeirim 1988, Haines-Young, Ward & Avery 1990, Shaw & Atkinson 1990). Other studies have extended the models which predict animal distribution based on habitat suitability to include climatic and topographical data, with or without land cover data, and incorporated these various habitat data as layers in a GIS (e.g. Walker & Moore 1988, Walker 1990, Aspinall & Veitch 1990, Pereira & Itami 1991, Breininger, Provancha & Smith 1991).

Two approaches to producing distribution maps of animal species, based on suitable habitat, are of interest when using GIS modelling. In the first method, deductive modelling, the GIS is used to identify where specific habitat requirements of a species are spatially concurrent (Walker & Moore 1988, Aspinall & Veitch 1991). This approach requires input of both habitat data and a prior knowledge of the habitat requirements of the species being considered. Thus, for example, areas of land could be identified that fall between certain altitudinal boundaries, were covered with a particular vegetation type and had a certain maximum rainfall, if each of these was known to individually be a prerequisite for occupation by a particular species. A number of GIS oriented studies have employed this type of approach (e.g. Scepan, Davis & Blum 1987, Stenback, Travlos, Barrett & Congalton 1987, Agee, Stitt & Nyquist 1989, Breininger, Provancha & Smith 1991). This approach may be considered somewhat limited as it takes a simple view of how species interact with their environment, not allowing for interactions between habitat features. It is, however, useful as an initial sieve to filter out areas of land clearly unsuitable to a species. The second approach, inductive modelling, does not depend on prior knowledge of the relationships between a species and its environment but seeks to establish statistical relationships between distribution of the animal species and the distribution of habitat variables and use these to derive probabilities of occurrence of the species for discrete units of interest, generally based on a grid cell pattern. Several recent GIS oriented studies have used an inductive approach to model animal distributions. A number of different statistical procedures have been employed in developing these models. These include procedures based on the generalised linear model using logistic regression (Walker & Moore 1988, Walker 1990, Pereira & Itami 1991) and procedures based on Baye's Theorem (Aspinall 1990, Aspinall & Veitch 1991, Pereira & Itami 1991). A number of studies have predicted animal distributions by developing discriminant function models, based on measurement of habitat variables, which are then used to assign discrete units of land as either suitable or unsuitable for occupancy. Haworth and Thompson (1990) used this method to assign occupancy to 500m. x 500m. grid cells when predicting bird distributions in the English Pennines, while Dubuc *et al* (1990) used watersheds as the predictive unit when predicting river otter occurrence in Maine. Neither of these two studies used GIS for manipulating data, although both incorporated a complex set of habitat measurements. Correspondence analysis has also been used to establish patterns relating species distributions to environmental features (Hill 1991). Of the two approaches based on the generalised linear model, logistic regression has been suggested as more appropriate to considerations of ecological data both on statistical grounds (Press & Wilson 1978) and for reasons related to the general nature of ecological relationships (Osbourn & Tigar 1992) than is discriminant function analysis.

In this chapter I describe the development of models to predict buzzard distribution in mid-Argyll, using habitat data derived from the GIS described in Chapter 6. Both logistic regression and discriminant function analysis were used to develop models and the relative merits of the resulting models are discussed.

METHODS

BIRD DATA

Bird data used in this chapter consisted of distribution maps of buzzard home ranges. During the study period, buzzards in mid-Argyll were not noted as defending fixed territory boundaries and so the distribution of perceived foci of buzzard activity were regarded as the centres of home ranges. During February to June of 1989, the distribution of the centres of all buzzard home ranges in the south-Lorn study area were established and mapped. These were identified as areas where buzzards were repeatedly observed and which contained nests from previous years breeding attempts. When nests in which a current breeding attempt was occurring were located these were taken to be the centre of a home range without further qualification. Repeated coverage of this area during May of 1990 failed to identify any further home ranges which might have been overlooked during the previous year. Within the south-Lorn study area, an area of 43 km^2 received sufficiently thorough coverage to establish the distribution of all home ranges. A similar approach was used to map buzzard home ranges in the north-Lorn study area where 140km^2 received thorough coverage. In this area knowledge of buzzard distribution was still incomplete after the end of the 1989 field season. Further work during March to June of 1990 was necessary before coverage was considered to have been total.

A similar approach was used in the Glen Lochy study area but coverage was insufficiently complete to be certain that no home ranges had been overlooked. Data of this kind was also available for the south-east Mull study area where it was collected during 1987 by Mr M. Madders (RSPB) and was believed to be reasonably complete. The model development undertaken here uses data mainly derived from the south-Lorn and north-Lorn study areas.

A grid of points was superimposed on maps of these two study regions. Grid points were spaced at 500m apart and represented the centre of a (500m)^2 grid cell aligned to the British National Grid. Each grid point was then classified, based upon whether or not the grid cell within which it lay approximated to the centre of a buzzard home range. In some cases a single area of buzzard activity spanned several grid points. In such cases more than one point would be classified as being at the centre of that home range. The grid spacing was chosen as a compromise between the need to keep grid cells small, and so maximise vegetation and topographical differences between them, and the need to keep grid cells large enough so that they could be identified with reasonable confidence on the ground.

HABITAT DATA

Habitat data were derived from the GIS using the automated data extraction described in Chapter 6. Habitat data associated with each grid point were measured at radii of 500m., 1000m. and 1500m. for each habitat feature.

Vegetation cover data were extracted to give the total area of each vegetation category to be found within each radius. Areas of vegetation cover in the unclassified category were apportioned proportionally between all categories actually represented within the radius being considered for a particular nest site. While the difference between some vegetation cover types is readily apparent, and distinct boundaries can be identified, boundaries between other vegetation types should be viewed more as an artefact of the mapping process rather than real landscape features. Consequently, in addition to the basic categories, several new categories, formed by collapsing vegetation cover divisions, between which a gradual change rather than distinct boundaries occur, were also included. Pre-thicket conifer plantation and post-thicket conifer plantation were combined to give a single conifer plantation category. Broadleaf woodland was combined with mixed woodland to give a single woodland category. Blanket bog, wet heath and heather moorland were combined to give a single heathland category.

The total length of each vegetation boundary type was also measured. With nine categories of land cover plus sea and fresh water boundaries there were many potential boundary combinations. In order to reduce this to a reasonable number, particular boundary types, thought to be appropriate to buzzard biology, were chosen for further consideration using biological rather than statistical criteria. The total length of habitat boundary was measured to provide an index of habitat heterogeneity because the more patches of distinct vegetation type that are present the higher will be the total boundary length. This was done both for boundaries between the original categories and boundaries between the collapsed categories. The total length of mature conifer plantation edge with all other habitats was measured as a component of forest fragmentation. The pattern of afforestation has previously been cited as potentially important in explaining local responses of buzzards to land use change (Mearns 1983). For similar reasons the boundary length between tree dominated vegetation (pre-thicket and post-thicket conifer plantation, broadleaf and mixed woodland) and open vegetation cover (grasslands and heath) was extracted. The boundary length between pre-thicket conifer plantation and open vegetation cover was included as a zone where high prey concentrations might be expected to occur. Pre-thicket conifer plantation is known to hold high concentrations of certain prey species but these are probably largely unavailable to buzzards. The zone of over spill of this prey into vegetation suitable for hunting may, therefore, be important. In Chapter 7, perennial grassland was identified as a favoured habitat, while buzzards clearly benefit from tree dominated vegetation which can provide nest sites and perhaps shelter. The boundary between these two vegetation types would therefore seem to provide an ideal combination and therefore the length of this boundary for each radius around each point of interest was also extracted.

Altitude data were extracted to give the area of land, falling into each of a number of altitude bands, found within each radius for each point of interest. During initial data extraction altitude bands of 50m. were specified (0m., 1m.-50m., 51m.-100m., ...). With altitudes in the study area of up to 1150m and each altitude band constituting a different variable, some collapsing of categories was desirable. Many of the higher altitude categories were rare for most points of interest leading to skewed distributions. Initial examination of these data lead to these categories being collapsed into the three broader categories of low (0m.-100m.), medium (101m.-200m.) and high (>201m.) altitude. This helped alleviate both these potential problems in the subsequent analysis. Median altitude, modal altitude, altitude range, minimum altitude and maximum altitude were also calculated for each radius for each point of interest. It was thought possible that these may have proved more useful than the actual areas within each altitude band in describing effects of altitude on buzzard distribution.

Slope data were extracted to give the area of land, falling into each of a number of slope categories, found within each radius for each point of interest. During initial data extraction slope categories with increments of 5° were specified (0°, 1°-5°, 6°-10°, ...). No land with slope greater than 50° was reported during data extraction. As for altitude, and for similar reasons, the initial slope categories were collapsed into three broader categories of low slope (0°-5°), medium slope (6°-15°) and high slope (16°-50°). Summary statistics of median slope, modal slope, slope range, minimum slope and maximum slope were also calculated for each radius for each point of interest.

Land ruggedness data were extracted to give the area of land, falling into each of a number of ruggedness categories, found within each radius for each point of interest. This is measured as altitudinal difference between an area of land and that surrounding it (see Chapter 6 for full explanation). During initial data extraction ruggedness categories with increments of 5m. were specified (0m., 1m.-5m., 5m.-10m.,...). No land with ruggedness greater than 45m. was reported. The initial ruggedness categories were collapsed into three broader categories of low ruggedness (0m.-5m.), medium ruggedness (6m.-15m.) and high ruggedness (16m.-45m.). Summary statistics of median ruggedness, modal ruggedness, range in ruggedness, minimum ruggedness and maximum ruggedness were also calculated for each radius for each point of interest.

Land aspect data were extracted to give the area of land, falling into each of a number of aspect categories, found within each radius for each point of interest. During initial data extraction aspect categories with increments of 45° were specified (clockwise from north 0°, 1°-45°, 46°-90°,...,316°-360°). These were then combined to give the area of land facing each of four directions, that is between north-west & north-east, north-east & south-east, south-east & south-west and south-west & north-west, plus land reported as having no overall aspect. Modal aspect was also calculated.

Measurements related to potential human disturbance such as length of roads and number of houses within a radius of the point of interest were also included. For each point of interest the total length of major roads (Ordnance Survey class A & class B) and the total length of minor roads (all other metalled vehicle tracks) was obtained for each radius. The total number of houses within each radius of each point of interest was also obtained.

This gave a total of fifty five measurements of habitat, each made at the three different radii, and so constituting one hundred and sixty five habitat variables from which those used in the development of predictive models would be chosen.

ANALYSIS

The aim of the analysis described in this chapter was to develop models, based on habitat, which might be used to predict the probability that points in the grid described above were at the centre of a buzzard home range. Such a model would then be available to map predictions of buzzard distribution in other parts of Argyll or after modelled changes in land cover within the same area. Using the north-Lorn study area, grid points classified as at the centre of a buzzard home range were compared with a random sample taken from those grid points identified as not being at the centre of a buzzard home range.

Statistical analyses were performed using the SPSS PC+ v.4.01 statistics package (Norušis/SPSS Inc. 1990). Habitat variables extracted from the GIS were examined using box plots, normal probability curves and detrended normal curves, produced using BOXPLOTS and NPPLOTS from the SPSS PC+ EXAMINE procedure. Normal probability plots and detrended normal plots were used to identify those variables for which an appropriate data transformation was desirable in order to satisfy assumptions of univariate normality. Box plots were used to identify outlying cases for each variable and to select variables that appeared to show differences in measurements of central tendencies of the distributions between the two groups. Each variable so identified for further consideration was then compared across the two groups using Student's t-tests or, where distribution of the variable was not normal and could not be normalised by a suitable transformation, Mann-Whitney U-tests (SPSS PC+ T-TEST and NPAR TESTS M-W respectively), after first removing cases identified as outliers by BOXPLOTS. Variables which differed between groups with a level of significance of α=0.05 were chosen for further consideration. The correlation matrix between these remaining variables was used in order to identify sets of independent variables which were highly correlated and, from within each set, select one for inclusion in the subsequent analysis. The variables selected were chosen for probability of significance between groups, to minimise correlation with other variables to be included in the model and for the ease with which they could be interpreted as features of the landscape. By way of validation the models derived from the north-Lorn study area were then used to classify grid points in the south-Lorn study area. Probability scores were used to produce a map representing likelihood of each grid cell being at the centre of a buzzard home range. This was then compared with known buzzard distribution determined during fieldwork.

RESULTS

A total of 46 grid points in the north-Lorn study area were identified as being at the centre of buzzard home ranges out of a total of 562 grid points. Consideration of nest site locations, which for the purposes of this analysis can be regarded as lying at the heart of a buzzard home range had shown that these were invariably associated with features that could be distinguished on Ordnance Survey 1:25000 scale Pathfinder maps. Thus out of seventy three nest sites occupied during 1989 and 1990 only one occurred in a grid cell which did not have a gully, cliff or woodland indicated on the Ordnance Survey Pathfinder map. Of the grid points not identified as lying at the centre of a buzzard home range 64 were therefore identified as unsuitable for buzzards on the grounds of absence of suitable nest sites. These were eliminated a priori from further statistical consideration, so as to avoid producing what would probably be reasonably robust models but ones which would discriminate only between obvious groups. Following recommendations from Tabachnick & Fidell (1989) regarding ratio of cases between groups for discriminant analysis 50 random points were chosen from the remaining 452 grid points.

Assumptions and sample size requirements necessary for valid application of discriminant function analysis are generally more restrictive that those to be met for logistic regression and, when these are met by a data set, logistic regression still performs well and is still an appropriate approach (Norušis/SPSS Inc. 1990). Consequently, subsequent treatment of variables prior to the modelling procedure aimed to meet the limitations imposed by discriminant function analysis.

Univariate comparisons of variables for which examination of the box plots suggested differences in the central tendencies of distribution between the two groups, identified 52 variables that showed significant differences between groups. The level of significance used was $\alpha=0.05$. In order to further reduce the number of variables, only one variable was retained where the same habitat measurement was represented at several radii by different variables. In each case the variable retained was chosen, in order of importance, by virtue of which showed least skew in distribution, which differed between groups at the smallest level of significance and which showed least outliers. This resulted in a reduced set of 20 variables, their definitions and univariate probability of significant difference between groups are given in Table 8.1.

Variable	Description	Univariate comparisons	Statistics (n=96)
AL_500_L	Area of land within 500m. radius of grid point that falls into the category of "low" altitude	H > R	U=797.0 P=0.0087
AL1500_M*	Area of land within 1500m. radius of grid point that falls into the category of "medium" altitude	H< R	t=-2.47 P=0.015
AL_500_H	Area of land within 500m. radius of grid point that falls into the category of "high" altitude	H < R	t=2.97 P=0.004
AL_500MI	Minimum altitude found within 500m. radius of grid point	H < R	U=752.0 P=0.0022
AL_500MA	Maximum altitude found within 500m. radius of grid point	H < R	t=2.59 P=0.011
AL_500MO	Modal altitude found within 500m. radius of grid point	H < R	t=3.20 P=0.002
AL_500ME*	Median altitude found within 500m. radius of grid point	H < R	t=3.23 P=0.002
SL1000_M	Area of land within 1000m. radius of grid point that falls into the category of "medium" slope	H < R	t=2.21 P=0.030
SL_500RA*	Range in slope categories found within 1000m. radius of grid point	H > R	t=-3.30 P=0.001
RU_500_L*	Area of land within 500m. radius of grid point that falls into the category of "low" land ruggedness	H < R	t=2.91 P=0.005
CAL_1000	Area of land within 1000m. radius of grid point for which vegetation cover type is heather moorland	H < R	t=3.22 P=0.002
PERE1500*	Area of land within 1500m. radius of grid point for which vegetation cover type is perennial grassland	H > R	t=-2.83 P=0.006
DEC__500	Area of land within 500m. radius of grid point for which vegetation cover type is deciduous woodland	H > R	U=716.0 P=0.0008
HEAT_500*	Area of land within 500m. radius of grid point for which vegetation cover type is either wet heath, blanket bog or heather moorland	H < R	t=2.79 P=0.006
TOTB1500	Length of borders between all land cover categories to be found within 1500m. radius of grid point	H < R	t=3.18 P=0.002
LUMP1500*	Length of borders between collapsed land cover categories to be found within 1500m. radius of grid point	H > R	t=-3.61 P<0.001
TREB_500	Length of conifer plantation and woodland edge to be found within 500m. radius of grid point	H < R	t=12.30 P<0.001
MATB1500	Length of mature forest edge to be found within 1500m. radius of grid point	H < R	U=343.5 P<0.0001
PROP_500*	Length of border between pre-thicket conifer plantation and open grassland to be found within 500m. radius of grid point	H > R	U=0.0 P<0.0001
PETR1500	Length of border between conifer plantation or woodland and upland perennial grassland to be found within 1500m. radius of grid point	H < R	t=4.58 P<0.001

Table 8.1: Landscape features, extracted from the GIS, which were considered for inclusion in the development of statistical models, to predict group membership, defined by whether or not a grid point lay within the perceived centre of a buzzard home range.

These are designated GROUP = H and GROUP = R respectively. Test statistics and probabilities are those obtained when central tendencies of each variable were compared univariately between groups. Test statistics and significance are based on all cases with no action to remove outliers.

* indicates habitat variables finally entered into the discriminant function analysis.

Given a sample size of about ninety cases, the precise number depending on how many were lost to outliers, this in turn being governed by which variables were included, ideally somewhere between five and ten variables would be considered an acceptable target for inclusion in the discriminant function analysis (Tabachnick & Fidell 1989, Norušis/SPSS Inc. 1990).

Consideration of the correlation matrix between the remaining twenty variables (Table 8.2) enabled this number to be reduced to eight. The variable AL1500_M showed no strong correlations with the other variables and so was retained. The other six altitude based measurements were all highly correlated. From these AL_500ME was retained as within the altitude based variables it differed between groups at the smallest level of significance during the univariate comparisons. Also it was not highly correlated with many other non altitude variables under consideration. The two slope based variables showed no strong correlation between themselves although SL1000_M was strongly correlated with AL_500ME. Accordingly only SL_500RA was retained. The land ruggedness based variable RU_500_L showed no strong correlations between any other variables under consideration and was therefore retained. The ecotone based measurements, TOTB1500, LUMP1500 and TREB_500 showed strong correlations between themselves. From this group LUMP1500 was retained as it was more strongly correlated with the other two than they were to each other and so would be expected to explain much of the variance in the dependent variable that would have been explained by the others. The variables HEAT_500 and CAL__500 were, not surprisingly, highly correlated, the area of heather moorland contributing to the total area of heathland. While HEAT_500 only differed between groups at a slightly higher level of significance than CAL__500 in the univariate comparisons, it was retained in favour of CAL__500, the inclusion of which would have resulted in the loss of an unacceptable number of cases as outliers. The variable DEC__500 was rejected as its inclusion would have resulted in the loss of an unacceptable number of cases as outliers. The variables PERE1500 and PROP_500 showed no significant correlations with other variables under consideration and so were both retained. The variables MATB1500, PETR1500 were rejected due to their strong correlations with other variables already retained and because they differed between groups only at higher values for level of significance in the univariate comparisons. The remaining eight variables were used in the further development of the models. Of these all exhibited reasonably normal distributions, with the exception of PROP_500.

VARIABLE	AL_500_L	AL1500_M	AL1500_H	AL_500MI	AL_500MA	AL_500MO	AL_500ME	SL1000_M	SL_500RA	RU_500_L	CAL_1000	PERE1500	DEC__500	HEAT_500	TOTB1500	LUMP1500	REB__500	MATB1500	PROP_500
AL1500_M	-0.16590	1.00000																	
AL1500_H	-0.78903	-0.25840	1.00000																
AL_500MI	-0.66272	-0.35232	0.76374	1.00000															
AL_500MA	-0.80188	-0.17733	0.83258	0.82665	1.00000														
AL_500MO	-0.81563	-0.22495	0.79352	0.80301	0.86668	1.00000													
AL_500ME	-0.82492	-0.22678	0.83666	0.87877	0.91876	0.95281	1.00000												
SL1000_M	-0.70076	0.28184	0.53104	0.54512	0.55126	0.57616	0.60425	1.00000											
SL_500RA	-0.40836	0.19035	0.46242	0.17469	0.44202	0.28290	0.32929	0.22044	1.00000										
RU_500_L	-0.02447	-0.04019	0.02002	0.05285	0.01536	-0.03713	0.00646	-0.00729	-0.09431	1.00000									
CAL_1000	-0.45706	-0.23407	0.49335	0.59594	0.47885	0.50958	0.52947	0.54883	0.01330	0.00794	1.00000								
PERE1500	-0.21638	0.04134	0.20534	-0.03481	0.16215	0.12516	0.11980	-0.08085	0.19849	-0.05436	-0.33594	1.00000							
DEC__500	0.44141	0.07107	-0.42536	-0.31134	-0.38153	-0.37491	-0.37334	-0.21369	-0.13780	-0.16876	-0.21025	-0.22575	1.00000						
HEAT_500	-0.33171	-0.28325	0.36488	0.53555	0.39469	0.43128	0.46032	0.31713	-0.16553	0.07667	0.75614	-0.20255	-0.22795	1.00000					
TOTB1500	-0.28540	0.12160	0.18110	0.21215	0.20383	0.16261	0.19695	0.16164	-0.13904	-0.00707	0.22742	0.11168	-0.05818	0.35794	1.00000				
LUMP1500	0.03827	0.16449	-0.09502	-0.19743	-0.10476	-0.15776	-0.14256	-0.22639	-0.10191	-0.03088	-0.42690	0.52569	-0.00387	-0.20052	0.65321	1.00000			
REB__500	0.19999	-0.08033	-0.16482	-0.10866	-0.09494	-0.11762	-0.10156	-0.32911	-0.17034	-0.08212	-0.29260	0.21318	0.32683	-0.15047	0.32712	0.52238	1.00000		
MATB1500	-0.33072	-0.13152	0.47431	0.39317	0.37293	0.35689	0.36509	0.36657	0.25167	0.09329	0.54281	-0.28076	-0.24032	0.26310	0.12154	-0.21911	-0.19074	1.00000	
PROP_500	-0.06909	-0.08663	0.19920	0.06324	0.06361	0.06981	0.07302	-0.00636	0.24567	0.02653	-0.11661	0.00473	-0.16481	-0.26939	-0.08662	0.10086	0.07293	0.33365	1.00000
PETR1500	0.62012	0.14108	-0.70599	-0.69318	-0.70608	-0.65843	-0.69964	-0.53953	-0.38406	-0.02476	-0.54268	0.04495	0.23618	-0.44642	-0.14538	0.34079	0.27998	-0.44583	-0.04642

Table 8.2: Correlation matrix between the twenty variables referred to in Table 8.1

DISCRIMINANT FUNCTION ANALYSIS MODEL

The eight habitat variables retained were entered into a discriminant function analysis which was performed using SPSS PC+ DSCRIMINANT . A stepwise data entry procedure was specified with inclusion and elimination criterion based on maximising minimum Mahalanobis' distance between groups. After removal of outliers, 93 cases were processed, of which 46 were in the grid points at the centre of buzzard home ranges group and 47 were in the grid points outside of centre of buzzard home ranges group. Outliers were characterised by very high values for RU_500_L, that is they were uncharacteristically flat land. Seven variables were retained by the analysis. These were AL_500ME, SL_500RA, RU_500_L, PERE1500, HEAT_500, LUMP1500 and PROP_500. The unstandardised canonical discriminant function coefficients are given in Table 8.3.

With specification of prior probabilities for each group according to their proportions in the sample this discriminant function was used to reclassify grid cells in the sample (standard SPSS PC+ output). This resulted in the correct classification of 84.95% of cases, with reasonably equal performance on both groups (see Table 8.4a). This reclassification procedure is inherently overly optimistic concerning the misclassification rate, as a model usually fits the sample from which it is derived better than it will fit another sample from the same population (Norušis/SPSS 1990). In fact this approach tests the process which is used to build the model rather than the strength of the model itself (Aspinall & Veitch 1991). When the model was tested more rigorously, by using it to classify a second sample from the south-Lorn study area, it still performed well, correctly predicting 74.51% of cases correctly. More importantly it performed especially well in predicting grid cells located at the centre of a buzzard home range , with all twenty one cases correctly classified (see Table 8.4b).

Variable	Unstandardised Canonical Discriminant function Coefficients
AL_500ME	-0.00830274
SL_500RA	0.06222220
RU_500_L	-0.00126321
PERE1500	0.00374081
HEAT_500	-0.02163131
LUMP1500	0.00002157
PROP_500	0.00083703
constant	-3.42634100

Table 8.3: Unstandardised canonical discriminant function coefficients describing the discriminant function, based on habitat, derived to separate groups of grid points defined by whether or not they lay at the centre of a buzzard home range. This model is based on data from the north-Lorn study area.

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	47	42 (89.4%)	5 (10.6%)
Grid Points Lying at the Centre of a Buzzard Home Range	46	9 (19.6%)	37 (80.4%)

Table 8.4a: Reclassification results produced when the discriminant function model from Table 8.3 is used to allocate grid points into groups defined by whether or not the are situated at the centre of a buzzard home range. The discriminant function correctly reclassified 84.95% of the overall sample.

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	30	17 (56.7%)	13 (43.3%)
Grid Points Lying at the Centre of a Buzzard Home Range	21	0 (0.0%)	21 (100.0%)

Table 8.4b: Classification results produced when the discriminant function model from Table 8.2, obtained for the north-Lorn study area was used to classify a sample of grid points from the south-Lorn study area.
The discriminant function correctly classified 74.51% of the overall sample.

Given that the discriminant function derived from north-Lorn performed well when applied to a sample of grid points from south-Lorn, data were extracted, for just the variables used in the discriminant function in Table 8.4, for all grid points in south-Lorn (172 points). No prior probabilities were specified for the classification as for each case the relative probability of each grid cell being assigned as being at the centre of a buzzard home range was required and not the actual group to which it was assigned. Each grid cell within the study area was assigned a class value of 1 to 6 representing increasing probability that they contained the centre of a buzzard home range. Of these 172 points, 33 were assigned probabilities of zero (class 1), using the initial Ordnance Survey Pathfinder map based filter on the grounds that they were very unlikely to contain potential nest sites. Class intervals were chosen to best represent the distribution of probabilities. These data were incorporated into the GIS and used to produce a raster map depicting the probability of each grid cell being at the centre of a buzzard home range. In Figure 8.1 actual home range centres are shown overlaid on this map in order to facilitate comparison.

As the discriminant function was seen to perform well when tested using the validation techniques just described, the two samples were combined together and used to derive a new discriminant function. Also included were cases from south-west Mull and Glen Lochy, however, cases from these two samples only refer to grid points which were identified as lying at the centre of buzzard home ranges. The same stepwise discriminant function procedure was specified. The same seven variables were retained and were seen to enter into the analysis in the same sequence as before. The unstandardised canonical discriminant function coefficients obtained are given in Table 8.5.

Variable	Unstandardised Canonical Discriminant function Coefficients
AL_500ME	-0.00855146
SL_500RA	0.06754444
RU_500_L	-0.00169240
PERE1500	-0.00069064
HEAT_500	-0.03234962
LUMP1500	-0.00001454
PROP_500	0.00109993
constant	-0.36622390

Table 8.5: Unstandardised canonical discriminant function coefficients describing the discriminant function model, based on habitat, derived to separate groups of grid points defined by whether or not they lay at the centre of a buzzard home range.
This model includes data from the north-Lorn, south-Lorn, Glen Lochy and Mull study regions.

With specification of prior probabilities for each group according to their proportions in the sample this discriminant function was used to reclassify grid cells in the sample. This resulted in the correct classification of 83.64% of cases, with reasonable performance on both groups (see Table 8.6a). When this discriminant function was tested more rigorously using a jackknife procedure it correctly classified 80.00% of cases overall, again with equally good performance on both groups (Table 8.6b).

Given that the discriminant function derived from data obtained for several study areas performed well when the jackknife procedure was used to test its discriminatory power, it was applied, in the same way as the previous model to assign probability class to all 172 grid cells in the south-Lorn study area. Figure 8.2 shows the overlay of this distribution model with actual home range centres.

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	77	65 (84.4%)	12 (15.6%)
Grid Points Lying at the Centre of a Buzzard Home Range	88	15 (17.0%)	73 (83.0%)

Table 8.6a: Reclassification results produced when the discriminant model from Table 8.5, is used to allocate grid points to groups defined by whether or not they are located at the centre of a buzzard home range.
The discriminant function correctly reclassified 83.64% of the overall sample.

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	77	62 (80.5%)	15 (19.5%)
Grid Points Lying at the Centre of a Buzzard Home Range	88	18 (20.5%)	70 (79.5%)

Table 8.6b: Classification results produced when the discriminant model from Table 8.5, is used to allocate grid points to groups defined by whether or not they are located at the centre of a buzzard home range using a Jackknife procedure.
The discriminant function correctly reclassified 80.0% of the overall sample.

LOGISTIC REGRESSION MODEL

The same subset of eight habitat variables used to derive the discriminant function model was considered in the development of a Logistic regression model. The analysis was performed using the SPSS PC+ LOGISTIC REGRESSION procedure. As had been done for the discriminant function models the north-Lorn study area was used to build the model and this was then tested using the south-Lorn study area for validation. Backwards elimination of variables, using the likelihood ratio test to select variables for removal was specified. No outliers were identified after examination of residuals. Four variables were retained by the analysis. Those variables retained were AL_500ME, LUMP1500, HEAT_500 and PROP_500. The model was highly significant (P>0.999) indicating a very good fit to the data. The regression coefficients are given in Table 8.7.

Variable	Regression Coefficients
AL_500ME	-0.01130000
LUMP1500	0.00000083
HEAT_500	-0.08740000
PROP_500	0.03800000
constant	-9.97770000

Table 8.7: Regression coefficients describing the logistic regression model, based on habitat, derived to separate groups of grid points defined by whether or not they lay at the centre of a buzzard home range.
This model is based on data from the north-Lorn study area.

When this model was used to reclassify the sample from the north-Lorn study area it correctly reclassified 96.88% overall. Only three grid cells identified as being at the centre of a buzzard home range were misclassified while all other grid cells were correctly classified (Table 8.8a). When the model was tested by using it to classify a second sample of grid points from the south-Lorn study area it still performed well, correctly predicting the presence or absence of the centre of a buzzard home range in grid cells in 82.35% of cases (Table 8.8b).

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	50	50 (100.0%)	0 (0.0%)
Grid Points Lying at the Centre of a Buzzard Home Range	46	3 (6.5%)	43 (93.48%)

Table 8.8a: Reclassification results produced when the logistic regression model from Table 8.7 is used to allocate grid points to groups defined by whether or not they are located at the centre of a buzzard home range.
The logistic function correctly reclassified 96.88% of the overall sample.

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	30	26 (86.7%)	4 (13.3%)
Grid Points Lying at the Centre of a Buzzard Home Range	21	5 (23.81%)	16 (76.19%)

Table 8.8b: Classification results produced when the logistic regression model from Table 8.7, is used to allocate grid points from a different area to groups defined by whether or not they are located at the centre of a buzzard home range.
The model, based on data from the north-Lorn study area was used to classify grid points from the south-Lorn study area. The logistic function correctly classified 82.35% of the overall sample.

As the logistic regression model was reasonably successful in classifying the sample of grid cells from south-Lorn, this model was used to classify 139 of the 172 grid cells in the south-Lorn area, as had been done for the discriminant function analysis based model. Each grid cell was assigned to a class with value between 2 and 5 representing increasing probability of it being at the centre of a buzzard home range. The remaining 33 grid cells were assigned a priori as having zero probability (class 1) of lying at the centre of a buzzard home range on the same criterion as before. Class intervals were chosen to best represent the distribution of probabilities (Figure 8.3). Due to the differences in the nature of the relationships modelled by discriminant function analysis and logistic regression it was not appropriate to standardise the probability classification scales used to produce the maps derived from the two methods.

A second logistic regression model based on data from north-Lorn, south-Lorn, Mull and Glen Lochy was also constructed. The regression coefficients for this model are given in Table 8.9.

Variable	Regression Coefficients
AL_500ME	-0.00690000
LUMP1500	0.00000053
HEAT_500	-0.05430000
PROP_500	0.01090000
constant	0.83500000

Table 8.9: Regression coefficients describing the logistic regression model, based on habitat, derived to separate groups of grid points defined by whether or not they lay at the centre of a buzzard home range.
This model is based on data from the north-Lorn, south-Lorn, Mull and Glen Lochy study areas.

Reclassification of the sample from which the model was derived resulted in 91.0% of cases being reclassified correctly. This was slightly more reliable for grid cells not at the centre of home ranges than for those which were at the centre of home ranges (Table 8.10a). When this was tested using a more rigorous jackknife procedure 74.5% of cases were still correctly reclassified (Table 8.10b).

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	80	75 (93.7%)	5 (6.2%)
Grid Points Lying at the Centre of a Buzzard Home Range	88	11 (12.5%)	77 (87.5%)

Table 8.10a: Reclassification results produced when the logistic regression model from Table 8.9 is used to allocate grid points to groups defined by whether or not they were located at the centre of a buzzard home range.
The model correctly reclassified 90.5% of the overall sample.

Actual Group	Number of Cases	Number of Grid Points Predicted not to Lie at the Centre of a Buzzard Home Range	Number of Grid Points Predicted as Lying at the Centre of a Buzzard Home Range
Grid Points not Lying at the Centre of a Buzzard Home Range	80	74 (92.5%)	6 (7.5%)
Grid Points Lying at the Centre of a Buzzard Home Range	88	14 (15.9%)	74 (84.1%)

Table 8.10b: Classification results produced when the logistic regression model from Table 8.9 is used to allocate grid points to groups defined by whether or not they were located at the centre of a buzzard home range using a jackknife procedure.
The logistic function correctly reclassified 88.10% of the overall sample.

This model was then used to produce a map for the south-Lorn area representing the probabilities for each grid cell lying at the centre of a buzzard home range. This model resulted in the identical classification to that seen in Figure 8.3, based on data from the north-Lorn study area only.

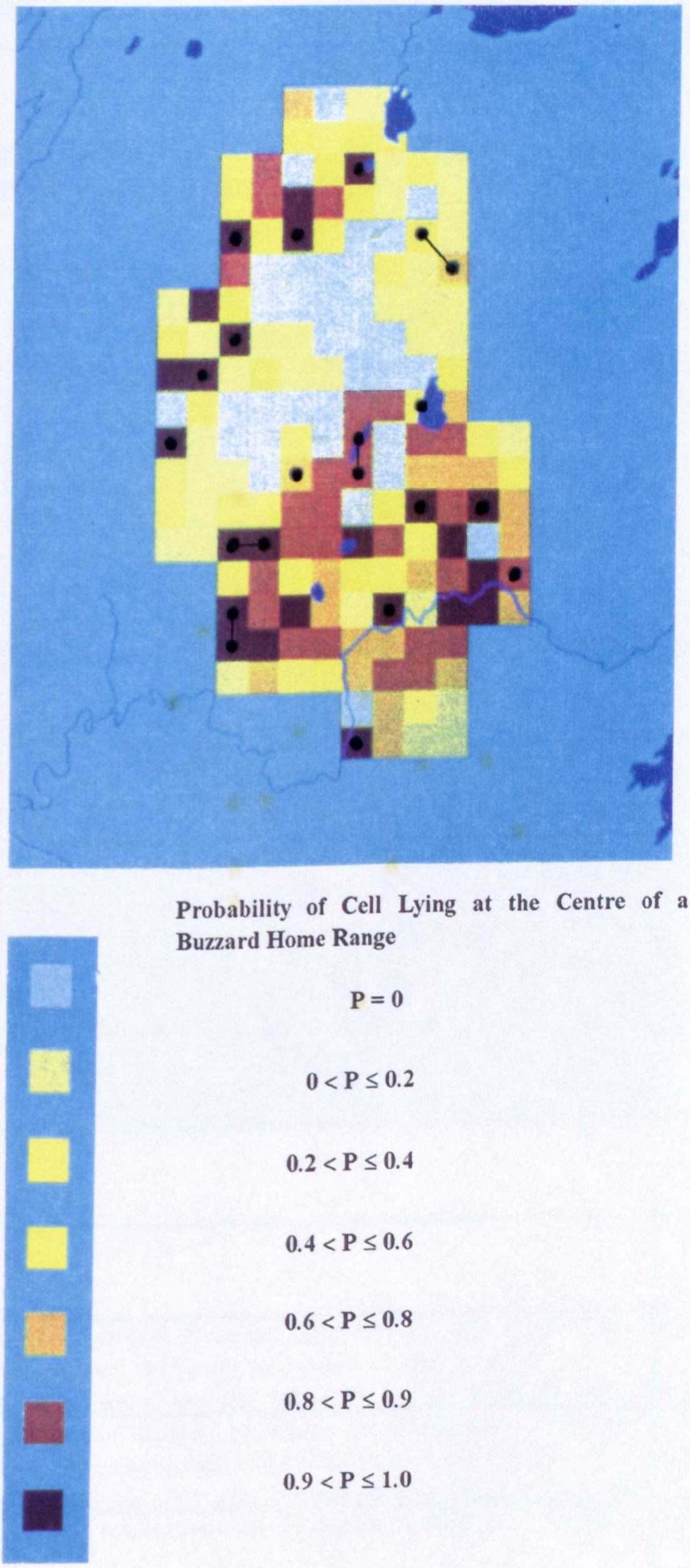
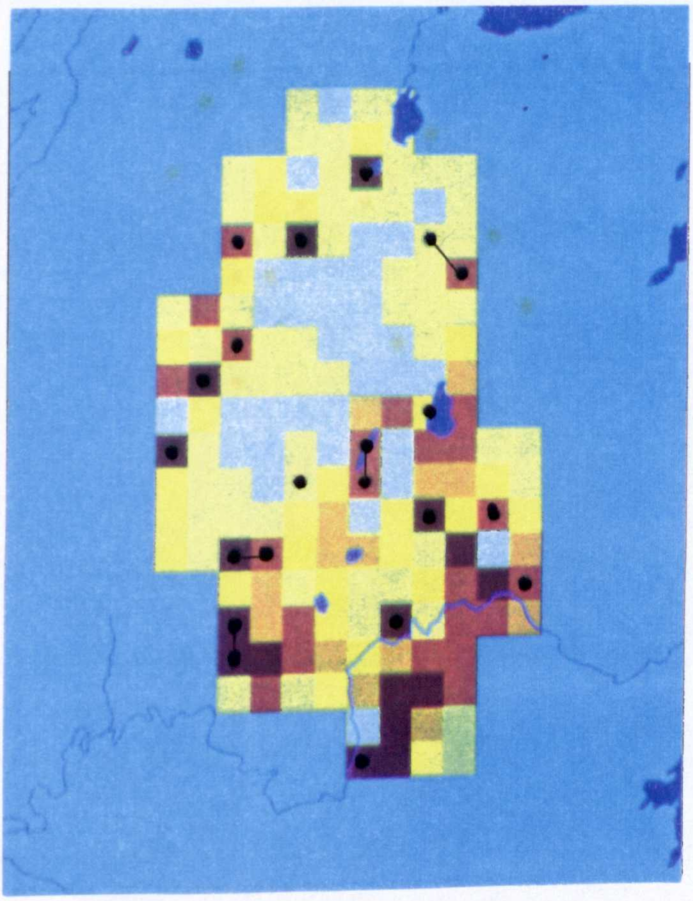


Figure 8.1: Predicted distribution of buzzard home ranges from a discriminant function model derived using habitat data from north-Lorn.
The south-Lorn study area is mapped on a grid cell basis. Each grid cell represents an area of 500m. x 500m. Grid cells are assigned a value of between 1 and 6 based on the probability that they lie at the centre of a buzzard home range. Probability scores were derived from the discriminant function model based on data from north-Lorn. Actual centres of buzzard home ranges are indicated in black. Where two of these are linked, this indicates that the centre of a home range spanned several cells.



Key as for Figure 8.1

Figure 8.2: Predicted distribution of buzzard home ranges produced from a discriminant function model derived using data from north and south-Lorn, south east Mull and Glen Lochy. The south-Lorn study area is mapped on a grid cell basis. Each grid cell represents an area of 500m. x 500m. Grid cells are assigned a value of between 1 and 6 based on the probability that they lie at the centre of a buzzard home range. Probability scores were derived from the discriminant function model based on data from north and south-Lorn, south east Mull and Glen Lochy. Actual centres of buzzard home ranges are indicated in black. Where two of these are linked, this indicates that the centre of a home range spanned several cells.

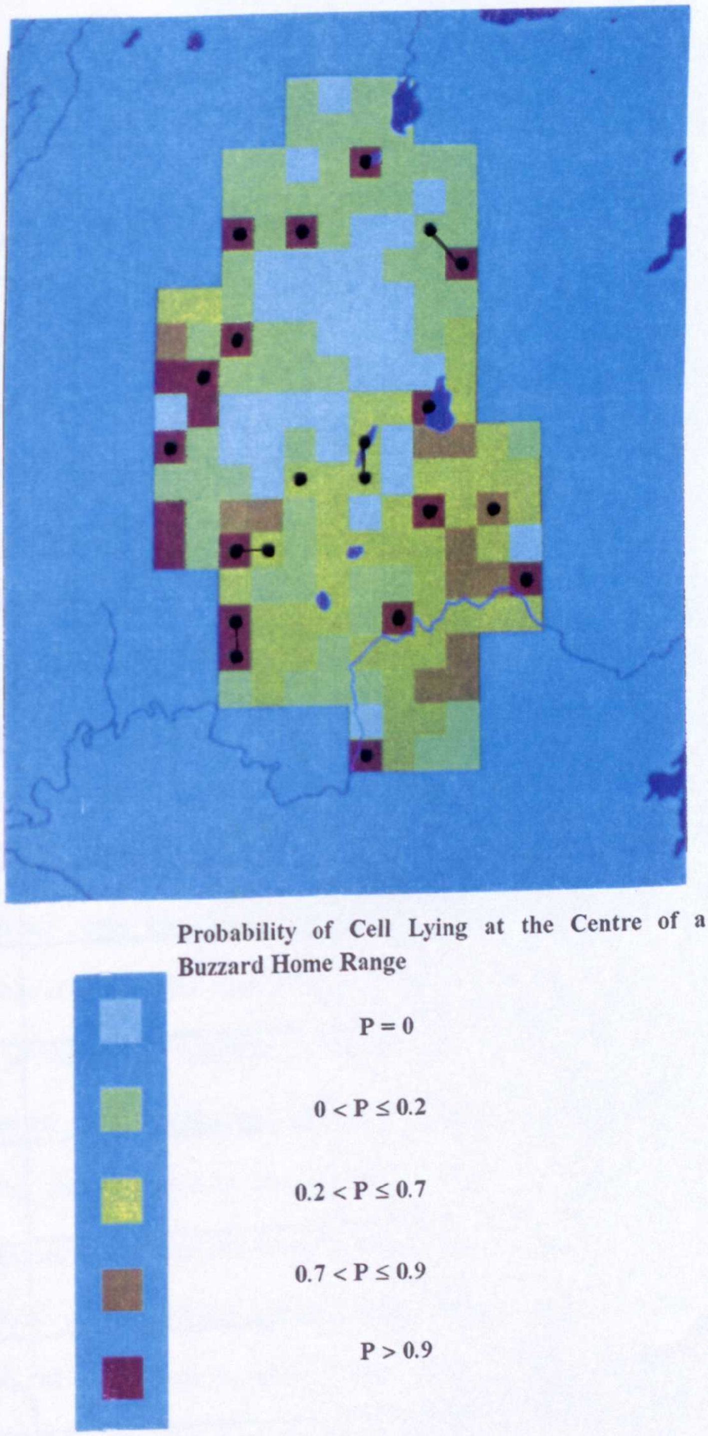


Figure 8.3: Predicted distribution of buzzard home ranges from a logistic regression model derived using data from north-Lorn.
The south-Lorn study area is mapped on a grid cell basis. Each grid cell represents an area of 500m. x 500m. Grid cells are assigned a value of between 1 and 5 based on the probability that they lie at the centre of a buzzard home range. Probability scores were derived from the logistic regression model based on data from north-Lorn. Actual centres of buzzard home ranges are indicated in black. Where two of these are linked, this indicates that the centre of a home range spanned several cells. A similar model derived using data from north and south-Lorn, south east Mull and Glen Lochy produced an identical predictive map.

DISCUSSION

Mapping of animal and plant distributions using grid units is a widely applied technique, for example national and regional atlases of species distributions (e.g. Sharrock 1976). Such mapping exercises are associated with huge input of dedicated manpower and organisation and this will be unfeasible for many parts of the world. Even with this intensive approach these exercises necessarily map distributions at a rather crude scale which may mask relationships between species and their environment which are apparent when smaller scales are used. Distribution maps based on survey do provide excellent baseline data on which to build future work but continued monitoring of populations necessarily involves repeating complete surveys. These surveys do not in themselves provide models with which predictions may be made although they may well be used to provide the basic distribution data on which a inductive model can be built. With the exception of one study, which employed a satellite land cover classification alone to identify potential nesting habitat for American kestrels *Falco sparverius* (Lyon 1983) and summarised habitat data centred on known nest sites, other studies have used sampling units which do not relate specifically to individuals in the population. A single sampling unit may contain a number of pairs of the species concerned and individuals are clearly not confined to within the sampling unit in which their activities are centred. Aspinall and Veitch (1990) make the point that modelling based on characteristics internal to the grid units are therefore necessarily incomplete, whereas habitat sampling unconstrained by the recording unit selected offers the potential of more reliable modelling. This study has been able to adopt this latter form of sampling, facilitated by the widely spaced distribution typical of many raptor species. The grid cell approach was retained for the purpose of applying the model to produce predictive maps but the unit was sufficiently small that it could be considered to correspond to the centre of a buzzards home range. It has been demonstrated elsewhere that different habitat features can be influential at different spatial scales (Steele 1992). By measuring not the habitat characteristics contained within the grid cell but rather habitat characteristics centred around a point central to the cell it allows consideration of different habitat features to be considered at a number of spatial scales. The importance of having taken this approach was demonstrated here as whilst the area of perennial upland grassland surrounding the centre of a buzzard home range contributed most to the predictive model when measured to within a radius of 1500m, the median altitude of land surrounding the centre of a home range contributed most to the predictive model when measured to within a radius of 500m.

The methods of modelling the predictions of buzzard distributions produce maps more readily interpreted than a simple statement of presence or absence of the species. The maps presented here show a high correspondence between those grid cells which the models predict to have a high probability of lying at the centre of a buzzard home range and the actual distribution of buzzard pairs. If the classification result tables are considered in isolation they give a very conservative impression of how well the model performs as no spatial information is incorporated. Thus while the discriminant function based models tend to misclassify many of the grid cells not lying at the centre of home ranges it is apparent from the maps that many of these grid cells are in fact clustered around the centres of home ranges and can be considered as part of the core of the home range. This misclassification is therefore due in part to the relative sizes of home ranges and grid cells. Likewise while the logistic regression based model misclassified some of the grid cells which should have been assigned to the centre of a home range some of these are compensated for by adjacent cells classified as being at the centre of a home range.

While the models produced here were only used to predict complete distribution maps for one small area where the accuracy of their predictions could be verified, there is good reason to believe them to have a wider application across Argyll. In this study, a split sample validation using models constructed on data from north-Lorn proved to be robust when applied to a second study area in south-Lorn, showing it to have wider application than within the area from which it was developed. Furthermore when data from further afield within mid-Argyll was incorporated within the model it still predicted buzzard distribution accurately. It therefore follows that the models could be applied across large areas of mid-Argyll with a reasonable level of confidence in the resulting predictions.

MODEL COMPARISONS

Reference to the predictive maps (Figures 8.1, 8.2 & 8.3) produced either by models based on discriminant function analysis or logistic regression show them to all have a high degree of correspondence with the actual distribution of buzzard home ranges. The sigmoidal relationships modelled by the logistic regression leads to probability values being assigned to grid cells which tend towards the extremes of possible values. This resulted in more precise locations for home range centres. The linear relationships modelled by the discriminant function analysis leads to more grid cells being assigned intermediate probability values. This resulted in home range centres being less precisely located than with the logistic regression based model. It is clear that had there been no prior knowledge of buzzard distribution in the south-Lorn study area a predicted distribution based on the logistic regression model would have been remarkably accurate. This is especially so if edge effects to this mapping exercise are considered as it may well be that several apparent gaps in the buzzard distribution could be explained by birds occupying grid cells adjacent to the predictive area. The logistic regression model would, therefore, be particularly useful in producing predictive maps of buzzard distribution or targeting fieldwork aimed at locating buzzard home ranges. A search of the 11% of all cells which were contained in the highest probability class would have located 80% of buzzard home range centres. If following the discriminant function model it would be necessary to search the 24% of all cells contained in the highest two probability classes but this would have located 88% of buzzard home range centres.

While, when taking into account requirements of home range spacing, it would be difficult to predict a distribution based on the logistic regression model much different to that which was actually determined by fieldwork. this would only be true of the northern part of the study area if applying the discriminant function analysis model. In the southern part of the area many alternative distributions would fit the discriminant function analysis model. Thus, so far as predicting actual distributions the logistic regression model is probably the better of the two approaches. If however the question being addressed relates to how buzzard distribution might respond to habitat changes the discriminant function analysis model may have more to contribute. For reasons given above the discriminant function model assigns many more intermediate probability values to grid cells than does the logistic regression model. The discriminant function models therefore identify more cells as having high probability of lying at the centre of a home range and so may be better for assessing how the population may respond to habitat changes in different areas. In the map based on the logistic regression model no differences were apparent between the northern and southern parts of the south-Lorn area whereas the discriminant function model suggests many more cells have a high probability of being at the centre of a home range in the southern part of the area. If the probability of a grid cell lying at the centre of a home range is related to the suitability of the habitat for supporting buzzards this would suggest that in the southern part of the area buzzards may be more able to withstand local changes in habitat by shifting to nearby areas which remain unchanged. In the northern part of the area this would not be possible as all alternative grid cells were assigned low probabilities of lying at the centre of a home range.

ECOLOGICAL INFERENCE

While it is possible to produce a model that predicts buzzard distribution using this approach it can be misleading to make ecological inference from this type of analysis. While the original habitat variables were measured because they were considered to have a potential biological significance, the final set of measurements included in the model were largely derived on statistical grounds. The caution that statistical relationships between bird distribution and specific habitat variables should not be taken as implying a causal effect is particularly apt here. The question being addressed here was 'what habitat features can be used to predict the distribution of buzzards?' but not 'what habitat features are important to buzzards?'. It is, however, worthwhile to look at those habitat measurements that were identified as good predictors of buzzard distribution and examine potential biological explanations which may explain their usefulness to the model.

The discriminant function models contained two measures of the general shape of the physical landscape. The range in slope of the land within 500m radius of the centre of a grid cell, was greater for grid cells associated with the centre of a home range than for those not so associated. The amount of land within a 500m. radius of the grid point which fell into the category of low land ruggedness was less for grid cells associated with the centre of a home range than for those not so associated. Both these associations indicate that buzzards tend to be associated with land with a varied physical structure. A number possible explanations could be put forward to explain this. The more varied the physical structure of the landscape the greater is the variation in habitats that might be expected. This might be important for an adaptable predator like the buzzard in that it would potentially provide more varied opportunities for hunting in different conditions of weather or buffer it from fluctuations in food supply. Also, hunting success may depend on surprising prey, which may be easier to achieve in a complex environment than in a flat, uniform one. An explanation, perhaps more relevant to modelling distributions is that the flatter landscapes offer fewer potential nest sites. In mid-Argyll most buzzard nests are associated with features themselves associated with uneven landscape. Many buzzard nests in the study area were located in gullies on the sides of glens whether they were bank nests or nests in trees. Most tree stands within the study area were also associated with steeper slopes, the flatter land, be it the higher mountain tops or the inbye land of the glen floors, being generally without suitable nest trees. Another measure useful in predicting distributions was the median altitude of land within a 500m. radius of the centre of a grid cell, used by both the discriminant function models and the logistic regression models. Again, this may be related to the availability of potential nest sites rather than any altitudinal limitations as some buzzards in the Glen Lochy study area were nesting at altitudes that would be considered as high altitude elsewhere in the study area.

The area of land within a 1500m. radius of the centre of a grid cell for which the land cover was perennial upland grassland was another important measurement in the discriminant function models. This is of interest as it was identified in Chapter 7 as a preferred habitat for buzzards and the mean area of this habitat was greater for grid cells associated with the centre of buzzard home ranges than those not so associated. The amount of heathland within a 500m. radius of the centre of the grid cell was also found to be important in predicting buzzard distributions. The mean area of heathland within a 500m. radius of the centre of a grid cell was lower for grid cells associated with home range centres than for those not so associated. Again this corresponds to the findings in Chapter 7 where it was found that buzzards appeared to avoid wet heath and blanket bog. Thus, if the importance of perennial grassland and heathland in predicting buzzard distributions are taken as being indicative of their relative importance to the birds, two very different approaches have identified similar habitat preferences.

Buzzards are generally considered to be at their commonest in areas where habitat is diverse and this appears to be true both when viewed nationally or regionally. The total length of boundaries between the collapsed land cover categories found within a 1500m. radius of the centre of a grid cell was found to be important in predicting buzzard distribution. Grid cells associated with the centre of a buzzard home range contained a higher mean total boundary length than those grid cell not so associated. Boundary lengths were included in the development of the models as they relate to the diversity of land cover structure. This is not only true because of the simple geometrical relationship between boundary length and fragmentation of the habitat, but also because boundaries are recognised as commonly supporting more species at higher densities, than either of the communities flanking them (Johnston & Bonde 1989). This habitat measure therefore ties in well with buzzard preference for a diverse habitat.

It is difficult not to interpret the final habitat measurement, important to the predictive model, as being important to the buzzards. The amount of boundary between pre-thicket conifer plantation and open grassland (agricultural or natural) was strikingly different between grid cells associated with the centres of buzzard home ranges and those not so associated. Looking at simply the presence or absence of this measurement for grid cells in north-Lorn, while only two grid cells associated with the centre of home ranges did not contain some of this feature all but four of the grid cells not associated with the centre of a buzzard home range contained none of this feature, a highly significant difference. This habitat measurement was included in the analysis as it was believed that it might offer especially favourable hunting opportunities, being the region of over spill of large numbers of prey items from the pre-thicket conifer plantation, in which prey biomass would be expected to be high, into grassland where prey visibility is good and hunting remains largely unobstructed by shrubby vegetation.

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CHAPTER 9: BUZZARD BREEDING PERFORMANCE IN RELATION TO HABITAT

CONTENTS:

INTRODUCTION

The breeding performance of individual pairs of birds or distinct populations of a species has been shown to be related to the quality of habitat available to them. For example, in southern Scotland, initial clutch size, laying dates and chick growth in sparrowhawks *Accipiter nisus* have all been related to habitat (Newton 1986, Newton & Marquiss 1984, Moss 1979). In south-western Switzerland growth and fitness of carrion crows *Corvus corone* was shown to differ between urban and rural populations (Richner 1989), and in north Wales, buzzard breeding performance also appears to differ in relation to habitat (Dare & Barry 1990). Consequently, ecologists frequently subdivide study populations into those occupying tracts of land of distinct habitat types and look for differences in breeding performance between these populations and seek to explain this in terms of the habitat differences observed. In this way differences in the suitability of distinct habitat types may be deduced. Differences in suitability of different habitat types are generally ascribed to differences in prey availability between them (e.g. Moss 1979, Newton, Davis & Moss 1981, Marquiss, Ratcliffe & Roxburgh 1985).

Although breeding performance will, at least in part, be dependent upon the quality of individual birds the results of the studies referenced above suggest that habitat quality either has a substantial modifying effect on the success of individuals or that higher quality individuals are occupying particular habitat types. In either case this might allow the prediction of breeding performance from measurement of habitat. Given that aspects of breeding performance of birds will be related either directly or indirectly to the habitat available to each pair, it follows that it may be possible to predict breeding performance by considering the habitat within a birds home range.

In this chapter, I investigate whether it is possible to predict the breeding performance of individual pairs of buzzards from a consideration of the habitat available within the vicinity of the home range. Such an ability would be a useful tool in the conservation of species where individuals occupy a large tract of land as it would allow recommendations to be made which might limit adverse effects of changes to the habitat at a local scale.

METHODS

GENERAL METHODS

Bird Data

Three parameters of breeding performance were used, these were laying date, clutch size and whether nests contained nestlings either larger or smaller than expected for their age, the latter being used as a measure of brood quality and hence the ability of adults to provide for their young. Fledging success was not considered in any of the analyses given here as, due to the low incidence of brood reduction found in buzzards within mid-Argyll, results would not be expected to reveal more than would already be apparent from consideration of clutch size. Of these two, clutch size was determined with greatest confidence.

The criterion for estimating laying dates for the first egg in each breeding attempt, and discussion of the use of this measurement as a parameter of breeding performance, were covered in chapters 3 and 4 where full details can be found.

Details of clutch sizes for each breeding attempt and discussion of the use of this measurement as a parameter of breeding performance are given in Chapter 4.

As a measure of how well adults were able to provide for their young, the presence or absence in each nest, of nestlings, significantly heavier, or significantly lighter, than expected for their age, was used. Details are given in Chapter 3.

Habitat Data

As in the consideration of buzzard distribution, covered in Chapter 8, habitat data associated with each breeding attempt were measured within radii of 500m., 1000m. and 1500m. of the nest site for each variable. The same habitat variables that were used in that analysis relating to vegetation cover and topography were again used here, but measurements related to potential human disturbance such as length of roads and number of houses within a radius of the nest location were not included as while they may have affected the distribution of buzzard territories it was considered unlikely that they would affect the actual outcome of a breeding attempt once started.

This gave a total of fifty two measurements of habitat, each made at the three different radii, and so constituting one hundred and fifty six habitat variables from which those used in the development of predictive models would be chosen.

ANALYSIS

All analyses presented in this chapter were performed using the SPSS PC+ statistic package (Norušis/SPSS Inc. 1990).

Laying Date

Two approaches were used to develop models the purpose of which was to enable laying dates to be predicted for buzzard breeding attempts based on readily available habitat measurements centred on a buzzard nest site. A multiple regression analysis was used to produce a model relating laying date, estimated for a sample of seventy breeding attempts, as a continuous dependent variable to measurements of habitat features as independent variables. The development of a multiple regression model considers only the linear component of any relationship which may exist between the dependent and each of the independent variables. Consequently this analysis would be somewhat weakened if statistical relationships were other than linear. In the second approach, each breeding attempt was classified into one of two laying periods, "early" or "late", defined by whether laying had commenced before or after the median laying date of April 14th, respectively. This division was chosen to give two approximately equal groups as no natural division (e.g. due to bimodality in laying date distribution) was apparent. Laying period was then used as a grouping variable in the development of both a logistic regression analysis based model and a discriminant function analysis based model which might be used to classify breeding attempts by whether they would be predicted to be early or late.

Clutch Size

Breeding attempts were categorised into groups according to clutch size. As clutches of 1 and 4 eggs were infrequently found, clutches were scored as either small (1 or 2 eggs) or large (3 or 4 eggs). This classification was used as a grouping variable for both logistic regression analysis and discriminant function analysis in order to develop models which might be used to classify breeding attempts by whether they would be predicted to produce small or large clutches, based on readily available measurements of habitat centred on a buzzard nest site.

Brood Quality

Breeding attempts were categorised into one of three brood quality groups. These groups were defined by whether they produced broods which contained a predominance of nestlings significantly heavier in weight, significantly lighter in weight, or no different in weight, on average, from that which would be expected for nestlings of their age. This classification was then used as the grouping variable in both a logistic regression analysis and a discriminant function analysis in order to develop models which might be used to classify breeding attempts by the expected brood quality.

RESULTS

LAYING DATE

Development of Multiple Regression Model

Habitat variables extracted from the GIS were examined for univariate correlations with laying date using DESCRIPTIVES from the SPSS PC+ REGRESSION procedure. Variables which correlated with laying date, using a level of significance criterion of $\alpha=0.10$, were chosen for further consideration. Eighteen variables were thus selected. Of these, several groups of variables each represented a similar measurement of habitat but considered at different radii. In such cases, the variable representing the radius at which the measurement showed a correlation with laying date at the smallest level of significance was chosen for further consideration. These variables, their definitions and univariate correlations with laying date are given in Table 9.1.

Of those variables remaining some groups can clearly be considered as different methods of measurement of single habitat features, for example, the modal and median land ruggedness measurements, and again one variable was chosen from each of these groups. The final set of variables was chosen not only based on their individual correlations with laying date, but also so as to minimise correlations amongst themselves. The correlation matrix between these variables is given in Table 9.2. Thus for example while RU1500RA was not as strongly correlated with laying date as was PRE_1500 it was included in preference because it was not highly correlated with any other variables already marked for inclusion, whereas PRE_1500 was highly correlated with POST1500, and so RU1500RA was likely to contribute more to the multiple regression model.

Following guidelines given by Tabachnick and Fidell (1989) with regard to cases to variables ratio and adjustments to this given the distributions of some of the variables included, a maximum of four independent variables was desirable. Given the magnitude of the univariate relationships between laying date and each of the remaining habitat variables with no individual habitat variable explaining more than 8.9% of the variance in laying date, it was inevitable that any multiple regression model that could be obtained would be unable to explain more than about 30% of the variation in laying date, although the actual figure would not be expected to be this high due to relationships between independent variables.

However, a multiple regression analysis using SPSS PC$^+$ REGRESSION was used to further investigate relationships between laying date and this set of habitat variables.

Variable	Description	Correlation Coefficient with laying date (n=70)	Also significant at radii****
AL1500_L*	Area of land within 1500m. radius of nest location which falls into the category of low altitude	r = -0.251 p = 0.032	1000*** 500
POST1500*	Area of land within 1500m. radius of nest location for which the vegetation cover type is post thicket forestry	r = 0.298 p = 0.010	1000*** 500
LUMP1500*	Length of habitat boundaries to be found within 1500m. radius of nest location **	r = 0.276 p = 0.276	
MATB1500*	Length of mature forest edge to be found within 500m. radius of nest location	r = 0.235 p = 0.046	1000*** 500
RU1500_L	Area of land within 1500m. radius of nest location which falls into the category of low land ruggedness	r = 0.208 p = 0.078	
RU1500RA	Range of land ruggedness found within 1500m. radius of nest location	r = -0.199 p = 0.091	500
RU_500MO	Modal land ruggedness found within 500m. radius of nest location	r = -0.208 p = 0.077	
RU_500ME*	Median land ruggedness found within 500m. radius of nest location	r = -0.207 p = 0.078	
PRE_1500	Area of land within 1500m. radius of nest location for which the vegetation cover type is pre thicket forestry	r = 0.227 p = 0.089	
BOG_1000*	Area of land within 1000m. radius of nest location for which the vegetation cover type is blanket bog	r = -0.216 p = 0 .067	500

Table 9.1: Landscape features, extracted from the GIS which were considered for inclusion in the development of a multiple regression model to predict laying date using readily available habitat measurements centred on a buzzard nest site.

Correlation coefficients are those obtained when each variable is considered individually in relation to laying date, with no action taken to remove outliers.

* Habitat variables finally entered into multiple regression analysis.

** Using combined vegetation categories (see text for details)

*** Univariate correlation for which $P<0.05$

**** Using a level of significance of $\alpha=0.10$.

When a stepwise procedure was specified, in which all variables were considered for both inclusion and elimination from the model at each stage, only POST1500 was retained by the analysis, explaining only 8.9% (using adjusted r^2) of the variance in laying date. When backwards elimination of variables was specified four variables, MATB1000, AL1000_L, LUMP1500 & POST1500, were retained by the analysis. Together these four variables explained only 14.2% (using adjusted r^2) of the variance of laying date. Given these results it was not appropriate to take this model development further.

VARIABLE	AL1500_L	POST1500	LUMP1500	MATB1500	RU1500_L	RU1500RA	RU_500MO	RU_500ME	PRE_1500
POST1500	-0.297	1.000							
LUMP1500	-0.108	0.237	1.000						
MATB1500	-0.131	0.689	-0.022	1.000					
RU1500_L	0.267	0.140	0.163	0.287	1.000				
RU1500RA	-0.275	-0.174	0.062	-0.255	-0.547	1.000			
RU_500MO	-0.331	-0.115	0.082	-0.213	-0.444	0.369	1.000		
RU_500ME	-0.301	-0.220	-0.058	-0.321	-0.561	0.502	0.717	1.000	
PRE_1500	-0.112	0.551	-0.192	0.896	0.302	-0.305	-0.157	-0.437	1.000
BOG_1000	-0.097	-0.449	-0.112	-0.457	-0.001	0.104	0.113	0.147	-0.283

Table 9.2: Correlation matrix between the ten habitat variables described in Table 9.1.

Development of Logistic Regression Model

Habitat variables extracted from the GIS were examined using box plots, normal probability curves and detrended normal curves, produced using BOXPLOTS and NPPLOTS from the SPSS PC$^+$ EXAMINE procedure. Those variables for which there appeared to be differences in the central tendencies of distribution, for early laying versus late laying breeding attempts, were further evaluated using student's t-tests or Mann-Whitney U-tests (SPSS PC+ T-TEST and NPAR TESTS M-W respectively), as appropriate after first removing cases identified as outliers by BOXPLOTS. Variables showing significant differences between early laying and late laying groups for univariate comparisons were chosen for further investigation. A level of significance of $\alpha = 0.10$ was used. These variables, their definitions and univariate probability of significant difference between early laying and late laying groups are given in Table 9.3.

With a sample size of between 63 and 70 (depending which variables were included and therefore how many cases were lost as outliers) a maximum of about five variables would be considered an acceptable target for inclusion in the development of the required model (Tabachnick & Fidell 1989, Norušis/SPSS Inc. 1990). Of the sixteen variables still under consideration, clear candidates for removal were evident. The list in Table 9.3 contains several pairs of variables in which members of the pair simply measure the same landscape feature at different radii (AL_500RA & AL1000RA, RU_500MI & RU1500MI, RU1000ME & RU1500ME, SL1000_L & SL1500_L and BOG__500 & BOG_1000), leading to high correlations within each pair. Accordingly one variable from each pair was dropped from the analysis. Which variable was dropped from each pair was decided by consideration of both the value of their univariate test statistic and so as to reduce correlations with other variables being considered. Those dropped were AL_500RA, RU_500MI, RU1500ME, SL1000_L and BOG_1000. The correlation matrix between these habitat variables is given in Table 9.4.

Variable	Description	Univariate comparisons	Statistics (n=70)
AL1500MA*	Maximum altitude found within 1500m. radius of nest location	E < L	t=1.81 P=0.074
AL1000MA	Maximum altitude found within 1000m. radius of nest location	E < L	U=461.5 P=0.089
AL1000RA	Altitude range found within 1000m. radius of nest location	E > L	U=454.0 P=0.082
AL_500RA	Altitude range found within 500m. radius of nest location	E > L	U=455.0 P=0.073
RU1500MI*	Minimum land ruggedness value found within 1500m. radius of nest location	E < L	U=478.0 P=0.094
RU_500MI	Minimum land ruggedness value found within 500m. radius of nest location	E < L	U=490.5 P=0.077
RU1000ME	Median land ruggedness value found within 1000m. radius of nest location	E > L	t=2.55 P=0.013
RU1500ME*	Median land ruggedness value found within 1500m. radius of nest location	E > L	t=1.68 P=0.098
RU_500_M*	Area of land within 500m. radius of nest location which falls into the category of "medium" land ruggedness	E > L	t=1.73 P=0.088
SL1000_L	Area of land within 1000m. radius of nest location that falls into the category of "low" slope	E < L	t=-1.68 P=0.098
SL1500_L	Area of land within 1500m. radius of nest location that falls into the category of "low" slope	E < L	t=-2.15 P=0.035
SL1500MI	Minimum slope found within 1500m. radius of nest location	E > L	t=1.98 P=0.052
SL1500ME*	Median slope value found within 1500m. radius of nest location	E > L	t=1.78 P=0.079
BOG__500*	Area of land within 500m. radius of nest location for which vegetation cover type is blanket bog	E < L	U=454.0 P=0.075
BOG_1000	Area of land within 1000m. radius of nest location for which vegetation cover type is either wet heath, blanket bog or heather moorland	E < L	U=463.0 P=0.094
MATB_500	Length of mature forest edge to be found within 500m. radius of nest location	E < L	U=465.0 P=0.080

Table 9.3: Features of landscape extracted from GIS as habitat variables, which were considered for inclusion in the development of statistical models to predict group membership, defined by laying period. The model uses readily available habitat measurements centred on a buzzard nest site. Test statistics and probabilities are those obtained when central tendencies of each variable is compared univariately between early (GROUP E) and late (GROUP L) laying periods (before and after median laying date of 14th.April respectively). Test statistics and significance are based on all cases with no action to remove outliers. * indicates habitat variables finally entered into the logistic regression analysis.

VARIABLE	AL1500MA	AL1000MA	AL1000RA	AL_500RA	RU1500MI	RU_500MI	RU1000ME	RU1500ME	RU_500_M	SL1000_L	SL1500_L	SL1500MI	SL1500ME	BOG__500	BOG_1000
AL1000MA	.96486	1.00000													
AL1000RA	.91962	.94990	1.00000												
AL_500RA	.78366	.83984	.88012	1.00000											
RU1500MI	.43823	.47147	.43044	.31681	1.00000										
RU_500MI	.42211	.36052	.31317	.27023	.55921	1.00000									
RU1000ME	.40436	.44516	.42237	.42981	.32990	.22659	1.00000								
RU1500ME	.32684	.33199	.36254	.32650	.20857	.18493	.79611	1.00000							
RU_500_M	.42839	.48641	.48245	.52448	.14126	.24947	.35995	.33884	1.00000						
SL1000_L	-.72578	-.74218	-.73053	-.65300	-.56638	-.56018	-.71710	-.61778	-.42305	1.00000					
SL1500_L	-.81925	-.81447	-.80965	-.67916	-.61305	-.56259	-.62934	-.54091	-.42017	.95241	1.00000				
SL1500MI	.45917	.48531	.42842	.32871	.97068	.57672	.33537	.22053	.13052	-.58640	-.62511	1.00000			
SL1500ME	.88687	.89711	.90749	.76611	.57485	.46691	.50493	.47920	.45060	-.85013	-.91016	.58476	1.00000		
BOG__500	-.01360	-.04551	-.20727	-.17344	-.04424	-.03072	-.00932	-.04193	-.10974	.14005	.15601	-.00550	-.16797	1.00000	
BOG_1000	.00530	-.01023	-.19678	-.11947	-.00872	-.00511	.06729	-.00135	-.00625	.06601	.11660	.03637	-.09951	.84518	1.00000
MATB_500	.04531	.04284	.06222	.03937	.04224	-.09399	-.17376	-.23287	-.03972	.21883	.08631	.02802	.00212	-.33497	-.32404

Table 9.4: Correlation matrix between the sixteen habitat variables described in Table 9.3.

Further consideration of the between variables correlation matrix enabled further reduction of the number of variables. SL1500_L was highly correlated with several other variables (AL1500MA, AL1000RA, RU1000ME, RU1500ME and SL1500ME) and so was likely to contribute little to the analysis if these other variables, some of which differed at smaller levels of significance in univariate comparisons, were included. Similar reasoning lead to the rejection of AL1000RA and SL1500MI. One variable, AL1000MA, was rejected due to its highly skewed distribution which would not respond to transformation and the large number of cases which would be lost to outliers.

The most reliable model for predicting whether a breeding attempt would fall into the early or into the late laying period group was obtained through the logistic regression analysis, performed using SPSS PC+ LOGISTIC REGRESSION. A backward elimination of variables procedure was specified with elimination criterion based on the likelihood-ratio statistic. No outliers were identified by the analysis and, of the 70 cases entered, 39 fell into the early laying period group and 31 fell into the late laying period group. The five variables retained by the analysis were AL1500MA, RU1500ME, RU_500_M, RU1500MI and BOG__500. The regression coefficients are given in Table 9.5.

Variable	Regression Coefficients
AL1500MA	-0.0022
RU1500ME	-0.2370
RU_500_M	-0.1035
RU1500MI	-0.0062
BOG__500	-0.0241
Constant	1.7802

Table 9.5: Regression coefficients describing the logistic regression model derived to predict laying date (early vs. late), based on readily available habitat measurements centred on a buzzard nest site.

When this model was used to reclassify the sample from which it was derived it correctly reclassified 71.43% of cases, but was seen to perform somewhat better at correctly classifying the early laying period group than the late laying period group (87.18% and 51.61% correct respectively (see Table

9.6a). However when this logistic regression model was tested more rigorously using a jackknife procedure it correctly classified only 58.90% of cases which is only slightly better than would be achieved by random allocation of cases to groups (see Table 9.6b).

A similar model, based on a discriminant function analysis correctly reclassified 70.77% of the overall sample. Again, this was seen to perform somewhat better at correctly reclassifying early laying breeding attempts than late laying breeding attempts (80.6% and 58.6% respectively). However, when this model was tested using a jackknife procedure it correctly classified only 50.8% of cases which is equivalent to what would have been obtained by random allocation of cases to groups.

Actual Group	Number of Cases	Number of Cases Predicted as Belonging to the Early Laying Group	Number of Cases Predicted as Belonging to the Late Laying Group
Early Laying	39	34 (87.72%)	5 (12.28%)
Late Laying	31	15 (48.39%)	16 (51.61%)

Table 9.6a: Reclassification results produced when the logistic regression model from Table 9.5 was used to allocate breeding attempts into groups defined by early or late laying date.
The logistic regression model correctly reclassified 71.43% of the overall sample.

Actual Group	Number of Cases	Number of Cases Predicted as Belonging to the Early Laying Group	Number of Cases Predicted as Belonging to the Late Laying Group
Early Laying	39	29 (74.36%)	10 (25.64%)
Late Laying	31	17 (54.48%)	14 (45.52%)

Table 9.6b: Classification results produced when the logistic regression model from Table 9.5 was used to allocate breeding attempts into groups defined by early or late laying date using a jackknife procedure.
The model correctly classified 58.95% of the overall sample (only marginally better than that which would be expected by chance).

CLUTCH SIZE

Initial examination of habitat variables extracted from the GIS, followed the same outline as that used to arrive at a reduced set of variables for the consideration of laying period, using box and whisker plots, normal probability plots and detrended normal plots. Those variables for which there appeared to be differences in the central tendencies of distribution, between nest locations where small clutches were laid compared with those where large clutches were laid, were further evaluated, as before using student's t-tests or Mann-Whitney U-tests, as appropriate, after first removing outlying cases. A large number of habitat variables showed significant differences when compared univariately between the two groups using a level of significance of $\alpha=0.05$. Many of the habitat measurements taken were significant at two or three of the radii at which they were made. For each of these groups of measurements, the variable representing the radius at which there was a significant difference in central tendencies between groups at the smallest level of significance was selected for further consideration. These variables, their definitions and univariate probability of significant difference between clutch size groups are given in Table 9.7.

Consideration of the correlation matrix between these variables (Table 9.8) using the same lines of argument used for the consideration of laying period was used to reduce this list of variables to five, which exhibited no strong correlations amongst themselves.

Variable	Description	Univariate Comparisons	Statistics (n=73)	Also significant at radii
AL1500_L	Area of land within 1500m. radius of nest location which falls into the category of low altitude	S > L	t=2.46 P=0.017	500 1000
AL1000_M*	Area of land within 1000m. radius of nest location which falls into the category of medium altitude	S < L	t=-2.19 P=0.032	1500
RU_500_M*	Area of land within 500m. radius of nest location which falls into the category of medium land ruggedness	S < L	t=-3.56 P=0.001	1000 1500
RU_500MO	Modal land ruggedness found within 500m. radius of nest location	S < L	U=381.0 P=0.010	
SL_500_L	Area of land within 500m radius of nest location which falls into the category of low slope	S < L	t=2.65 P=0.010	
SL_500MO	Modal slope found within 500m. radius of nest location	S < L	t=-2.28 P=0.025	
SL1500_M	Area of land within 1500m. radius of nest location which falls into the category of medium slope	S < L	t=-2.51 P=0.014	
SL1500MI*	Minimum slope found within 1500m. radius of nest location	S < L	U=398.5 P=0.024	
SL1000MO	Modal slope found within 1000m. radius of nest location	S < L	U=370.5 P=0.018	500
PERE1500*	Area of land within 1500m. radius of nest location for which the vegetation cover type is upland perennial grassland	S < L	t=-2.70 P=0.009	1000
BOG_1500	Area of land within 1500m. radius of nest location for which the vegetation cover type is blanket bog	S > L	U=397.5 P=0.049	
TREB1500*	Length of woodland and forestry edge opening onto open habitat to be found within 1500m. radius of nest location	S > L	U=359.5 P=0.015	500 1000

Table 9.7: Landscape features, extracted from the GIS, which were considered for inclusion in the development of statistical models to predict group membership, defined by clutch size.
The model uses readily available habitat measurements centred on a buzzard nest site. Test statistics and
probabilities are those obtained when central tendencies of each variable are compared univariately between small
(GROUP S) and large (GROUP L) clutches (clutch = 1 or 2 and clutch = 3 or 4 respectively). Test statistics and
significance are based on all cases with no action taken to remove outliers. * indicates habitat variables entered into
the discriminant function analysis.

VARIABLE	AL1500_L	AL1000_M	RU_500_M	RU_500MO	SL_500_L	SL_500MO	SL1500_M	SL1500MI	SL1000MO	PERE1500	BOG_1500
AL1000_M	-0.21477	1.00000									
RU_500_M	-0.50577	0.24391	1.00000								
RU_500MO	-0.27773	0.08912	0.41864	1.00000							
SL_500_L	0.54940	0.16441	-0.42593	-0.57271	1.00000						
SL_500MO	-0.41243	-0.30944	0.27513	0.45766	-0.76399	1.00000					
SL1500_M	-0.22425	0.51406	0.17562	0.01479	0.19033	-0.37241	1.00000				
SL1500MI	-0.40433	-0.20850	0.05710	0.19479	-0.44281	0.35504	-0.11996	1.00000			
SL1000MO	-0.49710	-0.16390	0.39258	0.32161	-0.66008	0.69575	-0.30815	0.40727	1.00000		
PERE1500	-0.14646	0.24679	0.14045	0.05676	0.01661	-0.05371	0.05679	-0.33123	-0.08441	1.00000	
BOG_1500	-0.18218	-0.05192	0.03822	0.17286	-0.08225	-0.09577	0.04259	0.05873	-0.01177	0.05842	1.00000
TREB1500	-0.12318	0.36464	0.08526	-0.07067	0.07520	-0.08413	0.22184	-0.19247	-0.03904	0.15302	-0.02609

Table 9.8: Correlation matrix between the twelve habitat variables described in Table 9.7.

The best model for predicting whether small or large clutches would be expected from a particular breeding attempt was obtained through a discriminant function analysis. This was performed using SPSS PC+ DSCRIMINANT. The five variables entered into this analysis were PERE1500, SL1500MI, AL1000_M, TREB1500 and RU_500_M. A stepwise data entry procedure was specified with inclusion and elimination criterion based on minimisation of Wilk's lambda. After removal of outliers, 66 cases were processed, of which 47 fell into the early laying period group and 19 fell into the late laying period group. The ratio of the sizes of the two sample groups, the size of the smallest sample group in comparison to the number of variables and the overall variables to cases ratio were therefore all within guidelines given by Tabachnick & Fidell (1989). Outliers were characterised by very low values of AL1000_M and low values for SL1500MI, typical of a few coastal home ranges thus any resulting model may not be applicable to very low lying and flat coastal home ranges. There was no evidence that the assumption of equality of group covariance matrices was violated (Boxes M=2.8604 with 2df, P=0.0942). Four variables were retained by the analysis procedure. The variable dropped was RU_500_M. The unstandardised canonical discriminant function coefficients are given in Table 9.9.

Variable	Unstandardised Canonical Discriminant function Coefficients
PERE1500	0.00764
SL1500MI	0.48176
AL1000_M	0.01022
TREB1500	-0.00004
constant	-1.79159

Table 9.9: Unstandardised canonical discriminant function coefficients describing the discriminant function derived to predict clutch size (small vs. large) based on readily available habitat measurements centred on a buzzard nest site.

With specification of prior probabilities for each group according to their proportions in the sample this discriminant function correctly classified 87.88% of cases overall. Prediction of cases from the small clutch size group was especially good with 93.6% correctly classified. (see Table 9.10a). When this discriminant function was tested using a more rigorous jackknife procedure it corrcctly classified 84.8% of cases. (see Table 9.10b).

Actual Group	Number of Cases	Number of Cases Predicted as Belonging to the Small Clutches Group	Number of Cases Predicted as Belonging to the Small Clutches Group
Small Clutches	47	44 (93.6%)	3 (6.4%)
Large Clutches	19	5 (26.3%)	14 (73.7%)

Table 9.10a: Reclassification results produced when the discriminant function model from Table 9.9 was used to allocate breeding attempts to groups defined by small or large clutch size.
The discriminant function correctly reclassified 87.88% of the overall sample.

Actual Group	Number of Cases	Number of Cases Predicted as Belonging to the Small Clutches Group	Number of Cases Predicted as Belonging to the Large Clutches Group
Small Clutches	47	42 (89.4%)	5 (10.6%)
Large Clutches	19	5 (26.3%)	14 (73.7%)

Table 9.10b: Classification results produced when the discriminant function model from Table 9.9 was used to allocate breeding attempts to groups defined by small or large clutch size using a Jackknife procedure.
The discriminant function correctly classified 84.8% of the overall sample.

The four variables found to be useful in discriminating between the small clutch and high clutch groups were further analysed using analysis of variance. After removal of outliers, 66 cases were processed, of which 47 belonged to the small clutch size group and 19 belonged to the large clutch size group. Examination of the correlation matrix of habitat variables indicated these to be correlated (Bartlett's test of sphericity with 6 df=7.513 , P=0.008) indicating that the analysis of variance approach was appropriate. Furthermore there was no evidence that the assumption of homogeneity of variance was violated (Boxes M test , $F_{10,6359}$=0.9862, P=0.453). A significant difference was found under the null hypothesis that there were no differences between the means of all four habitat variables between the two clutch size groups (Phllai's Trace test, F with 4 df. = 10.7236, P<0.001). Summary statistics for each habitat variable between the two groups, together with the univariate comparisons are given in Table 9.11. Examination of the univariate comparisons indicate that all four habitat variables are probably contributing to the significant result obtained.

Variable (and unit of measurement)	Small Clutch Group n=47		Large Clutch Group n=19		Univariate F statistic ($F_{1,64}$)	Significance of F
	Mean	S.E.	Mean	S.E.		
PERE1500 (Hectares)	147.548	13.530	244.169	16.948	16.6595	P<0.001
SL1500MI (Slope category)	1.042	0.180	1.750	0.263	4.7143	P=0.034
AL1000_M (Hectares)	67.784	6.423	94.721	9.907	5.1862	P=0.026
TREB1500 (Metres)	12050	951	7192	892	9.3742	P=0.003

Table 9.11: Mean and standard errors of habitat variables included in the discriminant function model derived to predict whether breeding attempts would produce small or large clutches.
Test statistics and probabilities are those obtained when central tendencies of each variable are compared univariately between groups. Test statistics and significance are based on samples from which outlying cases have been removed.

A similar model based on a logistic regression analysis correctly reclassified 83.56% of the overall sample. This analysis retained all four variables. The slightly lower performance, compared to the discriminant function analysis based model, was due to poor predictive power in assigning cases belonging to the large clutch size group (59.10% correct) although it performed equally well to the discriminant function model in assigning cases belonging to the small clutch size group (94.10% correct). This model was also robust when tested using a more rigorous jackknife procedure. Overall 84.82% of cases were correctly classified, however it performed particularly poorly in assigning cases belonging to the large clutch size group, correctly predicting only 54.55%. This was little better than could have been achieved by random assignment of cases to groups.

BROOD QUALITY

Initial examination of habitat variables extracted from the GIS, followed the same outline as that used to arrive at a reduced set of variables for the consideration of laying period, using box and whisker plots, normal probability plots and detrended normal plots. Those variables for which there appeared to be differences in the central tendencies of distribution, between nest locations where nestlings were significantly light in weight for their age compared with those where nestlings, were significantly heavy for their age and where all nestlings were within the expected weight margins, were further evaluated univariately using one-way analysis of variance, after first removing outlying cases. Eight habitat variables showed significant differences between their means for the three groups using a level of significance of α=0.10. Some of these habitat measurements were significant at two or three of the radii at which they were taken and so. for each set. the variable representing the radius at which differences were significant at the smallest level of significance was chosen for further consideration. These variables, their definitions and univariate probability of significant difference between clutch size groups, using one way analysis of variance, are given in Table 9.12.

Variable	Description	Statistics (n=73)	Also significant at radii
AL_500_L	Area of land within 500m. radius of nest location which falls into the category of low altitude	F=4.982 P=0.0095	1000 1500
AL_500_M	Area of land within 500m. radius of nest location which falls into the category of medium altitude	F=2.8313 P=0.0657	1000
RU1000MO	Modal land ruggedness found within 1000m. radius of nest location	F=3.8653 P=0.0256	
SL1000MO	Modal slope found within 1000m. radius of nest location	F=2.6104 P=0.0807	
PRE_500	Area of land within 500m. radius of nest location for which the vegetation cover type is pre-thicket forestry	F=2.7192 P=0.0729	

Table 9.12: Features of landscape extracted from GIS as habitat variables, which were considered for inclusion in the development of a discriminant function model to predict group membership, defined by brood quality, using habitat measurements.

Test statistics and probabilities are those obtained when central tendencies of the variables are compared univariately, using one way analysis of variance, between breeding attempts assigned to one of three groups defined according to whether broods contained nestlings which were below expected weight for their age, nestlings which were above expected weight for their age or nestlings which were not significantly above or below the expected weight for their age. Test statistics are based on all cases with no action taken to remove outliers.

For details of group means and standard errors of variables given in Table 9.12 refer to Table 9.16a. Consideration of the correlation matrix between the five remaining variables (Table 9.13) indicated that there were no marked correlations between them and so the five remaining variables were all entered into a discriminant function analysis.

VARIABLE	AL_500_L	AL-500-M	RU1000MO	SL1000MO
AL_500_M	-0.43610	1.00000		
RU1000MO	-0.30217	0.20951	1.00000	
SL1000MO	-0.38736	0.01369	0.44851	1.00000
PRE__500	0.11249	0.07471	0.26148	-0.04625

Table 9.13: Correlation matrix between the twelve habitat variables described in Table 9.12.

A stepwise data entry procedure was specified with inclusion and elimination criterion based on maximisation of minimum Mahalanobis' distance. After removal of outliers, 69 cases were processed, of which 23 fell into the low weight for age nestlings group, 16 fell into the high weight for age nestlings group and 30 fell into the normal weight for age nestlings group. The ratio of the sizes of the largest to smallest sample groups, the size of the smallest sample group in comparison to the number of variables and the overall variables to cases ratio were therefore all within guidelines given by Tabachnick & Fidell (1989). Outliers were characterised by high values for AL_500_L and low values of RU1000MO, typical of some coastal home ranges. Thus any model derived may not be applicable to low lying and flat coastal home ranges. Three variables were retained by the analysis procedure. The variables dropped were AL_500_M and SL1000MO. The unstandardised canonical discriminant function coefficients are given in Table 9.14.

Variable	Unstandardised Canonical Discriminant function Coefficients For Function 1	Unstandardised Canonical Discriminant function Coefficients For Function 2
AL-500_1	-0.01835	0.03181
PRE__500	0.05646	0.04382
RU1000MO	0.23399	0.09988
constant	-0.91152	-2.08373

Table 9.14: Unstandardised canonical discriminant function coefficients describing the discriminant function model derived to predict brood quality based on readily available habitat measurements centred on a buzzard nest site.

With specification of prior probabilities for each group according to their proportions in the sample this discriminant function correctly reclassified 62.32% of cases overall. Prediction of breeding attempts resulting in nestlings of expected weight for age was good and few breeding attempts resulting in nestlings of lower than expected weight for age were classified with the high weight for age group. Reclassification of the high weight for age group was, however, unreliable. (see Table 9.15a). When this discriminant function was tested using a more rigorous jackknife procedure it correctly reclassified 50.70% of cases, compared with the 34.80% that would be obtained by random allocation of cases to the three groups (see Table 9.15b).

Actual Group	Number of Cases	Number of Cases Predicted as Belonging to the Lower than Expected Weight for Age Group	Number of Cases Predicted as Belonging to the Expected Weight for Age Group	Number of Cases Predicted as Belonging to the Higher than Expected Weight for Age Group
Lower than Expected Weight for Age	23	14 (60.9%)	7 (30.4%)	2 (8.7%)
Expected Weight For Age	30	3 (10%)	25 (83.3%)	2 (6.7%)
Higher than Expected Weight for Age	16	4 (25.0%)	4 (25.0%)	8 (50.0%)

Table 9.15a: Classification results produced when the discriminant function model from Table 9.14 was used to allocate breeding attempts to groups defined by brood quality.
The discriminant function correctly classified 62.32% of the overall sample.

Actual Group	Number of Cases	Number of Cases Predicted as Belonging to the Lower than Expected Weight for Age Group	Number of Cases Predicted as Belonging to the Expected Weight for Age Group	Number of Cases Predicted as Belonging to the Higher than Expected Weight for Age Group
Lower than Expected Weight for Age	23	11 (47.8%)	8 (34.8%)	4 (17.4%)
Expected Weight For Age	30	4 (13.3%)	24 (80.0%)	2 (6.7%)
Higher than Expected Weight for Age	16	8 (50.0%)	8 (50.0%)	0 (0.0%)

Table 9.15b: Classification results produced when the discriminant function model from Table 9.14 was used to allocate breeding attempts to groups, defined by brood quality, using a Jackknife procedure.
The discriminant function correctly classified 50.70% of the overall sample.

The five variables which had been entered into the discriminant function analysis investigating brood quality groups were further analysed using mutivariate analysis of variance. Examination of the correlation matrix of habitat variables indicated these to be correlated (Bartlett's test of sphericity with 10 df=55.18106, P<0.001) indicating that the mutivariate analysis of variance approach was appropriate. The significance level of the test for homogeneity of variance (Boxes M, F with 30,10533 df.=1.92180, P=0.002) was within tolerances suggested by Tabachnick & Fidell (1989) for which robustness of the MANOVA could be assumed. A significant difference was found under the null hypothesis that there were no differences between the means of all five habitat variables between the three clutch size groups (Phllai's Trace test. = $F_{10,134}$ = 2.10222, P=0.028). Summary statistics for each habitat variable between the two groups, together with the univariate comparisons are given in Tables 9.16a and 9.16b. Examination of the univariate comparisons indicate that modal ruggedness value of land within 1000m. of nest location and the area of land which falls into the low altitude category and lies within 500m. radius of the nest location differs significantly between groups.

Variable	Small Nestlings For Age Nests n=23		Large Nestlings For Age Nests n=18		Normal Nestlings For Age Nests n=32	
(and unit of measurement)	Mean	S.E.	Mean	S.E.	Mean	S.E.
AL_500_L (Hectares)	32.570	23.777	27.205	28.370	49.308	26.606
AL_500_M (Hectares)	22.582	16.143	26.263	19.332	15.714	13.438
SL1000MO (Slope category)	11.630	8.346	10.556	7.304	7.578	5.099
PRE__500 (Hectares)	13.230	19.760	7.245	11.321	4.151	10.651
RU1000MO (Ruggedness category)	6.196	2.245	5.833	2.425	4.453	2.598

Table 9.16a: Mean and standard errors of habitat variables included in the development of the discriminant function model from Table 9.14.
Means and standard errors are based on sample from which outlying cases have been removed (see text for details).

Variable	Univariate F statistic ($F_{2,70}$)	Significance of F
AL_500_L	4.98253	P=0.009
AL_500_M	2.83130	P=0.066
SL1000MO	2.61036	P=0.081
PRE__500	2.71916	P=0.073
RU1000MO	3.86531	P=0.026

Table 9.16b: Test statistics and significance obtained when central tendencies of variables, used in development of the discriminant function model from Table 9.10, are compared univariately between the three groups.
Test statistics are based on sample from which outlying cases have been removed (see text for details).

DISCUSSION

LAYING DATE

While it was not possible to derive a model from the available habitat data which was sufficiently robust to predict laying dates, some important relationships were found during the attempt. Consideration of the univariate comparisons presented in Table 9.1 indicates that there was a general trend for early laying in the lower lying landscapes of varied topography and with only small tracts of forestry plantation. The positive correlation between laying date and the amount of land within a 1500m. radius falling into the low altitude category (≤100m. a.s.l.) implying that buzzards nesting near the coast and in the lower glens nest later than those in the higher glens. This is probably related more to the habitats available at these lower altitudes rather than to the altitude itself as in much of mid-Argyll it is this part of the land that contains much of the agricultural land, which is not a favoured foraging habitat of buzzards in mid-Argyll (Chapter 7). Above this altitude grassland is dominated by the semi-natural perennial grassland favoured by foraging buzzards. Trends found in laying date in relation to various measures of the shape of the landscape, based on land "ruggedness" all point to earlier laying the more varied the physical landscape is. There was also good evidence that laying dates were later with increased amount of forestry plantation within a pairs home range as both the absolute area of mature plantation within 1500m of the nest site and the amount of forest boundary within a 500m. radius of the nest site were strongly correlated with laying date.

Univariate comparisons between early and late laying periods (Table 9.3) all followed the same general pattern described above. Habitat features associated with a more varied landscape and with only small amounts of forest plantations also being associated with early clutches.

CLUTCH SIZE

Habitat features associated with clutch size correspond closely with those associated with laying date. Large clutch sizes were associated with habitat features representing a varied topography at medium altitude (100m to 200m a.s.l.), with large tracts of perennial upland grasslands and only small amounts of forest and woodland edge and therefore by inference small amounts of mature forestry plantation. Small clutch size was also associated with large tracts of blanket bog, a vegetation type not favoured by foraging buzzards in mid-Argyll (Chapter 7).

The discriminant function model derived here was found to be robust when tested using the jackknife procedure and offers considerable predictive power with only a minority of cases assigned to each group being misclassified.

BROOD QUALITY

The associations between habitat features and brood quality cannot be interpreted as easily as those found for the previous two breeding performance parameters. In the case of altitude, normal weight for age broods tend to be produced at lower altitudes than both small and large weight for age broods although high weight for age broods were produced in home ranges with the largest tracts of land in the medium altitude zone. Normal weight for age broods tended to be found in home ranges with the least varied topography while small weight for age broods were found in the most varied topography. Thus in both altitude and physical structure of the home ranges no clear trend from small weight for age to large weight for age broods was found. It was suggested above that associations between both laying date and clutch size with altitude were probably better explained by the predominant land use within the actual altitude zones than the altitude itself. It is possible that with brood quality the altitude is beginning to have an effect above that of differences in vegetation cover. Thus one might expect an increase in brood quality with an initial increase in altitude as the vegetation becomes more suitable but that brood quality is then reduced as conditions become less favourable at the highest altitudes.

The amount of pre-thicket forestry plantation within a home range also showed no clear trends from small weight for age broods to high weight for age broods with normal weight for age brood exhibiting a lower mean area of this vegetation cover and the small weight for age broods the highest mean area. This might be explained in view of what has been discussed in previous chapters. Pre-thicket forestry plantations are considered to hold high prey biomass which can only be utilised efficiently at the boundary between this and more open habitats. Thus initially, an increase in pre-thicket plantations may result in an increased food supply as boundary length increases. There will, however, come a point at which the benefit of increased pre-thicket plantation edge is out-weighed by overall loss of open foraging ground.

The discriminant function model derived here relating brood quality to habitat was found to be robust when tested using the jackknife procedure and results in a useful increase in predictive power over chance.

CONCLUSION

The main objective in this chapter was to develop models which could be used to predict the breeding performance of individual pairs of buzzards from measurement of habitat features within the pairs home range. This was successful to varying degrees between the breeding performance parameters chosen. A robust and useful model was derived for prediction of clutch size and a reasonably robust and useful model derived for the prediction of brood quality. Used in conjunction with each other they could be used to categorise breeding performance predictions. The ability to predict breeding performance for individual pairs of birds of species such as buzzards, which may occupy extensive home ranges, defended or otherwise, is clearly a useful conservation tool. For example, local land use changes may well only impinge on the home ranges of several pairs of birds in a population. In such a case, if it were possible to influence where such changes might occur it would be possible to direct these changes so as pairs affected by adverse changes would be those already least likely to have high breeding performance. It is also known that birds occupying large individual home ranges may well be able to tolerate a certain amount of habitat change, such as increased afforestation of territories before their breeding performance is reduced (e.g. Marquiss, Newton & Ratcliffe 1978, Newton, Davis & Davis 1982, Marquiss, Ratcliffe & Roxburgh 1985). Adopting this modelling approach would allow one to predict when this point will be reached.

During the development of this model interesting associations between habitat features and buzzard breeding performance have been highlighted. It is particularly noticeable that the habitat features associated with high breeding performance appear to correspond with those which determine the distribution of buzzards in mid-Argyll (Chapter 8). In general buzzard home ranges tended to be centred on areas of variable topography, dominated by perennial grasslands and with only low blanket bog cover. Furthermore those buzzards occupying home ranges with the most varied topography, with high upland perennial grassland cover and low mature forestry and blanket bog cover tend to produce larger and earlier clutches. Vegetation cover which appears important in the determination of distribution and breeding performance also corresponds closely to favoured foraging habitats (Chapter 7).

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CHAPTER 10: CONCLUSION

CONTENTS:

INTRODUCTION

As described in Chapter 1, the character of the British uplands is a semi-natural landscape, which has largely been brought about by human activity over the centuries, especially the past few hundred years, and has developed its own distinctive ecological character. This is epitomised by the open landscapes of heather moorland, blanket bog and sheepwalk which now support important populations of a number of predatory and scavenging birds the national or international status of which give cause for concern, for example, golden eagle *Aquila chrysaetos*, merlin *Falco columbarius* and red kite *Milvus milvus*. Not only are the species themselves important but so are the overall upland communities of which they are a part. Contemporary human activity in the uplands promises to bring new changes to this environment and changes in the ecological character of the uplands is anticipated. Some of these changes may be beneficial while others may be detrimental and changes which benefit one species may be detrimental to another. From a conservation perspective it is important to predict how land use changes might affect these upland communities. This involves both monitoring past and present trends in populations and understanding the ecology of species and communities. The interaction between these two areas can provide the means to the understanding of both. The ecology of a species dictates how it might react to changing habitat and explain its past and present fortunes, and looking at how habitat changes have affected the species may give an insight into their ecology.

In this thesis the buzzard was used as a model species for investigating new ways of predicting how birds are distributed in their environment and whether it is possible to predict how successful birds may be in various habitats. The buzzard was chosen for this study for, while it is a reasonably common species and from a practical and political point of view more amenable to study than some of the other upland raptors, it displays all the ecological characteristics exhibited by some of the other species mentioned which make them vulnerable to change and is the basis for their high conservation profile. That is large tracts of suitable land are necessary in order to hold viable populations and it appears that under some circumstances they are susceptible to the type of land use changes occurring in the uplands (e.g. Mearns 1983).

HABITAT UTILISATION

The aim of this thesis was to find ways of predicting buzzard distribution and breeding performance in relation to habitat features. Of these, the most important in respect of land use change is that of vegetation cover. In order to understand how changes in vegetation cover might be affecting buzzards it is first necessary to determine how buzzards are using habitats available to them. The habitat utilisation / availability analysis presented in Chapter 6 tackled this question. From this analysis certain habitat preferences became apparent. Buzzards were found to favour the richer perennial grasslands above the limits of cultivation, while agricultural grasslands, blanket bog and heather moorland were not favoured. It was argued that this might be related more to the prey availability than prey abundance in different vegetation structures. These habitat preferences were similar to those that have been suggested from other parts of Britain where, in general, buzzards tend to avoid the heather dominated moorland, conifer plantation and fields of the valley floors (Weir & Picozzi 1983, Dare 1989).

It is important to consider these habitat preferences when attempting to assess the likely impact of changes in land use on buzzards in a particular area. It is not sufficient to look just at the new land use regime. It is equally important to look at that which it is replacing. This might explain differences in the response of buzzards to afforestation between mid Wales, where buzzards were able to tolerate afforestation of their home ranges (Newton, Davis & Davis 1984), and the Southern Uplands of Scotland where they were adversely affected by afforestation (Mearns 1983). If forestry replaces heather moorland, blanket bog or agricultural land, the benefits it brings such as an increase in prey availability near the boundaries of new plantation may compensate for loss of, what are already less favoured, foraging areas. This would not be expected if forestry plantations replace semi-natural perennial grassland.

MODELLING BUZZARD DISTRIBUTION

Monitoring of populations of upland birds plays an important role in their conservation. If changes in bird distributions are to be recognised there is a need for baseline data on population size and distribution. This has traditionally involved extensive fieldwork by dedicated individuals. The British uplands cover huge tracts of land which in the past have needed to be exhaustively covered in order to follow the fortunes of the birds found there. Often it is only after many years of study that even the distribution of species becomes known. Remote sensing of the habitat and the data handling capabilities offered by Geographical Information Systems now provide an alternative method of investigating bird distribution.

In this thesis I have been able to show that by using inductive analyses it is possible to produce models which are able to predict with considerable accuracy the distribution of one particular species, the buzzard. The strength of this approach is that statistical methods are used to establish mathematical relationships between a species and its environment. These methods can be employed even in situations where the underlying ecological relationships are not understood as while these ultimately explain the statistical relationships which are observed they are not necessary for predictive purposes. Herein lies the principal advantage of this method as ecological relationships are inevitably highly complex and it may take many years of work before they are understood. When they are understood, their complex nature makes them extraordinarily difficult to apply in a predictive manner.

An important feature of the inductive statistical approach is that data included in the analysis can be restricted to that which is readily available whereas when predictions are to be made based on ecological relationships the data required will be dictated by the nature of this relationship. By way of example prey or food availability will undoubtedly be of overriding importance in any ecologically based model. In most cases, however, this will be difficult to establish for areas for which predictions are required. When making predictions concerning possible effects from foreseen habitat changes these data will never be available. Consequently in such cases any model relying on such a data set therefore fails at the outset.

A number of other studies have used similar methods to derive models for predicting the distribution of a species (e.g. Aspinall & Veitch 1991, Pereira & Itami 1991, Walker 1990) however none of these have derived models that were able to predict the distribution of individuals within a population. The models derived in Chapter 8 achieve the latter. This was possible because descriptions of habitat were not internal to pre-defined units of land, typical of the grid cell approach used in these other studies, but external to points of interest, meaning different features of the habitat could be considered at different scales. The grid approach was retained here only for the purpose of the mapping exercise which followed. There is every reason to believe that the approach explored in the thesis could be applied to a much wider range of species. This is particularly true of other upland bird species such as golden eagle, merlin, hen harrier and raven where birds occupy large home ranges and are widely spaced. Technically there is no reason why the same approach should not work on any species where pairs or individuals occupy distinct home ranges or territories. The only restriction is that habitat should be described at a scale finer than that which is used to describe the animal distribution. This has not been the case in previous studies where single sampling units for habitat descriptions encompassed areas which contained many individuals of the animal species being studied.

The approach used here demonstrates the potential for producing predictions of animal distributions over large tracts of land by extrapolation from concerted efforts in smaller areas. This may be a more economical use of resources than attempting to achieve complete manual coverage. This would be particularly true of regions where lack of manpower, coupled with extensive areas needing to be covered, make the latter goal unachievable, or when this must be achieved in a short space of time. When resources are at a premium, predictions of animal distributions could be useful in directing where effort should be concentrated. Some species can be especially difficult to survey, for example merlin in forestry plantations, and again there is potential for directed field work based on a detailed study on a smaller scale.

MODELLING BUZZARD BREEDING PERFORMANCE

There are many examples from the literature in which differences in breeding performance between populations of a species are attributed to the habitat that each occupies (e.g. Moss 1979, Dare 1986a, Dare 1986b, Dare & Barry 1990). Some studies have been able to show that aspects of breeding performance are related to habitat (e.g. Newton 1976, Newton & Marquiss 1984, Richner 1989, Högstedt 1980). Given that the habitat influences breeding performance it follows that inductive modelling techniques might be employed to predict breeding performance from habitat. The models developed in Chapter 9 demonstrate that this is possible. While the technique did not produce useful models for predicting laying date it was possible to predict clutch size and brood quality. This does not appear to have been demonstrated elsewhere. The same benefits apparent when applying this approach to studies of distribution in relation to habitat also apply when considering breeding performance.

There is clearly conservation potential in being able to predict breeding performance of individual pairs within a population. This technique could be used to identify areas within a species distribution likely to produce the highest number of recruits into the breeding population. It might be important to identify such areas when land use changes are foreseen. There is ample scope for combining predictions of breeding performance with those of distribution to refine the latter, that is to produce predictions of distribution and breeding performance.

MODELLING THE EFFECT OF LAND USE CHANGE

For the purpose of this study it was appropriate to make predictions which could be tested by comparison with actual breeding buzzard distributions and performance. However, these models would be equally applicable to the same areas after simulating changes in habitat, for example by simulating specific changes in vegetation cover by replacing one vegetation category with another. Using this approach it would be possible to predict the effect of, for example, afforestation of open hill ground, or agricultural land improvement. This clearly has potential in conservation planning.

THE USE OF REMOTE SENSING AND GIS IN STUDIES OF ANIMAL HABITAT

The statistical approach used in developing the models used here does not rely on using either GIS or remotely sensed data, although there are clear advantages to using both.

Dealing first with the use of remotely sensed data in the form of satellite imagery, there are a number of advantages to be gained by this approach. Two important advantages are that it allows objective methods to be used to classify land surface cover and that both historical and contemporary data are available. Satellite imagery also provides a means of classifying vegetation cover for vast tracts of land with no compromise in precision and without incurring time costs. The technology is well established, it has been successfully applied in many fields of research, technical expertise is widely available and when large areas of land are to be classified it is relatively inexpensive compared with, for example, interpretation of aerial photographs or field surveys. The use of satellite imagery in ecological studies is, however, often questioned because the classifications produced are rarely in complete agreement with vegetation maps produced by traditional field survey. The latter, however, will rarely have been subjected to the same degree of validation as satellite derived classifications and by their very nature are based on subjective methods. Providing that the classifications produced from satellite imagery can be equated with vegetation features which can be distinguished on the ground then there is no reason why they are any less informative than classifications based on botanical communities when looking at how animals are interacting with their environment. This has been demonstrated in this study.

The use of a GIS has allowed huge quantities of data to be incorporated into the development of the predictive models and habitat use studies. One benefit from incorporating these data into a GIS was that during data collection it was not necessary to simplify information by using summary descriptions at the outset. The data was in effect still in an unprocessed condition immediately prior to analysis. This meant that it was possible to go back to the unprocessed data as the analysis developed, for example to consider habitat features at different scales of measurement. The potential of the system in this respect comes were it to be used for further studies, perhaps incorporating other species where environmental factors may be influential at different scales. Data for such studies could be derived from the same database. This is possible because data on habitat features are not held in a buzzard specific form (e.g. measured at a scale applicable to typical buzzard home range size). This gives great potential for further development of this work to consider a number of species simultaneously, for example, the assemblage of predatory and scavenging birds in upland Argyll.

The use of GIS has great potential for studies where the aim is to model environmental change or the effect of environmental change. When models were used to predict both buzzard distribution and some aspects of their breeding performance the resulting predictions were shown to be robust. As already stated these models would be equally applicable to the same areas after simulating changes in habitat and GIS is the ideal platform for such studies.

Most of the data used in this thesis were collated specifically for this study. In many instances the required data will already be available, for example, in the form of digital data from Ordnance Survey and national and regional vegetation surveys. Where these "off the shelf" data sets can be incorporated into a habitat database this will further reduce the time scale required to produce predictive models. GIS is increasingly being incorporated into vegetation mapping and analysis and the potential for incorporating these data does not need emphasising. Furthermore the use of standardised data sets would enhance concord between studies.

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APPENDICES

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APPENDICES TO CHAPTER 6

The computer programs included in these appendices are those written to enable automated extraction of data from the Horizon GIS described in Chapter 6. The macros given in appendices 1a to 2 are examples of command procedures which are complete within themselves. The macros given in appendices 3a to 3f are an example of a group of inter related command procedures which, together, enable areas and boundary lengths to be extracted from data sets, originally in raster format (e.g. classified satellite image), by first converting these to vector format. This sequence of macros enable data extraction for a single point of interest (e.g. a buzzard nest site). The macro given in appendix 4 is a command procedure which enables extraction of data for multiple points of interest. It achieves this by itself writing a command sequence which makes repeated use of the macros in appendices 3a to 3f, as required by the task specified by a series of user responses to its own prompts (e.g. radii for which data is to be extracted, data to be interrogated, co-ordinate file off points of interest). Appendices 1.a through to 3.f are written in the Lites2 Macro language. Appendix 4 is written in DEC command language.

CONTENTS:

Appendix 1a: XGIS_GEA_POINTS.LCM. Horizon command macro used to extract information concerning vector point data from the GIS.

Output is in the form of a list giving difference in meters of northing and easting, between specified point features of interest (e.g. buzzard nest sites) from the same or other point features (e.g. buzzard nest sites human habitations) . Parameters are specified interactively. Program is in Lites2 Macro language.

```
!           File XGIS_GEA_points.LCM
!           Created G.E.Austin/C.J.Thomas 08&09/01/92
!A macro to report distance of points from a point feature (x & y distance)
!e.g. nest site. Note that the point feature and searched feature can have
!the same FCS i.e. can do nest sites around nest sites.
!output reports obsid easting-displacement northing-displacement
!This macro prompts for        input values for:-
!                                        1/radius of interest
!                                        2/point FC   e.g. fc of nestsite
!                                        3/searched for FC   e.g. fc of house or nestsite
!                                        4/filespec for output, assuming
!                                         topsc2$dka300:[user.gbzv45]*.dat
            decl integer _z_x
            decl integer _z_x_diff
            decl integer _z_y_diff
            decl integer _z_x_point
            decl integer _z_x_searched
            decl integer _z_y_searched
            decl integer _z_y_point
            decl integer _z_obs_fsn
            decl integer _z_test
            decl integer _z_rad              !asked for
            decl integer _z_searched_fc      !asked for
            decl integer _z_point_fc         !asked for
            decl character  _z_filename     !asked for
            decl character _z_user           !asked for
%macro _z_report
            %let _z_x_searched = '$cursx
            %let _z_y_searched = '$cursy
            %let _z_x_diff = '_z_x_searched - '_z_x_point
            %let _z_y_diff = '_z_y_searched - '_z_y_point
            %file write '_z_obs_fsn '_z_x_diff'_z_y_diff
            %search next
            %test $found
            %jtrue _z_report
%endmacro _z_report
```

(continued overleaf)

```
!macro to cope with points of interest that have had their FCS changed when
!point FC and searched fc are the same e.g. nest sites around nest sites
%macro _z_report_sup
        %select all FCS
        %select fc 789
        %select inregion 10
        %search all
        %test $found
        %then _z_report
%endmacro
%macro _z_restore
        %change fc '_z_point_fc
        %end
        %aba
        %search next
        %test $found
        %jtrue _z_restore
%endmacro
%macro _z_process
        %locate
        %test $found
        %abort false
        %let _z_obs_fsn = '$fsn
        %let _z_x_point = '$cursx
        %let _z_y_point = '$cursy
        %change fc 789
        %end
        %aba
!draw a "circle of radius _z_rad defined prior to starting job around the point of interest
        %set fc 999
        %let _z_x = '$cursx + '_z_rad
        %polygon centred 300
        %start
        %position '_z_x '$cursy
        %end
!refind this feature and define it as region 10
        %select all FCS
        %select fc 999
        %locate
        %region 10
        %aba
        %select all FCS
        %select fc '_z_searched_fc
        %select inregion 10
        %search all
        %test $found
        %then _z_report
        %let _z_test = '_z_searched_fc - '_z_point_fc
        %test _z_test < 1
        %then _z_report_sup
        %cancel region 10
        %select all FCS
        %select fc 999
        %locate
        %delete
```

(continued overleaf)

```
        %select all fcs
        %select fc '_z_point_fc
        %jump _z_process
%endmacro
!macro to start job
%macro _z_report_points
        %enable continue
        %enable substitution
        %disable bell
        %inquire _z_rad       "Radius of interest         "
        %inquire _z_point_fc  "FC of centre point of interest   "
        %inquire _z_searched_fc "FC of point features of interest "
        %inquire _z_filename  "file specification for output "
        %inquire _z_user      "are you GBZA44 or GBZV45 "
        %message
        %message
        %message OUTPUT WILL BE SENT TO
        %message Topsc2$dka300:[user.'_z_user]'_z_filename.dat
        %message
        %message
        %file create 2 TOPSC2$DKA300:[USER.GBZV45]'_z_filename
        %select all
        %select fc '_z_point_fc
        _z_process
        %select all fcs
        %select fc 789
        %search all
        _z_restore
!tidy up by cancelling things so they are not left lying around in horizon
        %message
        %message OUTPUT TO Topsc2$dka300:[user.'_z_user]'_z_filename.dat COMPLETE
        %message
        %aba
        %select all
        %cancel variable _z_obs_fsn
        %cancel variable _z_x
        %cancel variable _z_rad
        %cancel variable _z_test
        %cancel variable _z_searched_fc
        %cancel variable _z_point_fc
        %cancel variable _z_x_point
        %cancel variable _z_y_point
        %cancel variable _z_x_searched
        %cancel variable _z_y_searched
        %cancel variable _z_x_diff
        %cancel variable _z_y_diff
        %cancel variable _z_user
        %cancel variable _z_filename
        %cancel macro _z_restore
        %cancel macro _z_report
        %cancel macro _z_report_sup
        %cancel macro _z_process
        %cancel macro _z_report_points
        %file close 2
        %enable bell
```

(continued overleaf)

```
          %raspberry
          %message
          %message
          %message MAP HAS BEEN RESET AND SO CAN BE USED TO RUN MACRO AT
          %message ANOTHER RADIUS
          %message ALL VARIABLES AND MACROS HAVE BEEN CANCELLED
          %message TO RUN AT NEW RADIUS TYPE @xgis_gea_points TO RELOAD MACROS
          %message THEN TYPE _z_report_points TO START NEW JOB
%endmacro
```

Appendix 1b: XGIS_GEA_LINEAR.LCM. Horizon command macro used to extract information concerning vector line data from the GIS.

Output is in the form of a list giving lengths in meters of specified linear features of interest (e.g. coastline, roads), within a specified radius, from specified point features of interest (e.g. buzzard nest sites). Parameters are specified interactively.

```
!          XGIS_GEA_LINEAR.LCM
!          A macro to report lengths of linear features within a given radius
!          of a point of interest e.g. a nest site
!
!          Created G.E.Austin/C.J.Thomas 08&09/01/92
!This macro prompts for input values for:-
!                                                     1/radius of interest
!                                                     2/FC of e.g. nest site
!                                                     3/FC of linear feature to measure
!                                                     4/filspec for output assuming
!                                                       topsc2$dka300:[user.gbzv45]*.dat
           decl integer _z_x
           decl real    _z_sum
           decl integer _z_obs_fsn
           decl integer _z_clipped_fc
           decl integer _z_rad           !asked for
           decl integer _z_target_fc     !asked for
           decl integer _z_point_fc      !asked for
           decl character  _z_filename  !asked for
           decl character _z_user        !asked for
!macro to clip all found features to within the chosen region. Called if _z_process finds a feature
! to be clipped that cuts a region.
%macro _z_clip
           %clip cutregion 10
           %search next
           %test $found
           %jtrue _z_clip
%endmacro
!macro to compute total length of all features of specified FC Called by _z_process if features
! are found within the region
%macro _z_report
           %let _z_sum = '$length + '_z_sum
           %search next
           %test $found
           %jtrue _z_report
%endmacro
!macro to change all sites back to correct FC
%macro _z_restore
           %change fc '_z_point_fc
           %end
           %aba
           %search next
           %test $found
           %jtrue _z_restore
%endmacro
```

(continued overleaf)

```
!macro to process the points of interest
%macro _z_process
            %locate
            %test $found
            %abort false
            %let _z_obs_fsn = '$fsn
            %change fc 789
            %end
            %aba
            %set fc 999
            %let _z_x = '$cursx + '_z_rad
            %polygon centred 300
            %start
            %position '_z_x '$cursy
            %end
            %select all FCS
            %select fc 999
            %locate
            %region 10
            %aba
            %select all FCS
            %select fc '_z_target_fc
            %select cutregion 10
            %search all
            %test $found
            %then _z_clip
            %let _z_sum = 0
            %select all FCS
            %select fc '_z_target_fc
            %select inregion 10
            %search all
            %test $found
            %then _z_report
            %file write '_z_obs_fsn '_z_sum
            %cancel region 10
            %select all FCS
            %select fc 999
            %locate
            %delete
            %select all fcs
            %select fc '_z_point_fc
            %jump _z_process
%endmacro
!macro to start job
%macro _z_report_linear
            %enable continue
            %enable substitution
            %disable bell
            %inquire _z_rad        "Radius of interest "
            %inquire _z_point_fc  "FC of points of interest (nestsites?) "
            %inquire _z_target_fc "FC of features of interest (eg coast,roads) "
            %inquire _z_filename  "file specification for output "
            %inquire _z_user       "are you GBZA44 or GBZV45 "
%message
```

(continued overleaf)

```
        %message OUTPUT WILL BE SENT TO
        %message Topsc2$dka300:[user.'_z_user]'_z_filename
        %message
        %file create 2 TOPSC2$DKA300:[USER.'_z_user]'_z_filename
        %let _z_clipped_fc = 100        !fc 100 for clipped features
        %select all
        %select fc '_z_point_fc
        _z_process
        %select all fcs
        %select fc 789
        %search all
        _z_restore
!tidy up by cancelling things so they are not left lying around in lites
        %message
        %message OUTPUT TO topsc2$dka300:[user.'_z_user]'_z_filename COMPLETE
        %message
        %message
        %cancel variable _z_sum
        %cancel variable _z_obs_fsn
        %cancel variable _z_x
        %cancel variable _z_clipped_fc
        %cancel variable _z_rad
        %cancel variable _z_target_fc
        %cancel variable _z_point_fc
        %cancel variable _z_filename
        %cancel variable _z_user
        %cancel macro _z_report
        %cancel macro _z_process
        %cancel macro _z_report_linear
        %draw
        %enable bell
        %message
        %message
        %message MAP HAS BEEN RESET AND SO CAN BE USED TO RUN MACRO AT
        %message ANOTHER RADIUS
        %message NOTE FEATURES WILL BECOME INCREASINGLY FRAGMENTED THIS
        %message WILL NOT AFFECT THE OUTPUT BUT MAY SLOW DOWN
        %message PROCESSING
        %message ALL VARIABLES AND MACROS HAVE BEEN CANCELLED
        %message TO RUN AT NEW RADIUS TYPE @xgis_gea_linear TO RELOAD
        %message  MACROS THEN TYPE _z_report_linear TO BEGIN NEW JOB
%endmacro
```

Appendix 2: XGIS_GEA_GAUSS.LCM. Example of a horizon command macro written to extract pixel count data from raster images.

The output from this example is a list of values associated with specified vector point features (e.g.buzzard nests) derived from gaussian weighted values from a 5 x 5 pixel matrix, centred on each point, from a raster image (e.g. of altitude).

```
!		File lsl$lites2cmd:xgis_gea_gauss.lcm
!		Created G.Austin 10/8/91
!A macro to run in horizon. Works on a DTI file. Finds a point of interest,
!e.g. a spot observation. Reads variable $imagevalue for 25 neighbourhood pixels and
!then outputs feature serial number and a value based on gaussian weightings of the imagevalues.
!User sets up search interactively.
		decl real _z_sum
		decl real _z_value
		decl integer _z_target_fc
		decl integer _z_ax
		decl integer _z_bx
		decl integer _z_cx
		decl integer _z_dx
		decl integer _z_ex
		decl integer _z_ay
		decl integer _z_by
		decl integer _z_cy
		decl integer _z_dy
		decl integer _z_ey
		decl integer _z_obsid
!calculate coordinates to position cursor in 25 neighbourhood cells
%macro _z_gauss
		%enable continue
		%let _z_obsid = '$fsn
		%abandon
		%let _z_ax = '$cursx - 200
		%let _z_bx = '$cursx - 100
		%let _z_cx = '$cursx
		%let _z_dx = '$cursx + 100
		%let _z_ex = '$cursx + 200
		%let _z_ay = '$cursy - 200
		%let _z_by = '$cursy - 100
		%let _z_cy = '$cursy
		%let _z_dy = '$cursy + 100
		%let _z_ey + '$cursy + 200
		%let _z_sum = 0
!calculate gaussian value for point of interest
		%position '_z_ax '_z_ay
		%let _z_value = '$imagevalue * 0.0025
		%let _z_sum = '_z_value + '_z_sum
		%position '_z_ax '_z_by
		%let _z_value = '$imagevalue * 0.0125
		%let _z_sum = '_z_value + '_z_sum
		%position '_z_ax '_z_cy
		%let _z_value = '$imagevalue * 0.02
```

(continued overleaf)

```
%let _z_sum = '_z_value + '_z_sum
%position '_z_ax '_z_dy
%let _z_value = '$imagevalue * 0.0125
%let _z_sum = '_z_value + '_z_sum
%position '_z_ax '_z_ey
%let _z_value = '$imagevalue * 0.0025
%let _z_sum = '_z_value + '_z_sum
%position '_z_bx '_z_ay
%let _z_value = '$imagevalue * 0.0125
%let _z_sum = '_z_value + '_z_sum
%position '_z_bx '_z_by
%let _z_value = '$imagevalue * 0.0625
%let _z_sum = '_z_value + '_z_sum
%position '_z_bx '_z_cy
%let _z_value = '$imagevalue * 0.1
%let _z_sum = '_z_value + '_z_sum
%position '_z_bx '_z_dy
%let _z_value = '$imagevalue * 0.0625
%let _z_sum = '_z_value + '_z_sum
%position '_z_bx '_z_ey
%let _z_value = '$imagevalue * 0.0125
%let _z_sum = '_z_value + '_z_sum
%position '_z_cx '_z_ay
%let _z_value = '$imagevalue * 0.02
%let _z_sum = '_z_value + '_z_sum
%position '_z_cx '_z_by
%let _z_value = '$imagevalue * 0.1
%let _z_sum = '_z_value + '_z_sum
%position '_z_cx '_z_cy
%let _z_value = '$imagevalue * 0.16
%let _z_sum = '_z_value + '_z_sum
%position '_z_cx '_z_dy
%let _z_value = '$imagevalue * 0.1
%let _z_sum = '_z_value + '_z_sum
%position '_z_cx '_z_ey
%let _z_value = '$imagevalue * 0.02
%position '_z_dx '_z_ay
%let _z_value = '$imagevalue * 0.0125
%let _z_sum = '_z_value + '_z_sum
%position '_z_dx '_z_by
%let _z_value = '$imagevalue * 0.0625
%let _z_sum = '_z_value + '_z_sum
%position '_z_dx '_z_cy
%let _z_value = '$imagevalue * 0.1
%let _z_sum = '_z_value + '_z_sum
%position '_z_dx '_z_dy
%let _z_value = '$imagevalue * 0.0625
%let _z_sum = '_z_value + '_z_sum
%position '_z_dx '_z_ey
%let _z_value = '$imagevalue * 0.0125
%let _z_sum = '_z_value + '_z_sum
%position '_z_ex '_z_ay
%let _z_value = '$imagevalue * 0.0025
%let _z_sum = '_z_value + '_z_sum
%position '_z_ex '_z_by
```

(continued overleaf)

```
            %let _z_value = '$imagevalue * 0.0125
            %let _z_sum = '_z_value + '_z_sum
            %position '_z_ex '_z_cy
            %let _z_value = '$imagevalue * 0.02
            %let _z_sum = '_z_value + '_z_sum
            %position '_z_ex '_z_dy
            %let _z_value = '$imagevalue * 0.0125
            %let _z_sum = '_z_value + '_z_sum
            %position '_z_ex '_z_ey
            %let _z_value = '$imagevalue * 0.0025
            %let _z_sum = '_z_value + '_z_sum
!write this value to a text file
            %file write '_z_obsid '_z_sum
            %search next
            %test $found
            %jtrue _z_gauss
%endmacro
%macro _z_do_gauss
            %inquire _z_target_fc                    "fc of point feature to search for  "
            %file select 2
            %enable continue
            %select all
            %select fc '_z_target_fc
            %search all
            _z_gauss
%endmacro
```

Appendix 3a: XGIS_GEA_REPORT_AREAS.LCM. Lites2 command macro evoked by GEA_REPORT.COM via XGIS_GEA_BATCH_REPORT_AREAS.LCMto report areas from vector polygon data sets .

The output is in the form of a list of polygon areas (e.g. representing vegetation categories) within a specified radius from a point feature (e.g. a buzzard nest).

```
!           File: lsl$lites2cmd:xgis_gea_report_areas.lcm
!           Created G.Austin/C.J.Thomas 06/07/91
!           Revised TJ Ibbs, 10/07/91 - generalised version
! - predefined variables used to determine what we're doing:
!                    _z_rad          radius of region
!                    _z_obs          observation number (site/territory/spot obs)
!                    _z_fil          output text file name
! [[These are actually passed down to LITES2 by the command file running it]]
! For use in HORIZON, please work entirely in the scratch map!
! (ie, copy any features you might want to work with there first).
! report  AC_4, and area for all polygons in a defined region of _Z_RAD
            %declare integer _z_file_id                  ! number of file we write to
            %declare integer _z_fc                       ! fc of features to work on
            %declare integer _z_x                        ! used in creating circles
            %declare integer _z_circle_fc                ! fc to use for `circles'
            %declare integer _z_area                     ! area of the thing (integer)
            %let _z_file_id  = 1
            %let _z_circle_fc = 3                        ! nb actually a linear fc
            %let _z_fc       = 1                         ! features to get length of
! Macro goes into AC mode, which `gives it' the first AC entry,  writes out the observation number,
!the feature's area and the LH AC text to the current output text file, and then exits AC mode and
!loops
%macro _z_report
            %let _z_area = -'$area
            %test _z_area.lt.0
            %then _z_area = -'_z_area
            %ac
            %file write '_z_obs' '$actext' '_z_area'
            %end
            %search next
            %test $found
            %jtrue _z_report
%endmacro
%macro _z_set_search
!Open a text file for writing, so that we will append to it note that the file must already exist!
!- this also selects the file as the one that FILE WRITE will use
            %file append '_z_file_id' '_z_fil'
            %set fc '_z_circle_fc
            %absolute
            %let _z_x ='$cursx+'_z_rad'
            %polygon centred 300
            %start
            %position '_z_x '$cursy
            %end
            %abandon
```

(continued overleaf)

```
          %test $region 10
          %then %cancel region 10
          %select all
          %select fc '_z_circle_fc
          %find
          %region 10
          %abandon
          %select all
          %select inregion 10
          %select fc '_z_fc
          %search all
          _z_report
          %select all
          %select fc '_z_circle_fc
          %search all
          %delete
          %file close '_z_file_id
%endmacro
```

Appendix 3b: XGIS_GEA_BATCH_REPORT_AREAS.LCM. Lites2 command macro to enable the macro XGIS_GEA_REPORT_AREAS.LCM to run in batch mode under VMS..

```
!          File: lsl$lites2cmd:XGIS_GEA_BATCH_REPORT_AREAS.lcm
!          Created G.E.Austin 06/07/91
!predefined variables used to determine what we're doing:
!                    _z_rad              radius of region
!                    _z_obs              observation number (site/territory/spot obs)
!                    _z_fil              output text file name
           %frt xgis
           %disable graphics
           %disable inform
           %disable verify
           %enable substitution
           %enable continue
           @xgis_gea_report_areas
           %after input _z_set_search
           %iff'_z_iff'
           %exit
```

Appendix 3c: XGIS_GEA_REPORT LENGTHS.LCM. Lites2 command macro evoked by GEA_REPORT.COM via XGIS_GEA_BATCH_REPORT_LENGTHS.LCM to report boundary lengths between different categories in a vector polygon data set.

The output is in the form of a list of boundary lengths between different categories in a vector polygon data set (e.g. representing vegetation categories) within a specified radius from a point feature (c.g. a buzzard nest).

```
!          File: lsl$lites2cmd:xgis_gea_report_lengths.lcm
!          Created G.Austin/C.J.Thomas 06/07/91
!          Edit TJ Ibbs, 10/07/91 - generalise
! - predefined variables used to determine what we're doing:
!                    _z_rad             radius of region
!                    _z_obs             observation number (site/territory/spot obs)
!                    _z_fil             output text file name
! [These are actually passed down to LITES2 by the command file running it]
! For use in HORIZON, please work entirely in the scratch map!
! (ie, copy any features you might want to work with there first).
!report  AC_4, AC_5 and length for all features in a defined region of _Z_RAD
          %declare integer _z_file_id            ! number of file we write to
          %declare integer _z_fc                 ! fc of features to work on
          %declare integer _z_x                  ! used in creating circles
          %declare integer _z_circle_fc  ! fc to use for `circles'
          %declare integer _z_length             ! length of the thing (integer)
          %declare char   _z_first_ac    ! first acs text
          %declare char   _z_second_ac  ! second acs text
          %let _z_file_id  = 1
          %let _z_circle_fc = 3          ! nb actually a linear fc
          %let _z_fc      = 402                  ! features to get length of
! Macro goes into AC mode, which `gives it' the first AC entry,
! writes out the observation number, the feature's length and the
! LH and RH AC texts to the current output text file, and then exits AC
! mode and loops
%macro _z_report
          %let _z_length = '$length
          %ac
          %let _z_first_ac = '$actext
          %next
          %let _z_second_ac = '$actext
! Always output the two ACs in the `same' order - ie, with the largest one first - this will aid
!amalgamation of the length data for all features within the region...
          %test _z_first_ac.gt.'_z_second_ac'
          %then %file write '_z_obs' '_z_first_ac' '_z_second_ac' '_z_length'
          %else %file write '_z_obs' '_z_second_ac' '_z_first_ac' '_z_length'
          %end
          %search next
          %test $found
          %jtrue _z_report
%endmacro
```

(continued overleaf)

```
%macro _z_set_search
!Open a text file for writing, so that we will append to it note that the file must already exist!
!this also selects the file as the one that FILE WRITE will use
          %file append '_z_file_id' '_z_fil'
          %set fc '_z_circle_fc
          %absolute
          %let _z_x ='$cursx+'_z_rad'
          %polygon centred 300
          %start
          %position '_z_x '$cursy
          %end
          %abandon
          %test $region 10
          %then %cancel region 10
          %select all
          %select fc '_z_circle_fc
          %find
          %region 10
          %abandon
          %select all
          %select inregion 10
          %select fc '_z_fc
          %search all
          _z_report
          %select all
          %select fc '_z_circle_fc
          %search all
          %delete
          %file close '_z_file_id
%endmacro
```

Appendix 3d: XGIS_GEA_BATCH_REPORT_LENGTHS.LCM. Lites2 command macro to enable the macro XGIS_GEA_REPORT_LENGTHS.LCM to run in batch mode under VMS..

```
!         File: lsl$lites2cmd:XGIS_GEA_BATCH_REPORT_LENGTHS.lcm
!         Created G.E.Austin 06/07/91
!predefined variables used to determine what we're doing:
!                  _z_rad            radius of region
!                  _z_obs            observation number (site/territory/spot obs)
!                  _z_fil            output text file name
                                     %frt xgis
                                     %disable graphics
                                     %disable inform
                                     %disable verify
                                     %enable substitution
                                     %enable continue
                                     @xgis_gea_report_lengths
                                     %after input _z_set_search
                                     %iff'_z_iff'
                                     %exit
```

Appendix 3e: XGIS_GEA_CLIP.LCM. Lites2 command macro used by GEA_REPORT.COM to redefine vector features so that they are trimmed to within a radius of interest.

```
            ! File xgis_gea_clip.lcm
            ! Created G.E.Austin/C.J.Thomas 06/07/91
            ! This macro does the following:
            !  1. Puts cursor at grid coords of nest (centre of file)
            !  2. Draw circles around this point at a radius of _Z_RAD meters
            !  3. Define this feature  as  region 10
            !  4. Clips all features cutting the region
            !
            %declare integer    _z_x
!macro to clip features which cut the region
%macro _z_clip_cut
             %clip cutregion 10
             %search next
             %test $found
             %jtrue  _z_clip_cut
%endmacro
!macro to define region
%macro _z_define_region
             %abandon
             %set fc 999
             %absolute
             %let _z_x = '$cursx+'_z_rad
             %polygon centred 300
             %start
             %position '_z_x '$cursy
             %end
             %select all
             %select fc 999
             %find
             %region 10
!now go to a macro which clips features crossing region 1, after first selecting features to clip.
             %abandon
             %select all
             %select fc 402
             %select cutregion 10
             %search all
             _z_clip_cut
%endmacro
!macro to start the job
             %macro _z_start
             _z_define_region
             %endmacro
```

Appendix 3f: XGIS_GEA_BATCH_CLIP.LCM. Lites2 command macro to enable the macro XGIS_GEA_CLIP.LCM to run in batch mode under VMS.

```
!           File: lsl$lites2cmd:XGIS_BATCH_CLIP.LCM
!           Lites2 batch start up file
!           Created G.Austin 06/07/91
!LITES2 variable _Z_RAD is the radius to clip to
            %frt xgis
            %disable graphics
            %disable inform
            %disable verify
            %enable substitution
            %enable continue
            @xgis_gea_clip
            %after input _z_start
            %iff'_z_iff'
            %exit
```

Appendix 4: GEA_REPORT.COM. DEC command language macro which prompts user for parameters and then constructs command macro written to extract area and boundary length data from vector polygon data sets.

This macro evokes the Lites2 command macros given in appendices 3a to 3f.

```
$!        File: GEA_REPORT.COM
$!
$!        Created G.AUSTIN 06/07/91 adapted from File xgis_gea_rreport_lengths
$!        Extensive edit TJ Ibbs  10&25/07/91 customised
$!        Purpose: Create a command file for submitting to batch that will
$!        extract area data from polygons derived from a vectorised
$!        DTI file
$!        Input:  file containing lines of the form
$!                    obsid xmin ymin xmax ymax
$!          defining the window around each point of interest
$!
$ on control_y then goto exit_neatly
$ on error    then goto exit_neatly
$!
$! Useful abbreviations
$!
$ TRUE  = 1
$ FALSE = 0
$ wo   = "write outfile"
$ ws   = "write sys$output"
$ rrr  = "read/end_of_file=exit_neatly/error=exit_neatly"
$!
$ outfile_OK = FALSE                          ! output command file not OK
$!
$! Work out where to write output data files:
$!
$ username = f$getjpi(0,"USERNAME")           ! get our username
$ username = f$edit(username,"COLLAPSE")      ! remove any spaces
$ where = "TOPSC2$DKA300:[USER.''username']"  ! use the empty(ish) disk
$!
$! Check that directory exists...
$!
$ if f$parse(where).eqs.""
$ then
$    ws "Output directory ''where' does not exist"
$    ws "Giving up..."
$    exit
$ endif
$!
$! Get a reasonably unique `number' for use in file names
$!
$ unique = f$edit(f$getjpi("","USERNAME"),"COLLAPSE") + -
          f$cvtime(,,"DAY") + f$cvtime(,,"HOUR") + f$cvtime(,,"MINUTE")
$!
$! And construct two `base' names
$!
$ uuu = "UUU''unique'"
```

(continued overleaf)

```
$ vvv = "VVV"unique"'
$!
$! Ask a few questions and create a large command file for
$! submitting to batch...
$ rrr/prompt="Calculate Areas, Lengths or Both  (A or L or B) " -
              sys$output which
$ which = f$edit(which,"UPCASE")
$ if which.nes."A" .and. which.nes."L" .and. which.nes."B"
$ then
$    ws "Must be A for areas or L for lengths or B for both..."
$    exit
$ endif
$!
$ doing_areas   = (which.eqs."A" .or. which.eqs."B")
$ doing_lengths = (which.eqs."L" .or. which.eqs."B")
$!
$ xxx = ""
$ if doing_areas                  then xxx = xxx + "AREA"
$ if doing_areas.and.doing_lengths then xxx = xxx + " and "
$ if doing_lengths                then xxx = xxx + "LENGTH"
$get_inname:
$ rrr/prompt="Input `raster' file name                          " -
              sys$output inname
$ if inname.eqs."" then goto get_inname
$!
$! Work out the full name, and check it exists
$!
$ inname = f$parse(inname,"LSL$XGIS_DATA_ROOT:.DTI")
$ if f$search(inname).eqs.""
$ then
$    ws "Input raster file "inname' does not exist"
$    goto get_inname
$ endif
$get_range:
$ rrr/prompt="Range for vectorising                              " -
              sys$output range
$ if range.eqs."" .or. range.lt.1
$ then
$    ws "Range must be 1 or greater"
$    goto get_range
$ endif
$get_radii:
$ rrr/prompt="Radii of interest          (eg, 500 300 100) " -
              sys$output radii
$ if radii.eqs.""
$ then
$    ws "You must specify at least one radius of interest!"
$    goto get_radii
$ endif
$!
$ radii = f$edit(radii,"COMPRESS,TRIM")
$!
$ if f$locate(",",radii).lt.f$length(radii)
$ then
$    ws "Please separate radii with spaces (200 100), not commas (200, 100)"
```

(continued overleaf)

```
$    goto get_radii
$ endif
$!
$! Check the order is sensible...
$!
$ posn = 0
$ last_radius = 999999
$radii_check:
$!
$    radius = f$element(posn," ",radii)
$    posn = posn + 1
$    if radius.eqs." " then goto checked_radii
$    if radius.lt.last_radius then goto radii_check
$    ws "Radii must be specified in descending order (eg, 500 300 100)"
$    goto get_radii
$!
$checked_radii:
$get_winname:
$ rrr/prompt="Filespec of file containing observation windows " -
              sys$output winname
$ if winname.eqs."" then goto get_winname
$!
$! Check if that file exists
$!
$ if f$search(winname).eqs.""
$ then
$    ws "Input windows file "winname' does not exist"
$    goto get_winname
$ endif
$get_outname:
$ rrr/prompt="Name of command file to create    (eg VEGDATA) " -
              sys$output outname
$ if outname.eqs."" then goto get_outname
$get_basname:
$ rrr/prompt="Base name of output data file     (eg VEGDATA) " -
              sys$output basname
$ if basname.eqs."" then goto get_basname
$! Work out the name of our command file
$!
$ outname = f$parse(outname,".COM")
$!
$! And the base name of our output file(s)
$!
$ temp = f$parse(basname,where)
$ basname = f$parse(temp,,,"NODE") + f$parse(temp,,,"DEVICE") + -
                f$parse(temp,,,"DIRECTORY") + f$parse(temp,,,"NAME")

$!
$! Tell the user what we think we're doing
$!
$ ws "Creating command file "outname' to do:"
$ ws "   "xxx' calculations for radii "radii'"
$ ws "   DTI input from "inname'"
$ ws "   Data files will be called (where `typ' is ARE or LEN)"
$ ws "      "basname'_`radius'.`typ'"
$!
```

(continued overleaf)

```
 $ on control_y then goto exit_and_tidy
 $ on error     then goto exit_and_tidy
 $!
 $! Open the observation window file
 $!
 $ open/read/error=no_such_file winfile 'winname'
 $!
 $! Open the output command file
 $!
 $ open/write outfile 'outname'
 $!
 $! Start off the output file - it must initialise things
 $!
 $ wo "$! "xxx' calculations for radii "radii'"
 $ wo "$ SI "where'"
 $ wo "$ SD LSL$IF"
 $ wo "$ STRUCTUREINI"
 $ wo "$ TVESINI"
 $!
 $ if doing_areas then wo "$ POLYGONSINI"
 $!
 $! It must then create an output file for each radius
 $!
 $ radposn = 0
 $!
$CREATE_LOOP:
$           radius = f$element(radposn," ",radii)
$           if radius.eqs." " then goto DONE_CREATE
$!
$!work out our output file names
$!- these are formed from the base name, the observation id and the radius
$!
$           arename = basname + "_"radius'.ARE"
$lenname = basname + "_"radius'.LEN"
$           if doing_areas   then wo "$ CREATE "arename'"
$           if doing_lengths then wo "$ CREATE "lenname'"
$!
$           radposn = radposn + 1
$           goto CREATE_LOOP
$DONE_CREATE:
$!
$ count = 0
$!
$VECTORISE_LOOP:
$!
$! For each observation we must vectorize an appropriate area of data
$! - read a line from the input file to work out where that area is
$!   (that line is assumed to contain ``obsid xmin ymin xmax ymax")
$!
$next_line:
$           read error=no_more_lines/end_of_file=no_more_lines winfile winline
$           count = count + 1                          ! ie, the next line
$!
$           t$winline = f$edit(winline,"COMPRESS,TRIM")
$!
```

(continued overleaf)

```
$! Dissect the line into its constituents
$!
$           obsid = f$element(0," ",t$winline)
$           xmin  = f$element(1," ",t$winline)
$           ymin  = f$element(2," ",t$winline)
$           xmax  = f$element(3," ",t$winline)
$           ymax  = f$element(4," ",t$winline)
$!
$!
$           if ymax.eqs." "
$           then
$             ws "Error extracting values from "winname' line "count' for obs "obsid'"
$             ws "Line was """winline'""""
$             ws "(seen as """t$winline'""" after `massaging')"
$             goto exit_and_tidy
$           endif
$!
$! Compare the biggest radius to the window size
$! - NOTE that we assume that xmin, etc are integers... (since DCL
$!            cannot handle real numbers...)
$!
$           radius = f$element(0," ",radii)
$!
$           if (radius .gt. (xmax - xmin)/2) .or. -
              (radius .gt. (ymax - ymin)/2)
$           then
$             ws "!!! GIVING UP !!! (to prevent LITES2 collapsing)"
$             ws "Largest radius gives a circle larger than the window box"
$             ws "   From "winname' line "count' for obs "obsid'"
$             ws "   Radius is "radius' (ie, 2*radius is ",(2*radius),")"
$             xrange = f$integer(xmax)-f$integer(xmin)
$             yrange = f$integer(ymax)-f$integer(ymin)
$             ws "   X range is "xrange' and Y range is "yrange'"
$             ws "If you do want radius "radius', you need a different window file"
$             goto exit_and_tidy
$           endif
$!
$           wo "$! Observation "obsid'"
$           wo "$ VECTORISE"
$           wo "FILEIN "inname'"
$           wo "WINDOW "xmin' "ymin' "xmax' "ymax'"
$           wo "RANGE "range'"
$           wo "SET INTERIOR_FC 402"
$           wo "SET BORDER_FC 402"
$           wo "IFF "uuu'"
$           wo "GO"
$!
$!we now have a vectorised window centred on a nest
$!
$           wo "$ ILINK/MERGE "uuu'.IFJ "uuu'"
$!
$!- start with the first radius from our list
$!
$           radposn = 0
$RADIUS_LOOP:
```

(continued overleaf)

```
$!work out the next radius that we are to work with in this window
$!
$           radius = f$element(radposn," ",radii)
$!
$!if there are no more radii, then we have finished with this
$!section of vectorisation - jump back to do the next
$!
$           if radius.eqs." "
$           then
$             wo "$ delete "uuu'.*;*"           ! tidy up after ourselves
$             goto VECTORISE_LOOP
$           endif
$!
$!work out our output file names
$!
$           arename = basname + "_"radius'.ARE"
$           lenname = basname + "_"radius'.LEN"
$!
$           wo "$! Radius "radius'"
$!
$!get a fresh copy of the vectorised data to work with
$!
$           wo "$ COPY "uuu'.IFJ "vvv'      ! get a fresh copy of the vectorised data"
$!
$!now draw in the polygon which is the area of interest about the nest
$!(ie the centre of the file) and clip to it
$!
$           wo "$ DEFINE/USER SYS$INPUT SYS$COMMAND"
                                                                   + -
$           wo "$ LITES2 "
              "DECL INT _Z_RAD#LET _Z_RAD="radius'#"     + -
              "DECL CHA _Z_IFF#LET _Z_IFF="vvv'.IFJ#"    + -
              "@XGIS_GEA_BATCH_CLIP"
$!
$!we now have VVV`thing'.IFJ which contains the original boundary data clipped
$!to a circle centred on the centre of the file
$!
$!Now make certain that the file is "clean"
$!
$           wo "$ ILINK/MERGE "vvv'.IFJ "vvv'"
$           wo "$ ILINK/BREAK "vvv'.IFJ "vvv'"
$           wo "$ ILINK/STRUCTURE "vvv'.IFJ "vvv'"
$!
$! We now use a lites2 macro to find and describe all features in the file
$! within a given radius
$! Actually use `circles' of radius+1 here, just to prevent rounding
$! errors, etc
$!
$           nrad = radius + 1
$!
$           if doing_areas                    ! NB LITES2 works on the IFF (ordinary) file
$           then
$             wo "$ IPOLYGON/PROPAGATE=(FULL)" + -
                "/POLYGONS=(LABEL,LABEL_AC:4,OUTPUT:"vvv') "vvv'.IFJ"
$             wo "$ DEFINE/USER SYS$INPUT SYS$COMMAND"
                                                               + -
$             wo "$ LITES2 "
```

(continued overleaf)

```
              "DECL INT _Z_RAD#LET _Z_RAD="nrad'#"       + -
              "DECL INT _Z_OBS#LET _Z_OBS="obsid'#"      + -
              "DECL CHA _Z_FIL#LET _Z_FIL="arename'#"    + -
              "DECL CHA _Z_IFF#LET _Z_IFF="vvv'.IFF#"    + -
    "@XGIS_GEA_BATCH_REPORT_AREAS"
$          endif
$!
$          if doing_lengths       ! NB LITES2 works on the IFJ (junction) file
$          then
$            wo "$ DEFINE/USER SYS$INPUT SYS$COMMAND"
$            wo "$ LITES2 "                              + -
              "DECL INT _Z_RAD#LET _Z_RAD="nrad'#"       + -
              "DECL INT _Z_OBS#LET _Z_OBS="obsid'#"      + -
              "DECL CHA _Z_FIL#LET _Z_FIL="lenname'#"    + -
              "DECL CHA _Z_IFF#LET _Z_IFF="vvv'.IFJ#"    + -
              "@XGIS_GEA_BATCH_REPORT_LENGTHS"
$          endif
$!
$          wo "$ DELETE "vvv'.*;*"
$!
$! Go get the next radius
$!
$          radposn = radposn + 1
$          goto RADIUS_LOOP
$!
$no_more_lines:
$ outfile_OK = TRUE
$ close outfile
$ close winfile
$ ws "Found "count' observation windows in "winname'"
$ ws "Command file "outname' ready for submission"
$ exit
$no_such_file:
$          ws "Error opening file "winname'"
$          exit
$!
$exit_and_tidy:
$          on error then continue
$          if f$trnlnm("outfile").nes."" then close outfile
$          if f$trnlnm("winfile").nes."" then close winfile
$          if .not.outfile_OK then delete 'outname'
$          exit
$!
$exit_neatly:                  ! ^Z to a question
$          exit
```

APPENDICES TO CHAPTER 7

The tables included in these appendices are relevant to the analyses in chapter 7.

CONTENTS:

Vegetation Category	Proportion of Total Effort Prior to the Nesting Season	Proportion of Total Effort During the Nesting Season
Post-thicket Forestry	0.030	0.018
Pre-thicket Forestry	0.082	0.053
Heather Moorland	0.065	0.066
Blanket Bog	0.196	0.217
Wet Heath	0.255	0.297
Agricultural Grassland	0.078	0.068
Perenial Grassland	0.216	0.135
Broad Leaf Woodland	0.057	0.105
Mixed Woodland	0.020	0.041

Appendix 5: Proportional effort in each habitat for periods prior to and during the nesting season for the foot survey.

The vegetation cover in each grid square was described using the classified satellite image. Sample counts of pixels representing each cover type present were made in each grid square. The product of the count for each cover type and number of visits to each grid square was summed across all grid squares visited to provide an index of observer effort in each habitat.

Vegetation Category	Proportion of Total Effort Prior to the Nesting Season	Proportion of Total Effort During the Nesting Season
Post-thicket Forestry	0.054	0.051
Pre-thicket Forestry	0.152	0.154
Heather Moorland	0.071	0.079
Blanket Bog	0.162	0.150
Wet Heath	0.099	0.031
Agricultural Grassland	0.156	0.196
Perenial Grassland	0.169	0.189
Broad Leaf Woodland	0.103	0.114
Mixed Woodland	0.033	0.038

Appendix 6: Proportional effort in each habitat for periods prior to and during the nesting season for the vehicle survey.

The vegetation cover in each grid square was described using the classified satellite image. Sample counts of pixels representing each cover type present were made at regular intevals along each road section. The product of the count for each cover type and number of journies along each road section was summed across all road sections to provide an index of observer effort in each habitat.

Vegetation Categories	Observations Prior to the Nesting Season			Observations During the Nesting Season		
	Perched	Hunting Flight	Non Hunting Aerial Activity	Perched	Hunting Flight	Non Hunting Aerial Activity
Post-thicket Forestry	0	0	3	1	0	1
Pre-thicket Forestry	0	2	8	2	5	0
Heather Moorland	0	3	0	0	0	4
Blanket Bog	2	0	3	2	2	7
Wet Heath	1	0	4	0	0	1
Agricultural Grassland	0	0	6	0	1	3
Perenial Grassland	0	7	22	3	0	36
Broad Leaf Woodland	2	2	3	0	1	5
Mixed Woodland	1	0	0	0	0	8

Appendix 7: Frequencies of observations, made during foot survey, of buzzards in each vegetation cover type broken down by activity and between the periods prior to and during the breeding season

Vegetation Categories	Observations Prior to the Nesting Season			Observations During the Nesting Season		
	Perched	Hunting Flight	Non Hunting Aerial Activity	Perched	Hunting Flight	Non Hunting Aerial Activity
Post-thicket Forestry	0	9	10	0	1	1
Pre-thicket Forestry	6	4	4	0	2	3
Heather Moorland	3	0	2	1	1	2
Blanket Bog	3	3	7	1	1	3
Wet Heath	7	1	4	0	1	0
Agricultural Grassland	1	4	8	2	0	8
Perenial Grassland	17	5	18	1	5	6
Broad Leaf Woodland	3	8	17	1	0	5
Mixed Woodland	0	1	10	0	1	1

Appendix 8: Frequencies of observations, made during vehicle survey, of buzzards in each vegetation cover type broken down by activity and between the periods prior to and during the breeding season