The Ecology and Conservation of Hen Harriers (*Circus cyaneus*) in Ireland

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DECLARATION

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

Barry G. M. O'Donoghue
Béal na Sionainne,
September 2010

Dedicated to the memory my two young friends

Simon O’Hehir (RIP 18th April 2006) and Andrew McAllen (RIP 11th May 2009).

We set out together on this road of education.

We swooped, we looped, we climbed and dove,
we travelled at speeds like I've never known.
So fast a thing, so alien so strange,
yet within this beast I was at home.

Guy Stimpson. Dark Angel. 2007.

ABSTRACT

This research has been designed and undertaken to aid the understanding and knowledge of the Hen Harrier in Ireland. Year-round breeding and non-breeding ecology, breeding performance, habitat use, diet, movements and survival are all investigated to enable better conservation planning for this threatened and vulnerable bird of prey. A review of the history and assessment of current status in Ireland showed the Hen Harrier to have declined both in numbers and distribution, with further declines likely if appropriate action is not taken. Diet was found to be diverse; with passerines the most popular prey type, supplemented by small mammals, lagomorphs, waders, amphibians and reptiles. Meadow Pipit (*Anthus pratensis*) was the single most common prey species taken. Scrub and hedgerows held highest numbers of prey, while clearfelled forest and intensive grassland were poorest. Investigation of nest sites showed a bias towards nesting more in glens and further up hills than might have been expected by chance (random control nests). Three habitat categories were used for nesting; namely scrub, heather/bog and restock forest. Within these categories, five microhabitats were used, namely Bramble (*Rubus* spp.), Heather (*Calluna* spp. and *Erica* spp.), Rush (*Juncus* spp.), Gorse (*Ulex* spp.) and Bracken (*Pteridium* spp.). Breeding success and productivity varied between study areas. Population viability analysis predicted that populations in two of the areas may become extinct, while the other two are likely to remain viable. This study has shown that Ireland has one of the lowest breeding fecundities of any population in Europe and predation is a more significant issue than previously considered. Between 2005 and 2008, a total of 52 non-breeding roosts were located across the country, in both upland and lowland locations. Roost sites were typically undisturbed with rank vegetation, offering shelter and protection. The Hen Harrier was more widespread in distribution during the non-breeding season than in the breeding season. Movements by wing-tagged harriers showed a predominantly easterly or north-easterly movement. Apparent juvenile survival rate was calculated as approximately one in four, with the survival rate of young male harriers lower than that of females. For the first time, Hen Harriers were shown to travel outside of Ireland, providing basis for a British and Irish metapopulation hypothesis, given British Hen Harriers regularly travel to Ireland. Conservation recommendations aimed at improving the situation for Hen Harriers in Ireland revolve primarily around habitat management.

MÍLE BUÍOCHAIS

The first person I would like to thank is Cathryn Hannon of the National Parks and Wildlife Service. At the very earliest stages, Cathryn realised the necessity of this research and how it would first and foremost help the Hen Harrier and secondly, help Ireland meet its obligations under the EU Bird's Directive. I would also like to thank my immediate line manager Declan O'Donnell, as well as Frank McMahon, Aonghus O'Donnell and Jervis Good for their support throughout.

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happened in our conversation, linking past, present and future. I've been privileged to have many such encounters with old and young generations during the course of my work as a ranger and during my research. There is no doubting the importance of mindful stewardship to the future survival of the Hen Harrier on the Irish landscape.

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Finally, to the two most important women in my life, Joanne and Martina. I’m the luckiest man in the world to have you both. I don’t know how to begin thanking you for everything, so instead of writing on a piece of paper, I vow to do so in my actions for the rest of my days.

John and Kathleen Pender (27 May 2008), custodians of Hen Harrier habitat in Cahermurphy since 1916.

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GLOSSARY OF TERMS USED IN THESIS

Apparent Survival Rate	As tagged harriers are theoretically capable of remaining unreported, apparent survival rate accounts for those harriers which have been reported, plus an estimate of those which are unreported but still alive.
Aspect	The direction which a site faces.
Breeding Area	Assemblage of breeding territories in a given area; usually associated with a mountain range.
Breeding Dispersal	Movement of individual in terms of nesting site in different years.
Breeding Distribution	The arrangement or spread of nests in a given area.
Breeding Female	Female that has made a nest.
Breeding Productivity	Measured in terms of the number of chicks reared by all breeding females (including those that failed to rear any chicks), and/or the number of chicks reared by females that were successful in their attempts to rear chicks.
Breeding Range	The geographical extent of national or international populations.
Breeding Season	Time of year during which breeding takes place, roughly equating to spring and summer.
Breeding Site	Site where a breeding territory or nest has been confirmed.
Breeding Success	Percentage of breeding females which were successful in rearing at least one chick.
Breeding Territory	Area of undefined size occupied by a resident pair of Hen Harriers.
Brood Size	Number of chicks in nest.
Clearfell	Commercial forest plantation that has been felled and has had the timber removed.
Clutch Size	Number of eggs in nest.
Commercial Forestry	The process of growing trees for monetary profit.
Communal Roosting	The activity of roosting in numbers.
Core Breeding Density	The highest number of breeding females within 100km^2 zone for a given breeding area.
Core Nesting Zone	2m radius around nest.
Designated Area	An area protected for its ecological value.
Fecundity	Reproductive capacity.
Fen	Wetland fed by mineral-rich surface water or groundwater.
First Rotation (Forest)	Commercial forest that has been planted in a site for the first time.
Fledged Brood Size	Number of nestlings which fledged from a brood.
Fledgling	A chick which has recently gained the ability to fly.
Foraging	The activity of searching/hunting for food.
Foraging Range	The extent of an individual's hunting area.
Geographical Information System (GIS)	A computer system using cartography and databases to capture, store, analyse, manage and present data that are

	linked to location
Global Positioning System (GPS)	Global navigation system that provides details on location
Habitat Management	The process of maintaining or manipulating a given habitat.
Habitat Value	The usefulness of a habitat to Hen Harriers.
Heather/Bog	Habitat with peat substrate dominated by peatland vegetation.
Hedgerow	Field boundary typified by shrub vegetation.
Intensive Grass(land)	Grassland/pasture intensively managed, with little vegetative species other than grasses.
Juvenile Dispersal	Movement of a juvenile from natal site.
Lagomorph	In this thesis refers to rabbits and hares.
Lowland	Ground lower than 100m above sea level.
Mature Forest	Commercial forest that has surpassed thicket stage.
Migrant	Species that arrives in an area and leaves again, usually on a seasonal basis.
Migration	Movement to an area and back.
Mortality Rate	The percentage of Hen Harriers alive on a given day that are dead one year later.
Natal Dispersal	Movement of individual from natal site to place of first breeding.
Natal Philopatry	The relationship that Hen Harriers have with the site in which they were reared, when it comes to their own breeding attempts.
Natal Site	Birth place.
Natural Heritage Area (NHA)	Area considered by the Irish government as important for the habitats or species present.
Nearest Neighbour Distance	Distance between a nest and its closest neighbour.
Nestling	A chick in the nest, not yet fledged.
Non-breeding Area	Area where Hen Harriers frequent during the non-breeding season.
Non-breeding Roost	Place of (night-time) rest during the non-breeding season.
Non-breeding Season	Time of year during which the majority of birds are not breeding, roughly equating to autumn and winter.
Passerine	Bird of the order Passeriformes, which includes perching birds and songbirds.
Pellet	Casting of indigestible material from prey regurgitated by bird of prey.
Polyandry	The pairing of a female with more than one male.
Polygyny	The pairing of a male with more than one female.
Prey Delivery Rate	The amount of food delivered to a nest or nests in relation to time.
Reedbed	Area dominated by reeds (*Phragmites* spp.).
Restock (Forest)	Commercial forest that has been harvested and replanted.
Ringtail	Brown Hen Harrier, including adult females and juveniles of either sex.
Riparian	Associated with rivers and/or streams.
Roosting	The activity of resting overnight.

Rough Grass(land)	Grassland/pasture not intensively managed, often dominated by rushes (*Juncus* spp.).
Scrub	Area of shrub species that have not exceeded 5-6m in height.
Second Winter Male	Male Hen Harrier in second winter or third calendar year spring.
Site Fidelity	The relationship with a given site, at any time of year.
Sky Dance / Sky Dancing	The Hen Harrier's courtship display.
Small Mammal	In this thesis includes any mammal up to and including the size of Brown Rat (*Rattus norvegicus*).
Special Area of Conservation (SAC)	Areas of significance for the conservation of special habitats which have been designated under the EU Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (commonly referred to as the Habitats Directive).
Special Protection Area (SPA)	Areas of significance for the conservation of special habitats which are important for birds and have been designated under the EU Council Directive 79/409/EEC on the conservation of wild birds (commonly referred to as the Birds Directive).
Species Richness	The number of species in a given area or habitat.
Stooping	Defensive behaviour/mobbing action.
Survival Rate	The percentage of Hen Harriers alive on a given day that are alive one year later.
Tracking	The process of following the movements and survival of individuals.
Turbary	Area cut and harvested for peat (turf).
Upland	Ground higher than 100m above sea level.
Wader(s)	Group of birds with long-legs, associated with water, often living along shores, bogs or marshes.

Mean values are given plus or minus standard error (± s.e.).

All statistical tests are performed at the 0.05 level of significance (unless Bonferroni corrected).

Scientific names of species are presented at their first mention in each chapter.

All photographs and graphics by the author, Barry O'Donoghue, unless otherwise stated.
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PREFACE

This thesis is a composite of research into various aspects of the ecology of one of Ireland's rarest and most threatened birds of prey, the Hen Harrier (*Circus cyaneus*). While wide-ranging in its scope, there is one common objective: to inform a better understanding of the Hen Harrier's ecology in Ireland, so that appropriate conservation measures can be undertaken for the future of the species on this island. Until recently, the Hen Harrier has been poorly studied in Ireland and it has been usual to look to research on the nearest populations in Britain for knowledge. While such research from abroad has been, is and will continue to be useful in many ways, the Irish situation is not necessarily identical, or even similar to that elsewhere. The following chapters address key elements of Hen Harrier ecology; in all cases for the first time on a comprehensive and national scale in Ireland.

Chapter 1. Introduction

An introduction to the Hen Harrier across its global range, with particular reference to those features at the core of the current research. Taxonomy, distribution, appearance, habitats and biology are all addressed in a wide-ranging yet pertinent review. As this is the first Ph.D. undertaken on Hen Harriers in Ireland, the literature review should also serve as a bank of knowledge for future study of the species here.

Chapter 2. The Hen Harrier in Ireland

A review of the status of the Hen Harrier in Ireland, from earliest records to most recent; documenting likely causes of why the Hen Harrier has gone from being *"often met with"* to "*scarce"*. This review sets the current research in context, given a threatened population, with relatively little scientific study undertaken to date.

Chapter 3. Prey

A study of the Hen Harrier's diet, including a comparison of food provisioning rates between areas and an investigation of habitats in terms of prey availability. Identifying what Hen Harriers eat is imperative for any proactive habitat management or habitat protection. Furthermore, establishing prey delivery rates can give insight as to why some areas have higher breeding productivities than others. A baseline is thereby provided for future studies on diet and population trends.

Chapter 4. Nest Sites

The nest site associations of Hen Harriers are explored in order to determine the habitats used for nesting and the features that play a part in nest site selection. Such knowledge will facilitate a better understanding of habitat requirements, while data collected on nest sites are also useful in establishing the key factors affecting breeding success (Chapter 5, Breeding Ecology). In addition, the methods by which nest sites were located are documented, to advise future survey techniques.

Chapter 5. Breeding Ecology

This chapter examines the performance of breeding Hen Harriers in terms of success and productivity. The factors that are most highly influential on these parameters are established. Such information signals the fecundity of the Irish Hen Harrier breeding population and can be used in population viability analysis to determine whether the population here is likely to grow or decline.

Chapter 6. Non-breeding Ecology

The non-breeding season is studied so that a more complete understanding of Hen Harrier ecology in Ireland may be gained. This chapter is essentially built upon the first three winters of the Irish Hen Harrier Winter Survey. This national survey was founded by the author in 2005, to determine the distribution, habits and habitats of the Hen Harrier during this crucial time of the year.

Chapter 7. Movements and Survival

Hen Harriers are tracked from their natal sites by means of colour wing tags. In doing so, it is determined where Hen Harriers go upon leaving the nest, while survival rates to adulthood are also calculated. Links between breeding and non-breeding areas are established, as are fidelity to natal areas and winter sites. In general, an insight to this little understood aspect of Hen Harrier ecology is provided.

Chapter 8. Synthesis

In the final chapter, the findings of the previous chapters are summarised and integrated, to provide an overall view of what has been discovered about Hen Harriers in Ireland, arising from this research. An assessment of the conservation status of Hen Harriers in Ireland is made, using data from Chapter 5 (Breeding Ecology) and Chapter 7 (Movements and Survival), as well as general information garnered throughout the entire thesis. Recommendations are made for future conservation management and key areas for future research are identified.

Chapter One

Introduction

A hugh blue bird will often swim
Along the wheat when skies grow dim
Wi clouds – slow as the gales of spring
In motion wi dark shadowed wing
Beneath the coming storm it sails.

John Clare. The Shepherd’s Calendar. 1823.

The main aim of this chapter is to gather information and report on various aspects of the Hen Harrier's ecology, to serve as a basis from which to progress subsequent chapters and act as a bank of knowledge for those working on the species in the future.

1.1 Taxonomy, Distribution, Population and Conservation

The Hen Harrier (*Circus cyaneus*, Linnaeus, 1766) is of the order Falconiformes, family Accipitridae, and genus *Circus*; the harriers. There are sixteen recognised species of harrier worldwide (Simmons, 2000), but the Hen Harrier is the only regularly breeding harrier in Ireland. European (Western) Marsh Harrier (*Circus aeruginosus*) and Montagu's Harrier (*C. pygargus*) have bred in Ireland, though are largely confined to historical records or rarities (Gibbons *et al*., 1993; D'Arcy, 1999; Dempsey and O'Clery, 2002; but see Scott *et al*., 2010).

The Hen Harrier is the most northerly of four Western Palaearctic harriers (it breeds within the Arctic Circle in Scandinavia and Northern Russia) and has the widest distribution; extending from as far west as Ireland to as far east as Kamchatka and Sakhalin (Watson, 1977; Hagemeijir and Blair, 1997; Simmons, 2000; Ferguson-Lees and Christie, 2005). In winter, eastern populations can migrate to extend the Hen Harrier's range as far south as Iran, northern India, Myanamar and Vietnam (Watson, 1977), while the most southerly breeding area is central-southern Spain (Hagemeijir and Blair, 1997; García and Arroyo, 2001). Sympatric harriers include the Montagu's Harrier; the European (Western) Marsh Harrier; the Eastern Marsh Harrier (*C. spilonotus*); the Pallid Harrier (*C. macrourus*) and the Pied Harrier (*C. melanoleucos*) (Ferguson-Lees and Christie, 2005). The Northern Harrier (*C. hudsonius*) was until 2000, classed as the same species as the Hen Harrier, but modern phylogenetic investigations have revealed the two to be separate species (Simmons, 2000; Wink and Sauer-Gürth, 2004). Given their close relationship (and treatment as the same species in much of the literature), a number of references to Northern Harriers are made throughout this thesis.

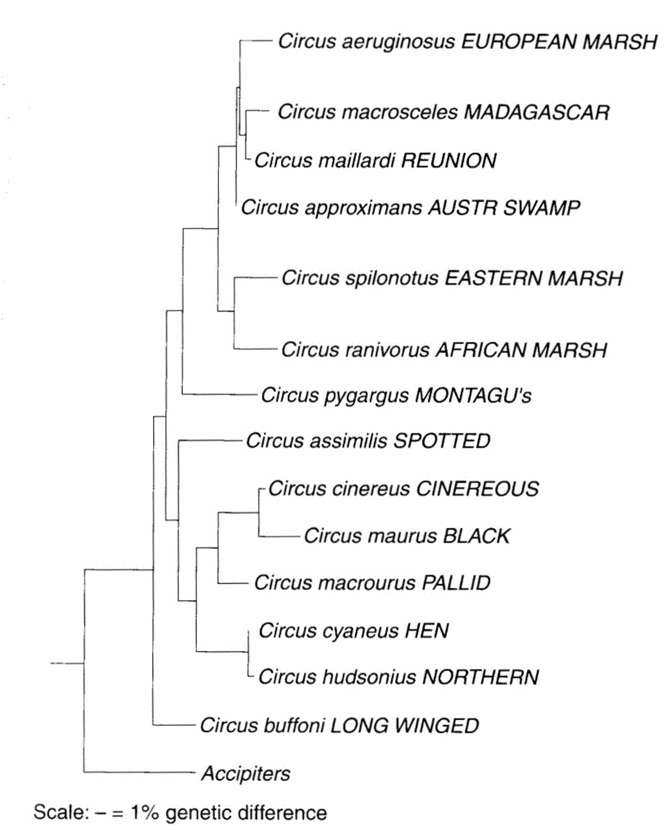

Figure 1.1. Phylogenetic tree of the genus *Circus* (from Simmons, 2000). Two additional species identified by Simmons in the same book are not included; Pied and Papuan Harriers (*Circus melanoleucos* and *C. spilothorax*).

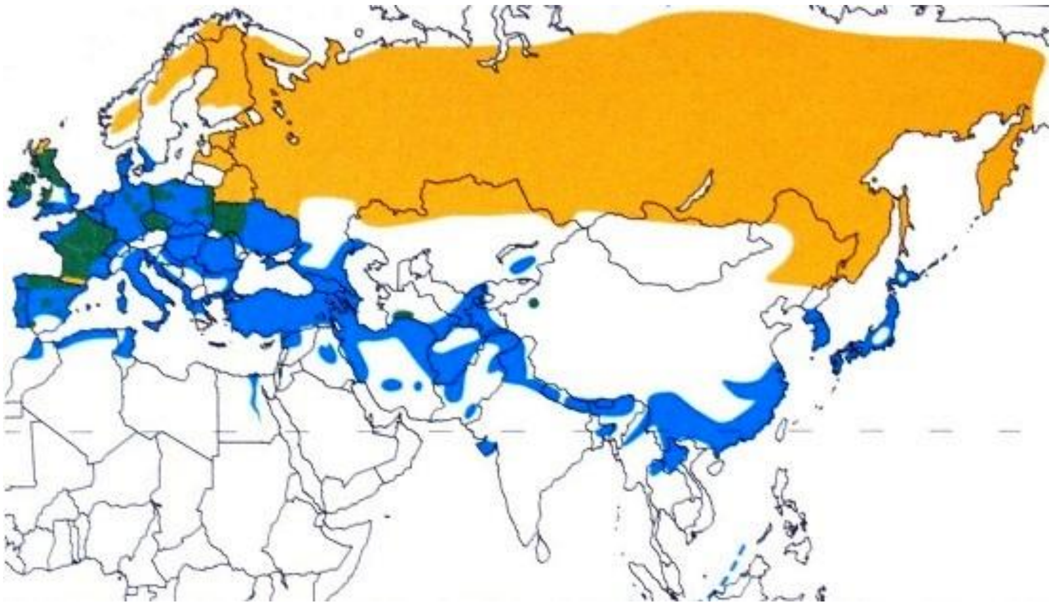

Figure 1.2. Global Distribution of the Hen Harrier (*Circus cyaneus*).

Green = resident; orange = breeding season only; blue = non-breeding season only.

(From Ferguson-Lees and Christie, 2005).

Globally, Hen Harriers are in decline, although the IUCN considers the Hen Harrier as of Least Conservation Concern (del Hoyo *et al*., 1994; BirdLife International, 2009). This consideration is disputed by Dobson (2009), who identifies a lack of information on populations across Europe and particularly in Asiatic Russia, where the majority of individuals are thought to occur (BirdLife International, 2004a). In addition, the IUCN categorises the Hen Harrier and Northern Harrier as one species. In Europe at least, the Hen Harrier is considered as one of the birds of greatest conservation concern and is assigned to SPEC (Species of European Conservation Concern) Category 3 (Tucker and Heath, 1994). Category 3 species are species whose global populations are not concentrated in Europe, but which have an unfavourable (vulnerable) conservation status in Europe (Burfield and von Bommel, 2004). Recent centuries have witnessed a serious decline in the Hen Harrier population (Ferguson-Lees and Christie, 2001), with BirdLife International (2004b) estimating the population of the European Union at 11,000 – 18,000 pairs.

Tucker and Heath (1994) listed habitat loss, change and fragmentation as the most common negative influences on diurnal bird of prey species with unfavourable conservation status in Europe. The same authors classed the Hen Harrier as the most vulnerable of harriers in Western Europe. The main threats to Hen Harriers are forestry (O'Flynn, 1983; Clarke and Watson, 1997), agriculture (Millon *et al*., 2002; Amar and Redpath, 2005), human development (Scott, 2000; Tapia *et al*., 2004); destruction of wetlands (Clarke and Watson, 1990; Ganesh and Kanniah, 2000) and persecution (Blake, 1976; Etheridge *et al*., 1997; Potts, 1998; Stott, 1998; Thirgood *et al*., 2000; Summers *et al*., 2003; Natural England, 2008; Whitfield *et al*., 2008; Fielding *et al*., 2009; Redpath and Thirgood, 2009). As with Peregrine Falcon (*Falco peregrinus*) (Ratcliffe, 1969 and 1970), organochlorine pesticides negatively impacted on harrier populations in the past (Hamerstrom, 1969 and 1986; Anderson and Hickey, 1972; Bijleveld, 1974; Noble and Elliot, 1990; MacWhirter and Bildstein, 1996). However, because Hen Harriers in Britain and Ireland were mostly removed from arable areas during the breeding season, they were not as heavily affected as other raptors (Clarke, 1990). Habitat loss has been cited as the main cause of population decline in the Northern Harrier (Adams *et al*., 1988).

Across the EU, as an Annex I species of the EU Birds Directive (The Council of the European Communities, 1979), *Circus cyaneus* is prioritised in terms of protection of individuals, populations and habitats. Article 4(1) of the Birds Directive requires Member States *"to classify in particular the most suitable territories in number and size as special protection areas..."*. The Directive states *"The species mentioned in Annex I shall be the subject of special conservation measures concerning their habitat in order to ensure their survival and reproduction in their area of distribution"*. The Hen Harrier is also listed on Appendix III of the Bern Convention 1979; Appendix II of the CITES Convention 1975 and Appendix II of the Bonn Convention 1982, and is protected by national legislation across different countries.

1.2 Description

Harriers are typified by slightly long wings and a light body, meaning a high wing to weight ratio, which allows highly skilled and seemingly effortless flight (Simmons, 2000). The wings of the Hen Harrier are usually held in a shallow dihedral ('v' shape) when flying (Watson, 1977). In comparison to other European harrier species, the Hen Harrier is smaller, slimmer and narrower-winged than the Marsh Harrier, but larger and broader-winged than Montagu's Harrier and the Pallid Harrier. It also has relatively short wing-tips and a relatively high tail to wing length ratio (Witherby *et al*., 1939; Nieboer, 1973; Watson, 1977). These differences in morphology allow the Hen Harrier to be more agile and more manoeuvrable, thereby reducing competition with the other sympatric *Circus* species (Schipper, 1973 and 1977; Schipper *et al.*, 1975).

The Hen Harrier displays reversed size dimorphism, as do all harriers (Simmons, 2000). Female Hen Harriers have a mean body mass of 500g; wing length of 381mm; tarsus length of 75.3mm and tail length of 381mm. Their smaller male counterparts have a mean body mass of 340g; wing length of 344mm; tarsus length of 69.4mm and tail length of 220mm (Nieboer, 1973). As well as differences in size, adult males and females differ remarkably in plumage, so much so, that for many centuries, the two were thought to be separate species (Watson, 1977)[1]. Even today, Hen Harriers are classed as either 'greys' (adult males and second winter males) or 'browns' or 'ringtails' (adult female and juveniles of either sex).

The adult male has silver/bluish-grey upperparts, head, throat and upper breast, with large black patches on the outer-wings extending to the primaries. Underparts are

[1] John Ray, in Nicholson (1926) is credited with the 'discovery' in 1678 and not Dr. Heysham in the late 18th century as credited by Watson (1977). Montagu (1892) clarified the matter beyond doubt by rearing three young harriers in captivity, one of which was male and moulted to grey plumage.

white and unmarked and there is a dark trailing edge to translucent white secondaries. The wings of males are relatively narrower than those of females.

The adult female is predominantly brown and is finely streaked on the underparts and underwing, with broad blackish-brown barring on the primaries, secondaries and tail. There are two white bands across the secondaries and rufous blobs on the undertail coverts. There is a large white patch on the uppertail coverts. The owl-like face is streaked brownish-buff, with a slightly darker crescent on the ear-coverts, which is separated by a very narrow pale collar from a ruff of dark streaks extending to the breast.

Juveniles of either sex, being brown in colour, resemble the adult female. Their plumage however (until at least mid-first winter) is a darker brown, and they have ochre/rusty underparts, whereas adult females are paler underneath. Tips to the upperwing coverts stand out as a pale/yellow line along the middle of each wing against the dark brown backs and are more obvious than with adult females. Juvenile secondaries look darker than the primaries and have pale/greyish bands, whereas the adult female has two white bands across the secondaries with more distinct barring. Cheek patches on the face can look darker than on adult females and the wings of juveniles appear narrower than on adult females. As nestlings, male and female Hen Harriers can be distinguished by iris colour; the males having greyish eyes and the females having dark brown eyes. Both the male and female eye colours will gradually turn to yellow, and become paler with time (Hamerstrom, 1968; Scharf and Balfour, 1971). Tarsus size can also be used to sex young, with only females having tarsi wider than 3.60mm (B. Etheridge and S. Murphy, pers. comm.; pers. obs.). For those familiar with Hen Harriers, the easiest way to determine between male and female juveniles in flight is size (females being larger).

Second winter males (including males in 2^{nd} calendar year autumn/3^{rd} calendar year spring) have moved closer to their adult plumage by moulting, but can retain juvenile feathers on the breast, rump or wing, but mainly on the crown. These males have duller-grey upperparts than adult birds and appear ‘dirty’ looking.

1.3 Landscape and Habitats

Harriers are essentially birds of open landscapes. Steppe, savanna and other grasslands, open taiga, heathlands, moors and bogs, young forests, cropland, wetland borders, scrub, marshes, reedbeds and coastal sand dunes have all been named among the habitats of the Hen Harrier (Dementiev *et al*., 1951; Balfour, 1962a; Schipper, 1973 and 1978; Watson, 1977; Cramp and Simmons, 1980; Boedeltje and Zulstra, 1981; Martin, 1987; Shepel, 1992; Tucker and Heath, 1994; Arroyo, 1996; Petty and Anderson, 1996; Redpath *et al*., 1998; García and Arroyo, 2001; Norriss *et al*., 2002; Millon *et al*., 2002; Barton *et al*., 2006; Klaassen *et al*., 2006; Sim *et al*., 2007; Cormier *et al*., 2008).

According to O'Donoghue (2004), the Irish Hen Harrier breeding landscape is typically in upland (>100m above sea level) dominated by farming (almost exclusively pastoral based livestock holdings; often rush-covered and typified by bushy hedgerows); active and degraded peatland (usually blanket bog) with Purple Moor-grass (*Molinia caerulea*) and heather (namely Ling (*Calluna vulgaris*), Cross-leaved Heath (*Erica tetralix*) and Bell Heather (*Erica cinerea*)); scrub (particularly Gorse (*Ulex* spp.), Willow (*Salix* spp.), Alder (*Alnus* spp.) and Birch (*Betula* spp.); and woodland (chiefly commercial plantations of the exotic species Sitka Spruce (*Picea sitchensis*) of different ages, with some natural or planted native woodlands). Wind farming has become a recent (generally post-2000) addition to this same landscape. Wintering habitats, commonly in lowland locations, include farmland (both pastoral and arable), bogland (including blanket and raised bogs, fens and reedbeds), scrub, estuaries and sand dunes (O'Donoghue, 2004).

Plate 1.1. Portraits of Hen Harriers (from Clark and Schmitt, 1999).

1.4 Breeding Biology

In early spring time, groups of harriers (typically four to six birds) may congregate in an area, prospecting for and visiting neighbouring territories (Balfour, 1962b). To claim territory and a mate, male harriers engage in spectacular courtship displays, eloquently coined by Hamerstrom (1969) as *sky dancing* (Plate 1.2). Sky dances are an effort on behalf of the male to advertise his prowess, skill, strength, agility and stamina to potential mates, and personal observations have shown such displays to last up to twenty minutes without break. Females may also partake in sky dancing, sometimes quite vigorously, but normally to a lesser extent than the males. In the mid to late 1970s in Orkney, there was such an imbalanced sex ratio in favour of females that it was more common to witness displaying females than males (Picozzi, 1984a). Adult males may display more often and more intensely in food-rich than food-poor years (Simmons, 1988a), while precipitation reduces its frequency (Follen, 1986).

Hamerstrom (1969) found that Northern Harriers showed virtually no pair fidelity from year to year, as only about 2% of females paired with a given male more than once, while Burke (1979) found just one in three birds returned to the same site in different years. Hen Harriers show a higher degree of mate fidelity (Picozzi, 1984b). Extra-pair copulations are also known to occur (Hamerstrom, 1969; Picozzi, 1984a; pers. obs.). During the courtship and early breeding period, females occasionally abandon prospective partners, principally those with low courtship-provisioning rates, implying active mate choice by females (Simmons *et al*., 1987). Some monogamous males also reject additional females (Simmons *et al*., 1987; Simmons, 1988b; pers. obs.). Once incubation has begun however, females rarely desert their mate (Simmons *et al*., 1987). Hen Harriers can breed in their first year, though most males probably don’t get a good chance to breed until their second year (Watson, 1977; Picozzi, 1984b; Etheridge *et al*., 1997; Millon *et al*., 2002; Whitfield and Fielding, 2009; pers. obs.).

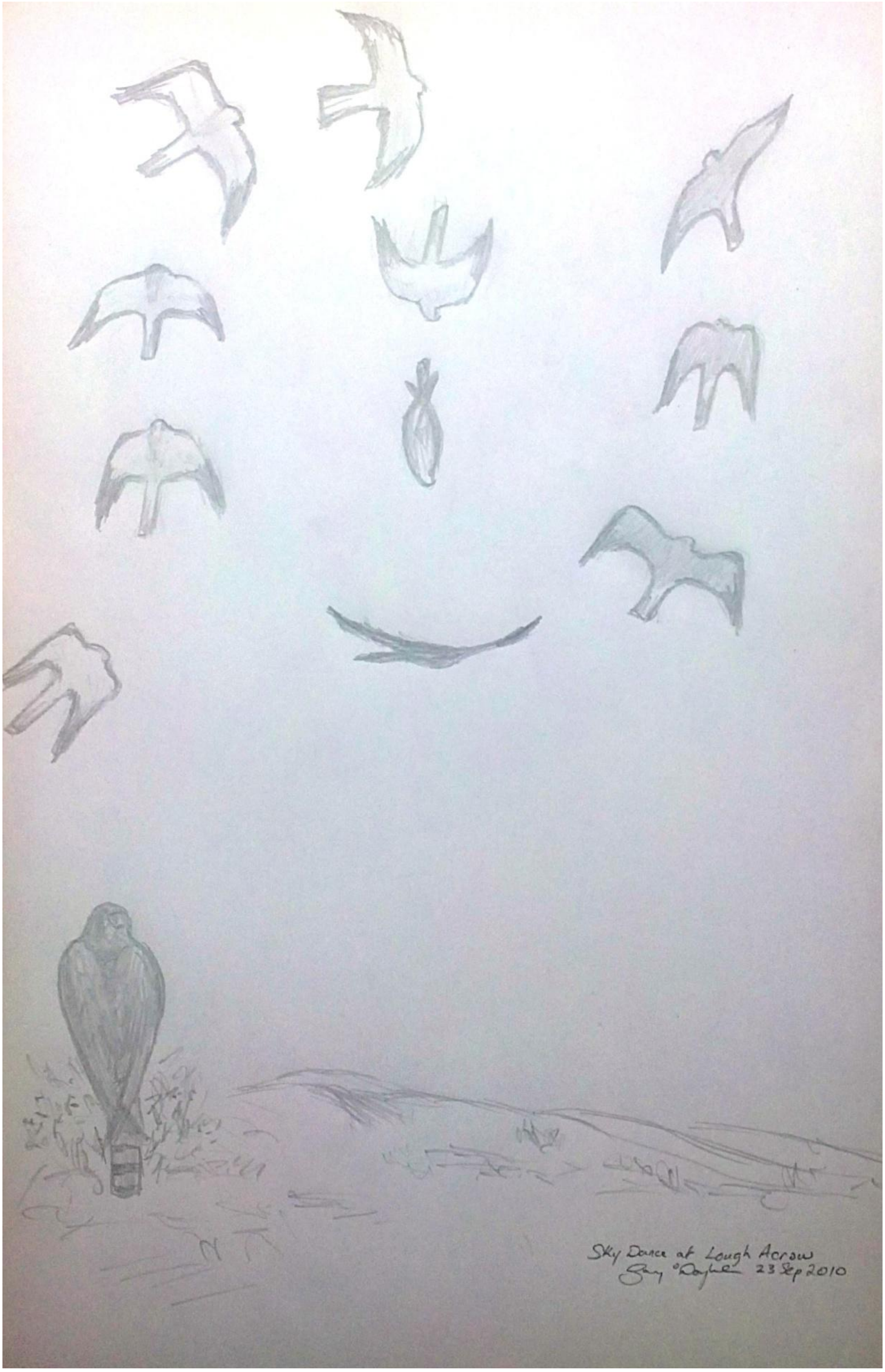

Plate 1.2. The Hen Harrier’s sky dance.

1.4.1 Polygyny

Polygyny is known in at least nine (out of 36) European raptor (Accipitriformes and Falconiformes) species (Korpimäki, 1988) and is regularly recorded with Hen Harriers (Watson, 1977; Schipper, 1978; Balfour and Cadbury, 1979; Picozzi, 1984b; Klaassen *et al*., 2006), in fact more frequently than with any other raptor species (Simmons *et al*., 1986a). 'Harems' of up to seven females per male have been reported in Holland (Daemen and Lorij, 1970) and Scotland (Balfour and Cadbury, 1979), though polygyny usually involves one male and two females (Simmons, 2000). While polygyny has been noted with Hen Harriers in Ireland (Jones, 1981; Ruddock *et al*., 2008; Scott, in press; pers. obs.), it does not appear to be commonplace and most pairings are monogamous (Ruddock *et al*., 2008; Scott, 2008; pers. obs.). In fact, polyandry (a female mated with more than one male) appears to be as common here as polygyny (O'Donoghue, 2008; Scott and Hipkiss, 2006).

First year males are mainly monogamous and polygyny is usually found among older, more experienced males (Balfour and Cadbury, 1975; Picozzi, 1984b; Hamerstrom, 1986; Simmons *et al*., 1986b). Polygynous breeding is usually associated with productive habitats, an abundance of food (Verner and Willson, 1966; Hamerstrom, 1969; Picozzi, 1984b; Simmons *et al*., 1986a and 1986b; Korpimäki, 1988; MacWhirter and Bildstein, 1996) or sex ratio (Balfour and Cadbury, 1979; Picozzi, 1984b; England, 1989).

While polygyny allows more breeding attempts to take place, particularly in populations where there are more females than males, it leads to increased demands on the male, which can have negative consequences for the nests involved. Within harems, there is a hierarchy, with primary females receiving most attention from males, laying eggs the earliest, hatching most eggs, suffering least predation and rearing most young (Balfour and Cadbury, 1979; Simmons *et al*., 1986a; Picozzi, 1984b; Simmons, 2000; Amar *et al*., 2003a and 2005). Balfour and Cadbury (1975) and Simmons (2000) argued that overall, the breeding success of a population is not negatively affected by polygyny.

1.4.2 Nesting

When mates have been selected, nesting takes priority. Nest site selection for birds is chiefly associated with safety, shelter and proximity to food resources (Newton, 1979; Janes, 1985; Walsberg, 1985; Simmons and Smith, 1985; Martin, 1993; Redpath and

Thirgood, 1999; Redpath *et al*., 2002a,b; Quinn and Ueta, 2008). In almost all cases across its range the Hen Harrier (as with most of the genus *Circus*) has been noted as a ground-nester, having evolved in open landscapes (Simmons, 2000). Ground-nesting species have devised various strategies to avoid predation from both ground and aerial predators, including nesting on predator-free islands, nesting colonially, nesting in association with fiercer species that will defend the area, and nesting in well concealed or hard-to-access sites (see Simmons and Smith, 1985 for a review). It is the latter strategy of nesting in tall and dense vegetation at secluded sites that appears as a common theme for harrier nest site selection (Balfour, 1962a; Watson, 1977; Schipper, 1978; Hamerstrom and Kopeny, 1981; Apfelbaum and Seelbach, 1983; Simmons and Smith, 1985; Sutherland, 1987; Kantrud and Higgins, 1992; Bibby and Etheridge, 1993; Redpath *et al*., 1998; Millon *et al*., 2002; Klaassen *et al*., 2006; Cormier *et al*., 2008). Unusual cases of nesting in exposed situations have however been documented by Watson (1977) and Schipper (1978). Unsuitable habitats for nesting are identified by Hardey *et al.* (2006) as hill farmland, improved pasture and arable land, degraded land with no heather cover and low vegetation, the vicinity of cliffs, rocky outcrops, boulder fields and scree.

The traditional nesting habitat of Hen Harriers across Britain and Ireland has been heather (Watson, 1977; Clarke, 1990) and there is still a strong association with this habitat in modern times (Etheridge *et al*., 1997; Redpath *et al*., 1998; Arroyo *et al*., 2005; Sim *et al*., 2007; Ruddock *et al*., 2008; Fielding *et al*., 2009). Jones (1981) reported that despite a large area of seemingly suitable forest habitat in south-west Ireland, all nests he observed over a seven year period were situated in tall heather. While not focussed on finding nests, the most recent breeding census for the Republic of Ireland (Barton *et al*., 2006) showed that forest plantation was the most popular nesting habitat in Ireland; with 39.6% of known nests in restock plantations, 21.9% in first rotation forest, 16.7% in heather/bog, 15.6% in post-thicket forest and 6.2% in scrub. Sim *et al.* (2007) estimated 68.0% of Hen Harriers in Britain occupied moorland Land Management Classes (LMCs), while 28.6% were found in afforested LMCs and just 3.4% were found in scrub/brash LMCs.

A rare exception to the rule of ground-nesting is a sub-population in Northern Ireland; breeding 250km from the present study area. There, a small number of harriers have been found nesting in distorted tree tops of conifer trees at heights above ground of 2-13m (Scott *et al*., 1991; Scott, 2008). This rare phenomenon, thought to have been forced largely by a lack of quality ground cover (Watson, 1991; Scott *et al.*, 1993), may ultimately prove maladaptive, given higher failure rates and lower breeding productivity related to chicks falling from their elevated platforms (Scott and Clarke, 2007; Scott, 2008). Tree-nesting is already beginning to show signs of decline as the harriers are moving back to nesting on moorland in the wake of environmental schemes improving heather cover (M. Ruddock, pers. comm.). An apparently once-off tree-nesting event was originally reported by Plesskiy (1971), when a Hen Harrier nest with three feathered young, attended by both parents, was found on a 9m high pine tree in Kirov, European Russia in July 1936.

In Britain and Ireland, Hen Harriers typically nest below 600m ASL (Hardey *et al.*, 2006), while in Spain the mean nesting elevation is 1,009m ASL (Tapia *et al.*, 2004). Northern Harriers have been recorded breeding at elevations greater than 2,400m ASL (MacWhirter and Bildstein, 1996), but are generally found in lowland locations. Watson (1977) suggested that lowland nesting was possible in North America due to a lack of competition with other harrier species such as the Marsh Harrier.

Hen Harriers do not nest in the same site in different years, but can occupy the same territory (Balfour, 1962a; Watson, 1977; Arroyo *et al.*, 2005). Whether it is the exact same pair of birds that occupy a territory from year to year is not definite – in some cases it is (Balfour, 1962a), while in others it is not (Hamerstrom, 1986). In Kerry, one territory has held breeding birds since at least 1974 (T. O'Donoghue, pers. comm.).

Nests are made from vegetative material indigenous to the territory and usually measure 33-51cm in diameter, with varying depths up to 25cm (Balfour, 1962a). Nest construction can be undertaken by both sexes, but the female is the primary builder (Watson, 1977; Balfour, 1962a; Toland, 1985). Both males and females can build 'cock nests' which are not used for nesting (Watson, 1977; pers. obs.).

1.4.2.1 Eggs

Three to seven white eggs (c. 46x36mm) are generally laid (Witherby *et al.*, 1939; Watson, 1977; Cramp and Simmons, 1980). Balfour (1957) recorded 'super-normal' clutches of nine, ten and twelve eggs. Clutch size is closely related to the provisioning of food to the female in the early part of the breeding season (Simmons *et al.*, 1986b; Redpath and Thirgood; 1999; Redpath *et al.*, 2002a). Eggs are laid on alternate days, usually 48 hours apart (Watson, 1977), though sometimes at three or four day intervals or even longer (Witherby *et al*., 1939; S. Murphy, pers. comm.). Though the Hen Harrier is single-brooded, replacement clutches may be laid if the first nest fails relatively early in the breeding season (Hardey *et al*., 2006). Replacement clutches are however, smaller (Etheridge *et al*., 1997). The incubation period typically lasts 28-32 days per egg and normally begins on the first or second egg (Breckenridge, 1935; Witherby *et al*., 1939; Balfour, 1957; Sealy, 1967; Hamerstrom, 1969; Watson, 1977; Cramp and Simmons, 1980; Simmons *et al*., 1986a; MacWhirter and Bildstein, 1996; Millon *et al*., 2002; Hardey *et al*., 2006). The eggs hatch in the sequence in which they were laid (MacWhirter, 1994).

1.4.2.2 Nestlings

The hatched chicks, which are semi-altricial and nidiculous, can be of varying ages, given the asynchronous chronology in which the eggs were laid and hatched (Watson, 1977). They are at first pinkish/white in colour; covered in soft down. At this stage, care and input by the female is most intensive, as without her constant attention, the chicks may succumb to predation or the elements. Contour feathers begin to emerge after about 14 days and soon after, the chicks are capable of thermoregulation and diurnal brooding is phased out, though nocturnal brooding can continue up to when chicks are almost ready to fledge (MacWhirter and Bildstein, 1996). The amount of time the female spends brooding decreases with nestling growth and increasing temperature (Redpath *et al*., 2002c). Female nestlings grow faster than males, but males reach a wing loading which enables them to fly at a younger age than females (Scharf and Balfour, 1971; Scharf, 1992). Juvenile females usually fledge at 35-38 days, while male harriers normally fledge at just 31-34 days (Scharf and Balfour, 1971; Watson, 1977). The weight of males at fledging is approximately 75% that of females (Picozzi, 1980a), so that females may weigh over 100g more than their male counterparts (Watson, 1977).

The sex ratio of nestlings and fledglings can vary between populations, years and individual nests (Schipper, 1978; Picozzi, 1980a; Etheridge *et al*., 1997; Simmons, 2000; Whitfield and Fielding, 2009) and appears to be under the control of parent birds, with females apparently more expensive to rear than males (Riedstra *et al*., 1998; Simmons, 2000).

1.4.3 The Role of Male and Female in Breeding Attempts

The roles of the male and female Hen Harrier during the breeding season are fairly well defined. The female incubates the eggs and broods the young. During this time, she will remain at or within sight of the nest at almost all times (Watson, 1977; Picozzi, 1978; García, 2003; García and Arroyo, 2005). The male is therefore the sole or primary provider for the female and the nest, particularly during the pre-lay, incubation and early brooding stages, up to the point at which the chicks become feathered and the female will begin hunting for food. Clutch size, hatching success and breeding performance are thus heavily dependent on the resourcefulness of the male and the landscape which he hunts (Watson, 1977; Amar and Redpath, 2002; Amar *et al.* 2003a; Arroyo *et al*., 2005). To transfer any captured prey to the female (usually at a distance of 10-200m from the nest), the male drops the quarry in the air, just as the female comes close, and she grabs it in her talons (by banking to one side or turning upside down under the male). This, described by Balfour (1962b) as a *"beautiful piece of behaviour...executed with grace and precision"*, is known as the *food pass* and is a defining characteristic of the harriers (Simmons, 2000). The female is usually vociferous in the lead up to a food pass and immediately after. Incessant begging calls prior to the food pass may elicit the male to drop the food, while further calling after the food pass may signal to the male to go out and provide more food (pers. obs.). When provisioning rates are adequate, the female may not give as many calls (pers. obs.). The female will then bring the food either to the nest or to a preferred plucking stand. Females will not usually bring food back to the nest unless a chick has hatched. Chicks are fed bill-to-bill by the female until they are able to tear up prey for themselves (Watson, 1977).

Plate 1.3. The Hen Harrier's food pass.

As long as the female is adequately provided with food, she does not usually need to leave the immediate nest area unless for a food pass or to fend off intruders. Breeding females generally only began to hunt for food during the nestling period (Martin, 1987; García and Arroyo, 2005). Polygynous females are often forced to begin hunting earlier than those in monogamous relationships (Balfour and Cadbury, 1979; Simmons *et al*., 1986a; MacWhirter and Bildstein, 1996). Overall, females have been found to contribute between a quarter (García and Arroyo, 2005) and a half (MacWhirter and Bildstein, 1996) of the food brought to the nest.

Incubation and care of the young by males has only been recorded on very rare occasions after the death of the female or nest abandonment (Bildstein, 1979b; Thompson and Cornely, 1982). Watson and Dickson (1972) provide a photograph of a male on a nest in 1947. The male Hen Harrier has been found to be more 'attentive' than the male Montagu's Harrier, having been noted in the immediate vicinity of the nest on 20-37% of occasions and hunting more often (García, 2003; García and Arroyo, 2005). However, adult males typically leave the family group earlier than females, though this can differ between individuals and sometimes it is the male that remains with the young the longest (Watson, 1977; Arroyo *et al*., 2005; pers. obs.). Simmons *et al.* (1987) suggested that males departing prior to fledging may be somehow linked to physiological condition.

Picozzi (1984b) found that the number of young a female produced per breeding season increased up until she was five years old, but thereafter productivity declined. Simmons *et al.* (1986a) also offered senescence as a possible explanation for differential breeding fecundities, when younger females were found to be more productive than older females. However, the opposite was found for females in Orkney (Balfour and Cadbury, 1975) while Picozzi (1984b) found young/yearling males to be generally less successful at rearing young than more mature males. Hamerstrom (1969) found younger and older birds equally successful in their breeding attempts. Older (3yr+) females may begin laying earlier than younger (1-2yr) females (MacWhirter and Bildstein, 1996). Breeding productivity may also be a reflection of an individual's breeding capabilities. Picozzi (1984b) for example found the clutch size of individuals (known from wing tags) remained the same across years, while consistent brood sizes for individual females have been found by S. Murphy (unpubl. data).

1.4.4 Sociability and Nest Defence

Hen Harriers can be relatively territorial in the early breeding season (Picozzi, 1984a,b). Thereafter, defensive behaviour is generally seen closer to the nest (Redpath, 1991; MacWhirter and Bildstein, 1996) and normally there is little hostility between neighbouring pairs (Errington, 1930; Balfour, 1962b; Watson, 1977; pers. obs.).

Hen Harriers will share their territory with neighbouring harriers (Watson, 1977; Balfour and Cadbury, 1979; Arroyo *et al*., 2005; Hardey *et al*., 2006), sometimes to the point where nests may be only 20m apart (Balfour, 1962b). There have even been documented instances of two females sharing the same nest (Picozzi, 1983; Scott, in press). David Scott (in Watson, 1977) stated that harrier nests in Ireland were generally one kilometre apart when in sight of one another, and closer if separated by a ridge. Watson (1977) reported regular, but unequal, spacing of 2-3km between nests. Picozzi (1978) recorded an average nearest neighbour distance of 1.52km, while Balfour and Cadbury (1979) found this distance to be 1.10km.

Other birds of prey that Irish Hen Harriers share the uplands with during the spring and summer include Merlin (*Falco columbarius*), Kestrel (*Falco tinnunculus*), Peregrine (*Falco peregrinus*), Sparrowhawk (*Accipiter nisus*), Common Buzzard (*Buteo buteo*), Barn Owl (*Tyto alba*), Long-eared Owl (*Asio otus*) and Short-eared Owl (*Asio flammeus*). Rare, but documented occurrences in Irish Hen Harrier breeding territories include Montagu's Harrier (*Circus pygargus*), Golden Eagle (*Aquila chrysaetos*), White-tailed Eagle (*Haliaeetus albicilla*), Goshawk (*Accipiter gentilis*), Osprey (*Pandion haliaetus*), Red Kite (*Milvus milvus*), Hobby (*Falco subbuteo*) and Snowy Owl (*Bubo scandiacus*) (O'Donoghue, unpubl. data.).

Raven (*Corvus corax*), Hooded Crow (*Corvus corone cornix*) and Magpie (*Pica pica*) are common species in many Hen Harrier territories in Ireland, all of which may predate Hen Harrier eggs and young. Other known and potential predators include Fox (*Vulpes vulpes*), Badger (*Meles meles*), Domestic Dog (*Canis famialis*), Domestic and Feral Cat (*Felis* spp.), Otter (*Lutra lutra*), Pine Marten (*Martes martes*), Stoat (*Mustela erminea*), Hedgehog (*Erinaceus europaeus*), American Mink (*Mustela vison*), Brown Rat (*Rattus norvegicus*), Gulls (Laridae), Jackdaw (*Corvus monedula*), Jay (*Garrulus glandarius*), and other birds of prey including Kestrel (*Falco tinnunculus*) and Common Buzzard (*Buteo buteo*). Sika Deer (*Cervus nippon*) have been recorded trampling harrier nests (G. Oliver, pers. comm.) and it is not impossible that they, or Sheep (*Ovis aries*), may eat harrier eggs, as has been recorded with Red

Grouse eggs (*Lagopus lagopus hibernicus*) (K. Buckley, pers. comm.). Both male and female harriers will vigorously defend the nest site from any intruders, including humans, by means of mobbing (Watson, 1977; García, 2003; Hardey *et al*., 2006; pers. obs.). The impact of predation, which is of great importance in bird populations and requires targeted study (Quinn *et al.*, 2008), has not previously been investigated for Hen Harriers in Ireland.

1.4.5 Timing of Breeding and the Effect of Weather

Breeding phenology is subject to many influences, and can vary spatially and temporally (Etheridge *et al*., 1997; Redpath *et al*., 2001a; García and Arroyo, 2001; Amar *et al*., 2003a and 2005). Simmons *et al.* (1986a,b) and MacWhirter and Bildstein (1996) reported significantly earlier egg laying in years of high, rather than low vole abundance. Clutch size can decline progressively with laying date (Simmons *et al.,* 1986a; Sutherland, 1987; Kantrud and Higgins, 1992; Etheridge *et al.*, 1997; Redpath *et al.,* 2001a) or after the peak laying period (Balfour, 1957). Millon *et al.* (2002) found no relationship with clutch size and date, but found breeding success and productivity decreased with increased laying date, as did Schipper (1978). Newton (1979) linked poor breeding performance by later settling females to a shortage of food; the reason why it took them longer to reach breeding condition in the first instance.

Weather can affect breeding success (see Redpath *et al*., 2002c for a review) and can often have greatest effect at the outer limits of a species range (Ontiveros and Pleguezuelos, 2003). Redpath *et al.* (2002c) found that low temperature, particularly associated with either food scarcity or high rainfall, was an important factor limiting Hen Harrier populations in Scotland. The same study found that in Spain, at the southern part of the Hen Harrier's range, rainfall had a positive effect and increased temperatures had a negative effect of on breeding productivity. It was previously found that lay date in Spain was delayed by the volume of rain between September and March (Arroyo, 1996). Balfour (1957) commented on snow delaying the onset of the harrier breeding season in Orkney. Simmons *et al.* (1986a,b) recorded no significant influence of precipitation or temperature on the onset of egg-laying.

Ireland is one of the wettest parts of the Hen Harrier's global range (Climate-Charts.com, 2007). Rainfall decreases hunting in raptors by increasing foraging costs and the likelihood of catching prey (Ratcliffe, 1980; Elkins, 1983; Redpath *et al*., 2002c). Schipper (1973) found less food was delivered to harrier nests when it rained, while Schipper (1978) found a negative relationship between rainfall and harrier breeding success in the Netherlands, though no apparent effect of temperature.

1.4.6 End of Breeding Season

There are numerous constraints on breeding success and productivity, but how many eggs hatch and how many young fledge is particularly related to food supply (Newton, 1979 and 1998; Hamerstrom *et al*., 1985; MacWhirter and Bildstein, 1996; Redpath *et al*., 2002a,b; Amar *et al*., 2003a,b; Millon, 2006; Fielding *et al*., 2009). Food supply is ultimately related to habitat, especially within 1km of the nest (Amar *et al.*, 2002). Thus, breeding productivity can differ even in the same area, according to habitat, prey availability and year (Watson, 1977; Bibby and Etheridge, 1993; Etheridge *et al*., 1997; Simmons, 2000; Redpath *et al*., 2002a). The chicks which are most at risk of dying in the nest are the youngest chicks (Redpath, 2002c), which are most vulnerable to cold, rain or lack of food (Hamerstrom, 1969; Scharf and Balfour, 1971; Picozzi, 1980a).

Chicks that fledge usually remain in the general nest area for a further two to four weeks after first flight and are tended to by one or both parents until they disperse (Breckenridge, 1932; Witherby *et al*., 1939; Beebe, 1974; Watson, 1977; Beske, 1982; Hamerstrom, 1986; Bildstein, 1992; MacWhirter, 1994). During this pre-dispersal period, they can be seen honing their flying skills and playing with each other and 'mock-killing' inanimate objects (Hamerstrom, 1986; pers.obs.) in advance of becoming independent of their parents.

1.5 Dispersal and Migration

Despite being the least migratory of Palearctic *Circus*, Hen Harriers can travel considerable distances on migration from breeding to non-breeding grounds. This is particularly true in Asia, where Hen Harriers may travel thousands of kilometres south to escape harsh winters in northerly latitudes (Cramp and Simmons, 1980; Ferguson-Lees and Christie, 2005). Juvenile birds, not long on the wing, are among those making such journeys. In several species of raptors, one sex moves further (or a greater proportion of one sex moves) than the other (Newton, 1979; Agostini and Pannuccio, 2010). This has been reported in Hen Harriers by Etheridge and Summers (2006), who found young males to travel further than young females. Beske (1982) found juvenile Northern Harriers to move between 14km and 106km daily when on migration, with temporary home ranges established along migratory routes. Russell (1991) documented observations of some Northern Harriers migrating at night.

Species that have a stable food supply are more likely to remain faithful to a particular area and less likely to travel than those with fluctuating food supplies (Newton, 1979). As Hen Harriers are generalist predators, a decline in any one prey type does not necessarily lead to a migration effect. Not many Hen Harriers leave Europe (Cramp and Simmons, 1980), with the normal southern limit of migration being the Mediterranean or occasionally northwest Africa (Vaurie, 1965). German Hen Harriers have been recorded in Holland, France, Italy, Spain and Portugal (Goethe and Kuhk, 1951; Bernis, 1966; P. de Boer, pers. comm.); Dutch harriers in France (Clarke and Watson, 1990) and Scandinavian harriers in Germany, Netherlands, Belgium and France (Cramp and Simmons, 1980; Klaassen *et al*., 2008). Britain, particularly the east of England, receives an influx of harriers each autumn and winter from breeding populations spread across Fennoscandia and adjacent areas of Northern Europe (Davenport, 1982; Clarke, 1986; Clarke and Watson, 1990 and 1997). Studies such as Etheridge and Summers (2006) and Murphy (unpubl. data) have shown that harriers from Britain can in turn disperse overseas, with a generally southerly movement and some exceptional birds travelling 500km or even 1000km (Mead, 1973; Watson, 1977; Cramp and Simmons, 1980; Etheridge and Summers, 2006). Individual harriers have been found to travel quite considerable distances, including a Finnish bird, which in 2009 was found dead in Holland, 2,030km from its natal site (van der Jeugd, 2010). While the Hen Harrier migrates mainly on broad fronts between breeding and wintering areas, considerable numbers are also recorded at specific migration points in autumn at Falsterbo (south Sweden) and in Spring at Skagen (north Denmark) as well as at the Straits of Gibraltar (Cramp and Simmons, 1980).

Given an absence of research on the subject here, little is known of Ireland's place in the 'bigger picture' of migration. Mead (1973) reported three (winter) recoveries of Hen Harriers in Ireland which were marked in Orkney. Etheridge and Summers (2006) found more Hen Harriers travelling to Ireland from Scotland. In 2007, a Hen Harrier from England was identified in Wexford, south-east Ireland (K. Mullarney, S. Murphy, pers. comm.). As Hen Harriers regularly migrate to and from Britain, and are not averse to crossing large tracts of water (Cramp and Simmons, 1980), there is no particular reason to suggest that emigration from Ireland does not occur, although Etheridge (2002) suggested that Irish Hen Harriers are largely resident and do not leave the country in the majority of cases.

1.5.1 Natal Philopatry and Site Fidelity

Picozzi (1980a and 1984b) reported Hen Harriers often returned to breed quite close to their natal sites, sometimes even usurping their natal territory. Of 217 Northern Harrier nestlings ringed by Hamerstrom (1969), only three were recorded to return to breed in the natal area. The same study found that 72% of adults marked at breeding sites did not return in subsequent breeding seasons, while those that were successful were more likely to return.

Picozzi (1984b) reported that the mean natal dispersal distance of males and females marked in Orkney was 6.3km and 5.7km respectively. Whitfield and Fielding (2009) suggested that in Wales natal dispersal was about 18km for females. Etheridge *et al.* (1997) reported a median breeding dispersal distance (between successive nests) of 0.7km, with no difference between the sexes. The same authors found median natal dispersal distances (from natal site to site of first breeding) differed according to the landscape in which the birds were reared, with birds from afforested areas breeding furthest from their natal sites. Etheridge *et al.* (1997) estimated that most harriers born in moorland habitats in Scotland would again nest in moorland; while most females born in conifer forests would again breed in conifer forests, although most males from nests in conifer forests would in contrast, breed on moorland. Scott (2007) believed imprinting of young was the reason tree nesting continued in Northern Ireland.

1.6 Survival Rates and Longevity

The first twelve months can be the most testing in terms of survival for birds of prey (Newton, 1979) and it has been shown that only one-third of fledged Hen Harriers may survive to their first breeding season (Etheridge *et al.*, 1997; Whitfield and Fielding, 2009). This figure may be as low as 14% (Picozzi, 1984a). In subsequent years, adult Hen Harriers have a survival rate of about 70-90% (Balfour and Cadbury, 1975; Etheridge *et al*., 1997; Whitfield and Fielding, 2009). Females have a greater chance of survival than males (Picozzi, 1984a; Etheridge *et al*., 1997; Whitfield and Fielding, 2009). The longest-lived Hen Harrier recorded, was one ringed and found dead (as a road casualty) aged 17 years and 1 month (Staav and Fransson, 2008).

Keran (1981) reported that among 114 ringed individuals, the mean age at death was 16.6 months.

1.7 Non-breeding Season

When breeding efforts are completed, harriers are no longer committed to a nest or brood and have only to fend for themselves. Harriers will begin to occupy their respective non-breeding quarters, which can involve migration, particularly from the uplands where they bred to lowlands where the winter climate will not be as harsh (Watson, 1977). Each evening, they may roost solitarily or communally. Communal roosting of Hen Harriers was first reported by Jardine (1838) who referred to *"general roosting places, either among whins or long heath and always on some open spot of ground*". Communal roosting is not specific to the Hen Harrier. It seems to be commonest among birds that feed together, but it occurs quite commonly with solitary feeders, including Wrens (*Troglodytes troglodytes*) (Armstrong, 1955), Grey Herons (*Ardea cinerea*) (Birkhead, 1973; Draulans and van Vessem, 1986) and raptors such as Merlin (*Falco columbarius*) (Clarke, 1993; Kelly and Thorpe, 1993) and Long-eared Owls (*Asio otus*) (Wijnandts, 1984; Escala *et al*., 2009). Communal roosting has been noted in at least seven species of Harrier (*C. cyaneus; C. aeruginosus*; *C. pygargus; C. buffoni; C. assimilis and C. melanoleucos*) (Martelli and Zarrelli, 1986), and different species of harriers are often observed roosting together (Ward and Zahavi, 1973; Schipper *et al.*, 1975; Watson 1977; pers. obs.).

1.7.1 Function of Communal Roosting

Ward and Zahavi (1973) define a roost as *"a place where a bird rests during a long inactive period"* and a communal roost as *"one where many birds converge, which have been feeding solitarily or in flocks"*. There are a number of hypotheses as to why Hen Harriers and other birds roost communally. According to Ward and Zahavi (1973), the more birds in a colony of a particular species, the more information that is being exchanged within that colony as regards feeding places (e.g. Hiraldo *et al*., 1993). Other authors, notably Lack (1968) believed communal roosting to have a primarily protective role. Ward and Zahavi (1973) had dismissed the notion that birds would roost communally for protection, but Picozzi and Cuthbert (1982) agreed with Lack's (1968) suggestion and also believed that communal roosts probably serve several functions simultaneously. Beauchamp (1999) also surmised that communal roosting in non-flocking species has a role other than food finding. Weatherhead (1983) hypothesised that different individuals gain different advantages from communal roosting. For example, older birds may tolerate younger birds learning of their feeding areas if younger birds provide an extra element of protection by increasing numbers at roost. Gurr (1968) suggested that pair formation was an important function of Australasian Harriers (*Circus approximans*) roosting communally. Watson (1977) supplied some observations, which would support such a theory for *Circus cyaneus*. Whatever the function(s) of communal roosting, it is clear that for harriers, roosts are used as bases from which to radiate out to hunt the surrounding landscape during the daytime (Watson, 1977; Picozzi and Cuthbert, 1982; Bildstein, 1987; Collopy and Bildstein, 1987).

1.7.2 Numbers at Roost

Numbers of harriers occupying a given roost is the most basic, yet most interesting and informative aspect of roosting studies. The largest roost in the world is believed to have been one containing over 3,000 Montagu's, Pallid and Marsh Harriers in India (Clarke *et al*., 1998). Helbig *et al.* (1992) reported what appears to have been a record number of 216 Hen Harriers, at a roost in Germany. The number of Hen Harriers at winter roosts in Britain are usually less than 20 (Picozzi and Cuthbert, 1982; Clarke and Watson, 1990 and 1997), but Cullen (1991) reported a maximum of 83 in the Isle of Man. The maximum number of Hen Harriers counted at a roost in Ireland has been twelve (O'Donoghue, 2004). McCurdy *et al.* (1995) reported a record 1053 Northern Harriers at a winter roost in Oklahoma.

The number of Hen Harriers occupying a non-breeding roost will fluctuate from count to count (Watson, 1977; Picozzi and Cuthbert, 1982; O'Donoghue, 2004). O'Donoghue (2004) found the peak month in terms of roost occupation in Ireland to be November. Clarke and Watson (1990) recorded maximum numbers at British roosts in mid-winter, but the pattern of attendance varied between regions. In Scotland, numbers at roosts have been found to peak in November and December, while in Eastern England the highest occupation has occurred during December, January and February (Clarke and Watson, 1997). On the Isle of Man, peak numbers have been recorded in November and February (Leonard, 2004). The duration spent by harriers at roosts will differ between sites, years and individuals (Watson, 1977; Picozzi and Cuthbert, 1982).

1.7.3 Composition of Roosts: Ringtails and Grey Males

Given ringtail harriers include both adult females and juveniles of either sex, in most cases there will be more ringtails or ‘browns’ at roost than identifiable males or ‘greys’ (Marquiss, 1980; Davenport, 1982; Picozzi and Cuthbert, 1982; Clarke and Watson, 1990 and 1997; Clarke *et al*., 1993; O’Donoghue, 2004). Adult males however sometimes predominate at communal roosts and geographical partitioning of harrier sexes during the non-breeding season has previously been noted (Watson, 1977; Clarke and Watson, 1990 and 1997).

1.7.4 Characteristics of a Roost Site

Physical characteristics of roost sites can differ between and even within sites. However, roost sites are typically in low lying areas, on open habitats and in coastal locations (Watson, 1977; Clarke and Watson, 1990; Clarke *et al*., 1993). Roosts are most often on wetland type habitats of bogs and reedbeds (Clarke and Watson, 1990), apparently for refuge from ground predators (Watson, 1977). However, roosts can also occur on dry ground (Martelli and Zarrelli, 1986; Clarke and Watson, 1990; Clarke, 1997). Clarke and Watson (1990) found salt marsh, reedbeds, rough grassland, heather moorland and lowland heath to be among the main habitat types of British winter roosts. Dunes, crops and scrub have also been noted as roosting habitats (Clarke and Watson, 1990 and 1997; Hadrill, 1990; Ottens, 1999). The habitat types of Irish roosts were unknown (Clarke and Watson, 1990), until O’Donoghue (2004) reported heather/bog and reedbeds to be the primary habitats used for roosting.

1.7.5 Behaviour at Roosts

Non-breeding roosts are generally used as places where harriers will rest at night. Hen Harriers typically vacate their roosts during the day, leaving at first light and returning as twilight approaches (Watson, 1977). Being diurnal and prompted by an internal circadian rhythm (Elkins, 1983), harriers will begin activity later and end activity earlier as the days shorten in winter, while the opposite is true as the days begin to lengthen again. O’Donoghue (2004) found birds came to roost each evening between 105mins before sunset to 40mins after sunset and rose and left roost each morning from 40mins to 5mins before sunrise. Some individuals remained at roost throughout the day.

In general, harriers will roost separately on the ground, on platforms which were either naturally occurring (e.g. clumps or tussocks or gaps in tall vegetation) or modified (e.g. grass/rush flattened out by the elements or the bird itself) (Watson and Dickson, 1972; Hardey *et al.*, 2006). The size of the platform can vary from just big enough to fit a harrier to 1m across (Clarke and Watson, 1990; pers. obs.). Clarke and Watson (1990) were unsure as to whether more than one bird would use a large platform simultaneously. A relatively common yet entertaining sight at communal roosts is that of birds displacing one another from their chosen positions, particularly when numbers in the roost are high (Watson and Dickson, 1972; Watson, 1977; pers. obs.). Such activity may be related to competition for the best places within the roost, attempted exertions of dominance, or simply playful/social interaction (Watson, 1977). Inter and Intra-specific antagonistic behaviour has been noted between harriers and various other birds during the non-breeding season (Bildstein, 1987; pers. obs.).

1.8 Foraging

Hen Harriers do not normally hunt by observations from perches as some other birds of prey might (e.g. Peregrine Falcon), but rather by actively coursing over and quartering habitats (Watson, 1997). The activity of foraging in Hen Harriers can be determined from the typical low, buoyant flight, often turning and twisting, balancing in the air as they move relatively slowly over the ground, using variation in the terrain and vegetation relief to surprise prey (Watson, 1977; Schipper *et al.*, 1975; Schipper, 1977; MacWhirter and Bildstein, 1996). A deliberate gliding flight is usually employed, pushed every now and again by one or more wing-beats, according to desired speed, prevailing conditions and other factors. The gliding motion of the Hen Harrier may be an adaptation to leave the hunter less conspicuous to its prey than if it were continuously beating its wings and ultimately means that less energy is used while in the air. Brown and Amadon (1968) estimated the Hen Harrier to fly "*about 100 miles every day of its life*", spending 40% of the daylight hours in the air. Martin (1987) calculated that breeding male Northern Harriers spent 2.6 hours hunting each day. García and Arroyo (2005) found male Hen Harriers spent about 45% of the time hunting during the nestling period. In surveying kilometre squares adjacent to nest sites, Madders (2003) observed foraging for 1.95% of observation time.

When prey is located, the harrier may employ up to five different methods of capture. Bildstein (1987) identified the hook pounce (a harrier will often 'cartwheel' onto its prey after checking its flight), hover pounce (where a harrier locates prey and hovers over or indeed harries the prey beneath before striking), straight pounce (with no change of flight direction or speed) and slow pounce (employed for example when a nest of voles was found and repeatedly returned to). Hen Harriers may also use fast and low 'ambush' techniques much like the Sparrowhawk (Wassenich, 1968; Schipper *et al*., 1975; Schipper, 1977; Temeles, 1986; Thorpe, 1994). The Hen Harrier has been known to make short chases after prey, certainly more so than the sympatric Montagu's and Marsh Harriers. This is apparently related to its ability to make quick turns and accelerations in flight while surprising prey (Schipper, 1977). The majority of captures however, are made on the ground (Schipper *et al*., 1975; Schipper, 1977; Collopy and Bildstein, 1987; Clarke *et al*., 1993; pers. obs.). Between 17% and 36% of strikes can be successful (Bildstein, 1987; Madders, 2000; Thirgood *et al.*, 2002; Redpath *et al*., 2002b). It is likely that juveniles may be less successful in their foraging attempts than adult birds (Errington and Breckenridge, 1936).

Rice (1982) demonstrated that harriers depend heavily on auditory signals, using their owl-like facial discs and large ear apertures to locate prey precisely, even when the prey cannot be seen under tall or dense vegetation. Koivula and Korpimäki (2001) found Hen Harriers may also use olfactory cues to locate prey. Further adaptations for seizing prey in tall and rank vegetation include long legs relative to body size (Simmons, 2000).

Schipper *et al.* (1975) found Hen Harriers to fly lower and slower with head-winds (and cross-winds to a lesser extent). The same study found that males generally flew lower than females, while Temeles (1986) found that males hunted faster than females. Schipper *et al.* (1975) referred to hunting speeds of 30km hr^{-1} as 'normal', while speeds of 40km hr^{-1} were classified as 'fast' and 20km hr^{-1} as 'slow'. Bruderer and Boldt (2001) measured the Hen Harrier to glide at 42.5km hr^{-1} and flap glide at 41.8km hr^{-1}. Hen Harriers can travel at speeds in excess of 80km hr^{-1} when migrating (S. Murphy, unpubl. data). The Hen Harrier will fly and hunt in light rain (Haugh and Cade, 1966; Schipper, 1973; pers. obs.) (Plate 1.4), but Redpath *et al.* (2002c) found that the amount of food brought to the nest by males decreased with higher rainfall (in wet climates) as well as higher temperatures (in hot climates).

Plate 1.4. Male carrying prey in rain, Knocknagashel, Co. Kerry, 10 July 2006.
Photo credit: Mike Brown

The Hen Harrier is primarily adapted to hunting in open landscapes (Watson, 1977). Selection of hunting habitat is affected by several variables including proximity to the nest site (Schipper, 1977; Martin, 1987; Madders, 2000; Amar and Redpath, 2005), sex and age of the individual (Schipper *et al*., 1975; Bildstein 1979a; Marquiss 1980), prey abundance and availability (Schipper *et al*., 1975), vegetation structure (Schipper *et al*., 1975; Temeles, 1986) and the presence of competitors (Temeles, 1986). Optimal foraging theory predicts that birds will forage where they will get greatest return from their efforts (Krebs *et al*., 1983). Harriers select habitats on the basis of the availability and abundance of prey species (Picozzi, 1978; Simmons and Smith, 1985). In Britain and Ireland, heather/bog, scrub and rough grassland are the quintessential Hen Harrier foraging habitats (Watson, 1977; O'Flynn, 1983; Redpath, 1992; Dickson, 1997; Madders, 1997, 2000 and 2003; Amar and Redpath, 2002 and 2005; Amar *et al*., 2003a,b; O'Donoghue, 2004; Arroyo *et al*., 2005; Scott, 2008). Early stages of forest plantations are also hunted (Madders, 1997, 2000 and 2003; O'Donoghue, 2004) and arable areas are made extensive use of during the non-breeding season (Jardine, 1838; Watson, 1977; Clarke and Watson, 1990; Clarke *et al*., 2003; Dobson, 2009). O'Donoghue (2004) found Hen Harriers in the south-west of Ireland were actively selecting to hunt heather/bog, pre-thicket forest, rough grassland and scrub. However, they tended to largely avoid foraging over post-thicket forest, improved grassland and bare ground. Linear features and edge habitats such as hedgerows and riparian zones have also been noted as important foraging features (Schipper, 1977; Temeles, 1986; Bildstein, 1987; Clarke, 1990; Redpath, 1992; Thorpe, 1994; Madders, 1997; O'Donoghue, 2004).

The extent of the hunting range of a male Hen Harrier, who is for the most part the primary hunter during the breeding season (Watson, 1977; Picozzi, 1978; Thirgood *et al*., 2003; García and Arroyo, 2005), has been estimated with variable results (Table 1.1).

Table 1.1. Estimated foraging ranges of male Hen Harriers and Northern Harriers.

Publication	**Location**	**Range (km^2)**
Breckenridge (1935)*	Minnesota	2.5
Craighead and Craighead (1956)*	N. America	0.6-6.3
Hamerstrom and De La Ronde Wilde (1973)*	Wisconsin	8.8
Schipper (1977)	Holland	1.8-12.3
Picozzi (1978)	Scotland	14
Thompson-Hanson (1984)*	Washington	72-366
Martin (1987)*	Idaho	15.7
Arroyo *et al.* (2005)	Scotland	6.5-11.8

*Northern Harrier (*Circus hudsonius*)

Estimates of female ranges in contrast are much lower (e.g. 0.1-5.4km^2 (Schipper, 1977); 1.13km^2 (Martin, 1987) and 2.5-3.9km^2 (Arroyo *et al*., 2005)), but as the breeding season progresses this can get progressively larger (Schipper, 1977; Balfour and MacDonald, 1970; Arroyo *et al*., 2005; but see García and Arroyo, 2005). Home range size has also been shown to vary during the dispersal period (Beske, 1982). The variation of range size estimates is most likely a reflection of the landscape within the territory and its profitability for the occupying harriers (McNab, 1963; Newton, 1979; Marquiss and Newton, 1982; Village, 1982). Hen Harrier home ranges are not necessarily spread out evenly from the nest, but adapted to what are assumed to be the most productive areas (Arroyo *et al*., 2005).

Beske (1982) found that most hunting occurred soon after sunrise and before sunset. Dickson (1995) observed a peak in winter hunting activities around mid-morning and afternoon, with a definite lull around mid-day. Similarly, Hamerstrom and De La Ronde Wilde (1973) found that most hunting activity by Northern Harriers occurred during the morning time, with a mid-day lull followed again by a late afternoon period of hunting. Schipper (1973) and Hamerstrom (in Bildstein, 1987) also reported mid-day lulls in hunting activity. Redpath and Thirgood (1997) found deliveries were fairly constant throughout the day, with lowest delivery rates at dawn and slight peaks in the late afternoon and early evening. Watson (1977) and Picozzi (1980a) found no peak in foraging activity. Breckenridge (1935), Martin (1987) and Simmons *et al.* (1987) found prey deliveries by the male to the nest peaked after hatching and intervals between prey deliveries by both male and female to shorten, while observed hunting activities increased. Breckenridge (1935) found the prey intake of nestlings to increase until they were about 25d, after which time, provisioning rates decreased. Hen Harriers have also been known to cache their prey (Dickson, 1998; T. O'Donoghue and S. Murphy, pers. comm.).

Cotgreave (1995) reported that the Hen Harrier requires approximately 71g of food per day, while Craighead and Craighead (1956) found that a female Northern Harrier requires about 100g d^{-1} for maintenance and a captive male 42g d^{-1} (19.0% and 12.1% of body mass respectively). For free-ranging Hen Harriers wintering in the Netherlands, a gross biomass intake of 187g d^{-1} was recorded (Raptor Group RUG/RIJP, 1982). Female nestlings in America were recorded to consume 127.4g d^{-1}, which was more than their male siblings at 117.6g d^{-1} (MacWhirter, 1994). Brown (1976) identified two critical periods for food supply to the nest of a bird of prey; (1)

the pre-egg laying and laying period, when the female needs extra food to form eggs and increase body reserves and (2) the early nestling period (when the male is the sole provider of prey for himself, the female and the young). Newton (1979) recognised that this may vary from raptor to raptor, their associated breeding ecology and that of their prey.

1.9 Diet

As a predator, the Hen Harrier’s diet has been well studied. Table 1.2 summarises a range of studies and what harriers have been found to eat. The Hen Harrier is clearly a generalist predator and typically the most abundant, available and profitable prey is taken (Clarke *et al.* 1993; Redpath and Thirgood, 1999). The diversity of prey taken by Hen Harriers is evident in research by Schipper (1973) who reported Hen Harriers to prey on animals from 9-612g. MacWhirter and Bildstein (1996) found Northern Harriers to take prey weighing 7-1000g. Young prey is often taken. Madders (1997) for example, found 83% of passerines, 67% of waders and game birds, and 83% of lagomorphs to be juveniles.

The varied nature of the Hen Harrier’s diet extends to an apparent divergence of male and female preferences (probably as a result of the reversed size dimorphism), with females often taking larger prey and males taking smaller, more agile prey like passerines (Nieboer, 1973; Schipper *et al.*, 1975; Watson, 1977; Marquiss, 1980; Temeles, 1986; Bildstein, 1987; Clarke *et al.*, 1993 and 1997; Redpath and Thirgood, 1997). Bildstein (1987) found that the diet of unsexed juvenile Northern Harriers resembled that of the adult females. The prey taken by raptors is ultimately a reflection of the prey that exists in the habitat they occupy (Newton, 1979). Arroyo *et al.* (2005) suggested that the female’s general restriction to the nest area and the male’s wide-ranging behaviour explained why habitat close to the nest affected prey delivery to the nest by females, but not males (Amar *et al*., 2004).

Table 1.2. Diet of Hen Harrier and Northern Harrier.

Category	Reported by
Small mammals (voles, mice, shrews and other such animals)	Selby (1833); Morriss (1897); Breckenridge (1935); Witherby *et al.* (1939); Hecht (1951); Craighead and Craighead (1956); Hagen (in Bannerman and Lodge, 1956); Balfour and MacDonald (1970); Dickson (1970); Jackson *et al.*, (1972); Watson and Dickson (1972); Schipper *et al.* (1975); Rees (1976); Watson (1977); Marquiss (1980); Picozzi (1978); Picozzi (1980a); Picozzi and Cuthbert (1982); Hamerstrom (1986); Simmons *et al.* (1986); Barnard *et al.* (1987); Bildstein (1987); Collopy and Bildstein (1987); Martin (1987); Redpath 1991; Clarke *et al.* (1993); MacWhirter and Bildstein (1996); Roulin (1996); van Manen (1996); Madders (1997); Millon *et al.* (2002); Simmons (2000); Redpath *et al.* (2002a); O'Donoghue (2004); Amar and Redpath (2005); García and Arroyo (2005); Klaassen *et al.* (2006); Scott (2008).
Small birds/Passerines	Selby (1833); Morriss (1897); Jardine (1838); Breckenridge (1935); Errington and Breckenridge (1936); Witherby *et al.* (1939); Hecht (1951); Craighead and Craighead, (1956); Hagen (in Bannerman and Lodge, 1956); Balfour and MacDonald (1970); Dickson (1970); Jackson *et al.*, (1972); Watson and Dickson (1972); Schipper (1973); Schipper *et al.* (1975); Watson (1977); Picozzi (1978); Marquiss (1980); Picozzi and Cuthbert (1982); Bildstein (1987); Collopy and Bildstein (1987); Martin (1987); Temeles (1985 and 1987); Barnard *et al.* (1987); Redpath, 1991; Redpath (1992); Clarke *et al.* (1993 and 1997); MacWhirter and Bildstein, (1996); Madders (1997); Millon *et al.* (2002); Simmons (2000); O'Donoghue (2004); Amar and Redpath, (2005); García and Arroyo (2005); Klaassen *et al.* (2006); Scott (2008); Dobson *et al.* (2009).
Lagomorphs	Morriss (1897); Breckenridge (1935); Witherby *et al.* (1939); Hecht (1951); Hagen (in Bannerman and Lodge, 1956); Balfour and MacDonald (1970); Jackson *et al.* (1972); Watson and Dickson (1972); Schipper (1973); Balfour and Cadbury (1975); Schipper *et al.* (1975); Watson (1977); Picozzi (1978); Marquiss (1980); Picozzi (1980a); Picozzi and Cuthbert (1982); Bildstein (1987); Redpath (1991); Redpath (1992); Clarke *et al.* (1993 and 1997); Madders (1997); Millon *et al.* (2002); O'Donoghue (2004); Amar and Redpath (2005); García and Arroyo (2005); Klaassen *et al.* (2006); Scott (2008).
Other mammals	Errington and Breckenridge (1936) [ground squirrel]; Picozzi and Cuthbert (1982) [hedgehog]; Wilson-Parr (2005) [stoat].
Waterfowl/Waders	Watters (1853); Morriss (1897); Witherby *et al.* (1939); Hecht (1951); Hagen (in Bannerman and Lodge, 1956); Schipper (1973); Balfour and Cadbury (1975); Picozzi (1978); Marquiss (1980); Godfrey and Fedynich (1987); Clarke *et al.* (1993); Madders (1997); O'Donoghue (2004); Amar and Redpath (2005); Scott (2008); Dobson *et al.* (2009).
Game Birds	Selby (1833); Jardine (1838); Morriss (1897); Breckenridge (1935); Witherby *et al.* (1939); Watson and Dickson (1972); Schipper (1973); Schipper *et al.* (1975); Watson (1977); Picozzi (1978); Jones (1981); Bildstein (1987); Redpath 1991; Redpath (1992); Clarke *et al.* (1993); Madders (1997); Millon *et al*. (2002); Scott (2008).
Reptiles/Amphibians	Selby (1833); Jardine (1838); Morriss (1897); Breckenridge (1935); Witherby *et al.* (1939); Hecht (1951); Hagen (in Bannerman and Lodge, 1956); Schipper (1973); Picozzi (1978); Barnard *et al.* (1987); Collopy and Bildstein (1987); Martin (1987); MacWhirter and Bildstein, (1996); Madders (1997); Klaassen *et al.* (2006); T. O'Donoghue, pers. comm.
Fish	Morriss (1897); Witherby *et al.* (1939); Noble Proctor (1973); M. Marron pers. comm.
Insects	Breckenridge (1935); Hecht (1951); Witherby *et al.* (1939); Hagen (in Bannerman and Lodge, 1956); Jackson *et al.*, (1972); Schipper (1973); Watson and Dickson (1972); MacWhirter and Bildstein (1996): Madders (1997); Millon *et al.* (2002); O'Donoghue (2004); Klaassen *et al.* (2006); Scott (2008).
Carcass/Carrion	Bent (1937); Schipper (1973); Watson and Dickson (1972); Watson (1977); Picozzi (1978); Bildstein (1987).
Prey robbery/Piracy	Clark (1975); Schipper (1977); Bildstein (1987); A. O'Donnell, pers. comm.

While the diet of the Hen Harrier across its range has been studied extensively, along with numerous studies on the Northern Harrier, just one investigation of Hen Harrier diet has taken place in the Republic of Ireland (O'Donoghue, 2004). That study concentrated mainly on winter diet, with a small-scale breeding season dietary investigation. Hen Harriers were shown to prey mostly on small birds, with small mammals also taken. The importance of small mammals is of particular interest, given the fact that *Microtus* voles (e.g. *Microtus agrestis, M. arvalis orcadensis* and *M. arvalis*), which are so important throughout the global range of *Circus cyaneus* (Bannerman and Lodge, 1956; Schipper, 1973; Watson, 1977; Cramp and Simmons, 1980; Picozzi and Cuthbert, 1982; Hamerstrom, 1986; Simmons *et al.* 1986; Barnard *et al.*, 1987; van Manen, 1996; Redpath *et al.*, 2002a; Amar and Redpath, 2005), are absent in Ireland (Savage, 1966; Fairley, 1984; Hayden and Harrington, 2000). O'Flynn (1983) believed the absence of *Microtus* voles was a limiting factor on the Irish population. The Bank Vole (*Myodes glareolus*) is the only vole found in Ireland, and is a relatively modern addition to the national fauna, discovered in 1964 in North County Kerry (Claassens and O'Gorman, 1965). Since then, they have spread to cover the southern half of Ireland (Meehan, 2004), infiltrating all the present strongholds of the Hen Harrier there. A more recent introduction has been the Greater White-toothed Shrew (*Crocidura russula*) (Tosh *et al.*, 2008). At present this shrew has a limited distribution range in Counties Tipperary and Limerick, and the closest record of this mammal to the current study area is less than 3km (J. Lusby, pers. comm.).

1.10 Study Areas of this Research

Ireland is an island of 84,421 sq. km., situated in the North Atlantic (51-55°N, 5-10°W), approximately 450-500km off the north west of mainland Europe and 20km west of the closest point of neighbouring Britain; the Mull of Kintyre in Scotland. The island is politically divided between the Republic of Ireland (consisting of 26 counties or an area of 70,282 sq. km) and Northern Ireland (consisting of six counties in the north east) (Nolan, 2010).

The island is encircled by mountains, with low-lying plains in the centre. The average elevation of Ireland is 110m above sea level (UCC Geography Department, pers. comm.), with six peaks extending above 1,000m, four of which happen to be in Kerry (Stewart, 2010). The West of the island depicts the influence of the Atlantic

Ocean and is rugged in appearance. The middle of the island is dominated by the country's longest river, The Shannon and associated raised bogs. The south and east of the country is generally the most agriculturally fertile. The predominant land-use across the entire island is agriculture (Feehan, 2003), with pasture accounting for over half of the entire land area (Environmental Protection Agency, 2006). Having a wet climate, Ireland has one of the highest concentrations of peatlands, though this has been greatly reduced, in particular by commercial harvesting and afforestation (Feehan and O'Donovan, 1996). Presently, just less than 17% of Ireland's land area is accounted for by peatland (Environmental Protection Agency, 2006). By the end of 2008, commercial forestry accounted for 10.6% of the entire land area of Ireland, though the extent of forest cover varies greatly between regions (Forest Service, unpubl. data).

Ireland's climate is greatly influenced by the Atlantic Ocean, with prevailing south-westerly winds bringing a temperate climate without the extremes of temperature experienced by other countries at similar latitude. Average annual temperature is approximately 9ºC, ranging from 2.5ºC during the winter months (November-February) and 19ºC for the summer months (May-August). Average rainfall varies between about 800mm in the east and 2,800mm in the west, where the annual number of days with more than 1mm of rain exceeds 200 (Met Éireann, 2010).

A bilateral approach was adopted for this study, in accordance with the Hen Harrier's non-breeding and breeding seasons. The entire land area of the Republic of Ireland was taken as the study area for the non-breeding season, while breeding season research was based in four of the most important breeding areas in Ireland; Kerry, West Clare, Ballyhouras and Slieve Aughties. Together, these four areas account for approximately a third of all breeding territories on the island (Barton *et al.*, 2006; Sim *et al.*, 2007) and reflect the typical breeding landscape, as well as a reasonable geographical spread. In addition, supplementary data from a fifth breeding area, the Boggeragh Mountains, was collected but was useful to diet and nest site studies only. The following is an account of the individual study areas:

Kerry

Kerry, in the south-west, has long been heralded as the stronghold of the Hen Harrier in Ireland (Thompson, 1849; Ussher and Warren, 1900; Sharrock, 1976; O'Flynn, 1983; Norriss *et al.*, 2002; Barton *et al.*, 2006). While Kerry boasts the highest

mountains in Ireland (high point Corrán Tuathail, 1,038m), it is the lower rolling landscape of the north and east of the county which holds breeding Hen Harriers. This massif (high point Knockfeha, 451m; average elevation 235m) is connected to the Mullaghareirk Mountains and the entire area has been designated as a proposed Special Protection Area (pSPA) by the Irish Government. The area studied as part of this current research was the largest of the four breeding study sites, running from a line east of Tarbert in the north to Killarney in the south, over to the eastern boundaries of County Kerry, encompassing a total area of approximately 600km^2. This area did not equate to the area termed *Stack's, Glanarudderies, Knockanefune, North of Abbeyfeale, Mullaghareirks* by Barton *et al.* (2006) so breeding densities cannot be drawn from previous surveys. Over 43km separated the two furthest apart nests during the current study.

West Clare

The West Clare study area, overlooking the Atlantic Ocean in the mid-west of Ireland is an area of low-lying rolling hills (average elevation 160m), dominated by small extensive agricultural holdings, with one stand-alone mountain (Mount Callan 391m). Whereas in the absence of comprehensive surveying, this area was shown to hold just one breeding pair by Norriss *et al.* (2002), intense observations since 2005 have shown a much larger population to exist in the 200km^2 study area of West Clare (O'Donoghue, unpubl. data). A distance of 15.4km separated the two furthest apart nests during the current study. The area involved in this present study did not equate to the area termed *North and West Clare* by Barton *et al.* (2006) so breeding densities cannot be drawn from previous surveys.

Ballyhoura Mountains (Ballyhouras)

The Ballyhouras in North County Cork and East County Limerick is a heavily afforested upland landscape of approximately 130km^2 (high point Seefin, 528m; average elevation 198m). Relatively small amounts of heather/bog remain un-afforested or converted to intensive grassland, which surrounds the perimeter of the massif. O'Flynn (1983) reported Hen Harrier breeding to have ceased in this once active landscape due to the high amounts of afforestation. Hen Harriers re-colonised the area when the forests began to be cut down and in the 2005 national breeding census (Barton *et al*., 2006), it was found to be the most densely populated range in the country (13.3-14.8 pairs/100 km^2). However this density may be artificially high and unsustainable as it appears heavily reliant on the existence of pre-thicket restock forest, which is ephemeral in nature. For this reason, it was not chosen as a Special Protection Area, in which the population would have to be stabilised or improved. A distance of 17.0km separated the two furthest apart nests in the Ballyhouras during the current study.

Slieve Aughty Mountains (Slieve Aughties)

The Slieve Aughties is an upland range (high point Maghera, 400m; average elevation 160m) of approximately 500km^2; straddling the borders of Counties Clare and Galway in the mid-west of Ireland (the entire mountain range was not surveyed). The Slieve Aughties experienced large-scale afforestation in the 1960s, with extensive amounts of open moorland and marginal land which typified the Hen Harrier's landscape, lost to commercial plantations. While Sharrock (1976) noted the Slieve Aughties to hold breeding Hen Harriers, O'Flynn (1983) reported that by the early 1980s breeding attempts there had apparently ceased. The Slieve Aughties was found in the 2005 national breeding census (Barton *et al.*, 2006) to have a breeding density of 4.9-5.5 pairs/100 km^2). A distance of 24.9km separated the two furthest apart nests in the Slieve Aughties during this research. The Slieve Aughties is the largest pSPA (in terms of area) designated by the Irish Government.

Boggeragh Mountains (Boggeraghs)

The Boggeragh Mountains in mid-west Cork (area 320km^2, high point Musheramore, 644m) were surveyed in 2008 only, and while only two nests were found, these were deemed useful in providing supplementary nest site and dietary data to that collected in the four main study areas.

The composition of the main study areas in terms of habitats relevant to Hen Harrier research is given in Table 1.3.

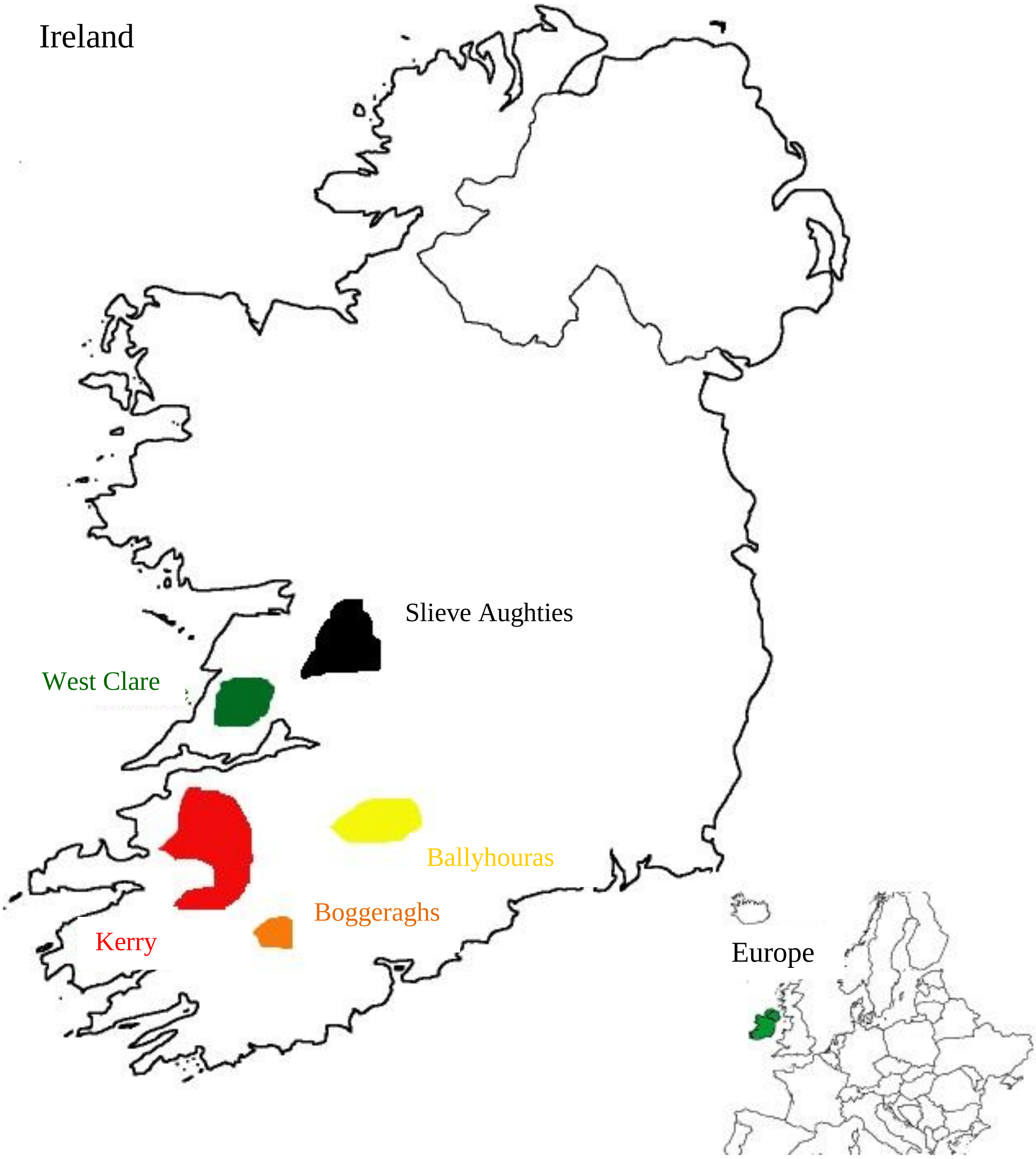

Figure 1.3. Map of the study areas involved in this research.

Table 1.3. Habitat composition (%) of the main study areas involved in this research. (Source: University College Cork).

	Kerry	**West Clare**	**Ballyhouras**	**Aughties**
Heather/Bog	28.5	27.9	10.7	24.5
Rough Grassland	16.6	18.0	10.1	19.9
Intensive Grassland	11.9	6.6	6.6	7.6
New forest	17.1	12.7	6.1	9.1
Restock	1.6	1.9	13.6	6.5
Closed Canopy	22.9	26.7	40.9	28.0
Clearfell	0.6	1.0	10.4	2.2
Scrub	0.8	3.7	1.6	1.2
Water	0.0	1.5	0.1	1.0
% Afforested	42.2	42.3	71.0	45.7

Chapter Two

The Hen Harrier in Ireland

What burned in their hearts
With their quenching could not die, but
Floated over heather hills,
To be forever there –
A part of Kerry sky!

Dónal Ó Siodhacháin. Freedom Skies. 2004.

This short chapter, following from the general introduction, aims to provide a context and rationale for the current research, by documenting the Hen Harrier in Ireland from earliest records to the present day, including trends in population and distribution, its threats and conservation.

The earliest records of Hen Harriers (*Circus cyaneus*) in Ireland date back to the 10th Century, when bones were found as part of archaeological excavations at Fishamble Street, Dublin (D'Arcy, 1999). The first mention of harriers in Irish literature appears to be that in Plunkett's Latin-Irish dictionary (1662), where *'Circus'* is translated to *'Fos gné sheibhce'*, meaning a 'type of hawk'. In the first direct account of the 'Common Harrier' from Jardine (1838), it was said to be "*of general distribution in Ireland"*. Thompson (1849) concurred and noted that Hen Harriers were *"pretty generally distributed over the island",* were *"often met with"* and had breeding strongholds in Kerry, Wicklow and the Tipperary/Waterford border in the south, and Derry and Antrim in the north. Shawe-Taylor (in Watson, 1977) said that the Hen Harrier was *"common on all the hills in Connemara"* in 1851, even though Thompson (1849) stated that its breeding status there was rare. In addition to the widespread distribution recounted by Thompson (1849), Watters (1853) said the Hen Harrier existed *"in considerable numbers both north and south"*, but was rare in the east. However, both authors ominously referred to the decline of the species as they wrote their accounts.

By the turn of the 20th Century, Ussher and Warren (1900) confirmed this decline. While it was present in the counties of Kerry, Cork, Limerick, Tipperary, Waterford, Wicklow, Dublin, Offaly, Laois, Galway, Mayo, Fermanagh, Donegal, Derry, Antrim and Down, and could be seen in other counties outside of the breeding season, the Hen Harrier was *"decreasing in numbers, in many mountainous districts"*, and had *"ceased to breed in other localities where it used formerly to do so"* (*sic*). This decline has been attributed to widespread persecution of birds of prey in general at this time (O'Flynn, 1983), to the point where the Hen Harrier was listed under the Wild Birds Protection Act, 1894 (Chomley-Farran, 1907). It is also likely that the decline was exacerbated by drainage by the Commissioners of Public Works throughout the 19th century. Humphreys (1937) believed the Hen Harrier in the 1930s was still probably resident in a *"few of its original haunts, the wilder mountain districts"*, but numbers had decreased significantly. Meinertzhagen (1947) for example mentioned the Hen Harrier had become extinct as a breeding species in South Kerry by 1945. By the 1950s it was considered by some to have become extinct as a breeding species in Ireland altogether (Kennedy *et al.*, 1954; Bannerman and Lodge, 1956) but had in fact continued to survive in a few areas such as the Slieve Bloom Mountains in Laois, the Tipperary/Waterford border and the Cork/Kerry border (Watson, 1977; F. King, pers. comm.).

The population then began to recover in the 1950s (Andrews, 1964), with increased planting of young coniferous forests (O'Flynn, 1983). It was not the trees *per se* that brought the lifeline, but the fact that the land was fenced off. Persecution declined as an issue as these tracts of land began to hold less interest for shooting and agriculture. Forests were less likely to have been burned than open ground (a traditional practice in upland areas of Ireland to increase the amount of grass available to livestock) and when ground was fenced off for forestry, it allowed vegetation between the sapling trees to grow unhindered, thereby creating increased harrier nesting habitat, as well as habitat for passerines (O'Flynn, 1983; Hamerstrom, 1986; Madders, 2003). New forests probably also facilitated an expansion of the (at the time) recent introduction of the Bank Vole (*Myodes glareolus*), as it did with the Short-tailed Vole (*Microtus agrestis*) in Scotland (Picozzi, 1978; Harris, 1983).

By 1964 at least 35 pairs were known to be breeding in six southern counties; Cork, Waterford, Kilkenny, Laois, Wicklow and Wexford (Ruttledge, 1966; O'Flynn, 1983). Sharrock (1976) suggested this was an underestimate and believed 75 breeding pairs existed at that time. The increase continued in line with the increase in planting, with an estimated 250-300 pairs breeding on the island of Ireland in the 1970s (David Scott in Watson, 1977) when harriers were found *"with ease"* (O'Flynn, 1983).

In the late 1970s however, with forest maturation came a marked decline in breeding numbers, and by the early 1980s, breeding attempts had apparently ceased in the Slieve Aughty Mountains (Clare and Galway), the hills of North Tipperary, the Ballyhoura Mountains in North Cork, the hills of South Kilkenny and the Comeragh Mountains in Waterford (O'Flynn, 1983); all areas where harrier breeding was recorded not long before (Sharrock, 1976). A similar pattern was noted in Northern Ireland (Scott, 2008). Such detrimental effects of afforestation on Hen Harriers have been widely acknowledged (Galloway and Meek, 1978; O'Flynn, 1983; Clarke, 1990;

Bibby and Etheridge, 1993; Redpath *et al*., 1998; Madders, 2000 and 2003; O'Donoghue, 2004; Wilson *et al*., 2006a; Klaassen *et al*., 2008). The Wicklow Mountains, once a stronghold for breeding Hen Harriers (Ruttledge, 1966; O'Flynn, 1983) on the east coast of Ireland are a prime example of this decline associated with afforestation. The only areas reputed to have been *"holding their own"* at that stage were those where no significant change in habitat had occurred (O'Flynn, 1983). O'Flynn (1983) suggested the counties of the west and north-west were not recolonised to the extent that other areas were during the new forest upsurge, as the new forests had matured before this range expansion from the South Leinster/East Munster (where harriers apparently never disappeared at the turn of the 20th Century), was possible. This period also coincided with intensified farming, land 'improvement', hedgerow removal and scrub clearance under the Common Agricultural Policy (CAP). Given almost a quarter of a million hectares of land were drained by arterial drainage and almost 1.2 million hectares by field drainage between 1950 and 1979 (Temple-Lang, 1988), much potential Hen Harrier habitat in lowland locations was also lost.

The cause of decline and mainstay of threats had then, shifted from persecution to habitat loss, which is arguably more enduring. The Irish breeding population of Hen Harriers was estimated at just 70 pairs in 1982 (Watson, 1983). Habitat loss, primarily by afforestation and overgrazing of mountains and bogs, continued through the 1980s (Temple-Lang, 1988). Whilde (1993) considered there may have been no more than 50-70 pairs still breeding in Ireland in the early 1990s and accordingly included the Hen Harrier as a Red Data Book species. However in the absence of a national survey, estimates of population size varied and Gibbons *et al.* (1993) calculated the population for the whole island of Ireland in 1988-91 to be 180 pairs, assuming an average density of two pairs per 10km square where breeding was probable or confirmed. De Buitléar (1993) and Murphy (1995) continued in documenting the damaging effects of afforestation and overgrazing on the Hen Harrier, along with other upland birds.

Reform of the Common Agricultural Policy, since 1992, resulted in a shift from market and price supports for European farmers and an increase in direct payments (Feehan, 2003). The reform also saw an increased importance of care for nature and the environment. Council Regulation (EEC) No. 2078/92 saw farmers, for the first time, as managers and custodians of the rural environment as well as producers of food. In Ireland, the regulation was implemented through the introduction of the Rural Environmental Protection Scheme (REPS) in 1994, which encouraged farmers to protect natural heritage. Uptake of REPS was particularly high in uplands where Hen Harriers existed (C. Keena, pers. comm.).

The conflict between game keeping interests and Hen Harriers, which is of serious concern in Britain (Redpath, 1991; Etheridge *et al*., 1997; Redpath and Thirgood, 1997; Potts, 1998; Green and Etheridge, 1999; Thirgood *et al*., 2000; Natural England, 2008), is not a major issue in Ireland, as commercially-run shooting estates are not as common or as intense here. As above however, there have been many documented instances of persecution in Ireland (Ussher and Warren, 1900; Kennedy *et al*., 1954; Anonymous, 1961; Ruttledge, 1966; Jones, 1981; O'Flynn, 1983; F. King, pers. comm.). In 2003, a Hen Harrier was shot and posted to a regional newspaper, and to this day it is suspected that persecution of harriers takes place in Ireland.

The first Republic of Ireland census of breeding Hen Harriers (Norriss *et al*., 2002) confirmed 102 breeding pairs, while Sim *et al.* (2001) reported up to 38 breeding pairs in Northern Ireland, to give an all-Ireland breeding population of 140 pairs. Surveys were repeated for Northern Ireland and the Republic of Ireland in 2004 (Sim *et al*., 2007) and 2005 (Barton *et al*., 2006) respectively, and up to 50 extra territorial pairs were found, probably due to an increased availability of young forest as opposed to mature forest, as well as better quality surveying (Barton *et al*., 2006). The Hen Harrier was downgraded from a red-listed to an amber-listed Species of Conservation Concern in Ireland (Lynas *et al*., 2007), on the basis of this apparent 20% increase in population between the two national surveys (Norriss *et al*., 2002; Barton *et al*., 2006), despite remaining on the red list in Britain (including Northern Ireland) (Eaton *et al*., 2009), where the same period saw an apparent increase of 41% in population (Sim *et al*., 2001 and 2007).

The National Parks and Wildlife Service designated and notified six proposed Special Protection Areas (pSPAs) for the Hen Harrier on 07 November 2007, covering a total of 169 sq. km., while the Northern Ireland Environment Agency classified two SPAs for Hen Harriers on 20 June 2003, covering a total of 36.03 sq. km. (Table 2.1). The Hen Harrier is further protected in Ireland under the Wildlife Acts, 1976 and 2000 and the Wildlife (Northern Ireland) Order, 1985, as well as the Bern, CITES and Bonn Conventions.

With currently less than 200 breeding pairs across the entire island, the Hen Harrier in Ireland has experienced much change in population, distribution and range since the earliest accounts. The species is no longer as widespread or as commonly met with as Thompson (1849) had experienced and Hen Harriers have been lost from a number of the regions where Ussher and Warren (1900) reported them as common. Unfortunately, threats to remaining Hen Harriers in Ireland have not subsided and are as evident now, as ever before.

The main issues facing Hen Harrier conservation in Ireland today are identified as poor public opinion and persecution, forest maturation, wind farming and loss of traditional farming practices (O'Donoghue *et al.*, unpubl. data). To address these issues fully and to stabilise the population, an entire programme of education, habitat management and policy enactments will be necessary. Fundamental to all of this, is a sound understanding of the Hen Harrier's ecology in Ireland. This thesis carries the overarching objective of establishing such an understanding, for the first time in the history of the species here.

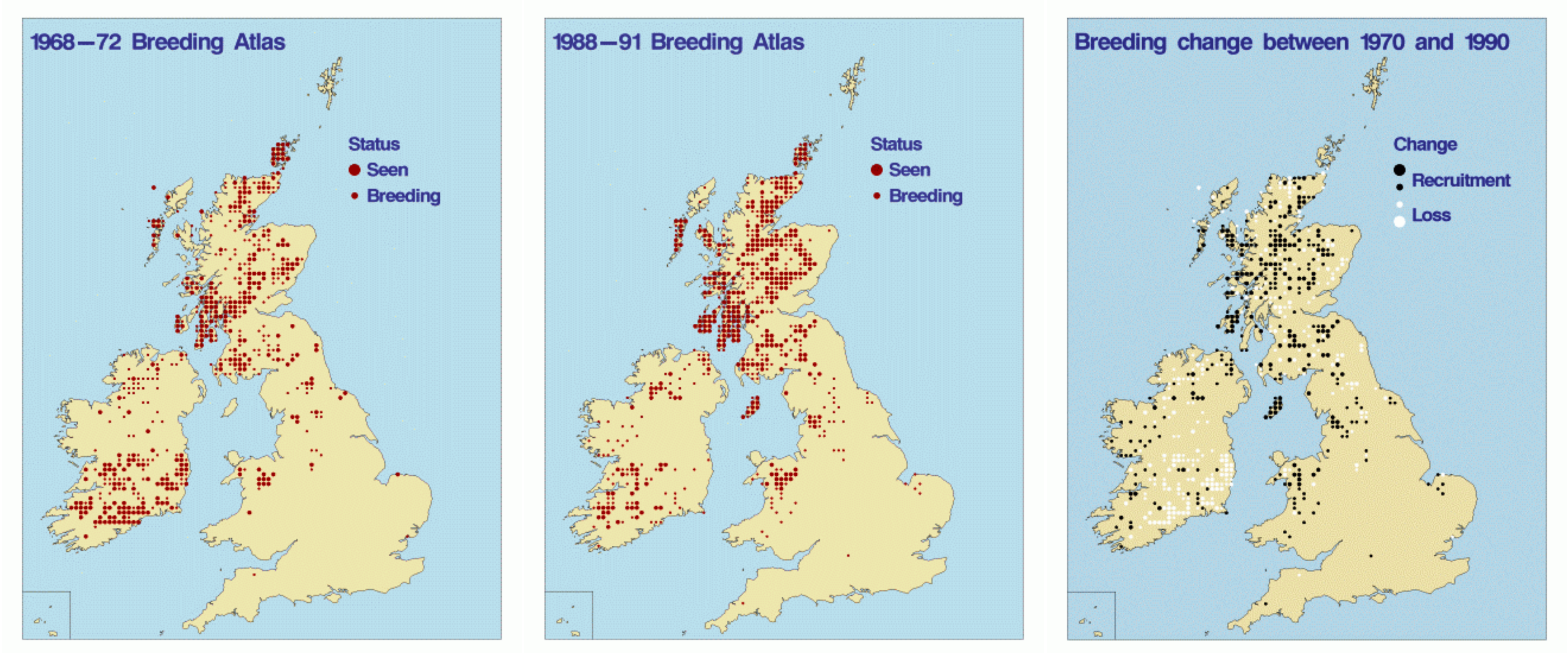

Figure 2.1. Breeding Atlas maps of Britain and Ireland, showing distribution of Hen Harriers circa 1970 and 1990 and the corresponding change in distribution during this time (British Trust for Ornithology, 2009a).

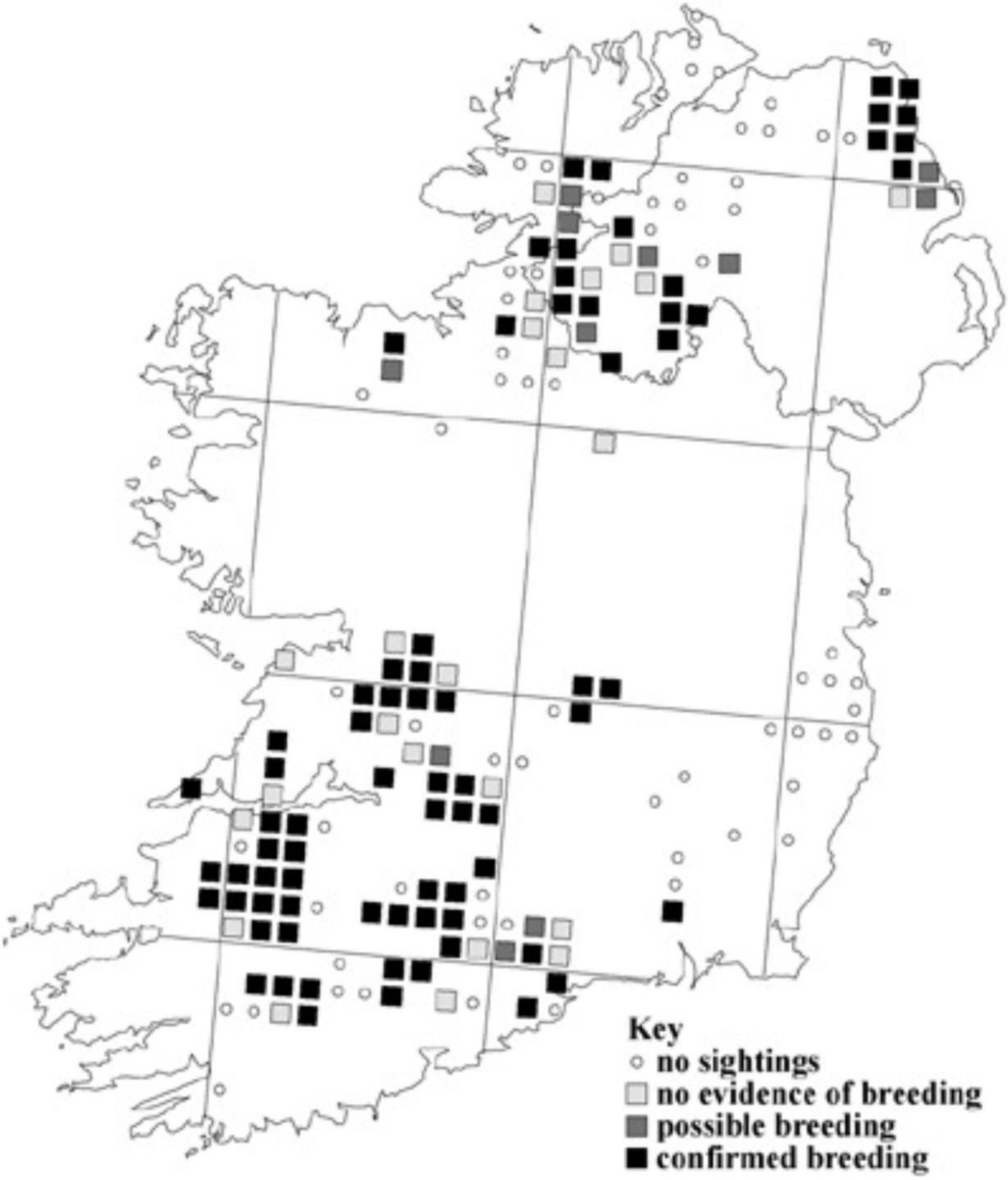

Figure 2.2. All-Ireland breeding distribution of Hen Harriers (from Barton *et al*., 2006).

Table 2.1. Proposed Special Protection Areas for Hen Harrier in Ireland (sources: National Parks and Wildlife Service and Northern Ireland Environment Agency).

SPA name	SPA Code	Size (km^2)	Confirmed breeding pairs within pSPA at time of designation	% of confirmed All-Ireland population
Slieve Bloom Mountains pSPA	004160	218.4	5	2.6
Stack's to Mullaghareirk Mountains, West Limerick Hills & Mt. Eagle	004161	567.3	40	21.1
Mullaghanish to Musheramore Mountains	004162	50.6	3	1.6
Slievefelim to Silvermines Mountains pSPA	004165	207.0	4	2.1
Slieve Beagh[*]	004167	35.5	4	2.1
Slieve Aughty Mountains	004168	611.2	24	12.6
Antrim Hills	UK9020301	270.93	25	13.2
*Slieve Beagh – Mullaghfad – Lisnaskea**	UK9020302	89.36	10	5.3
All SPAs		2050.29	115	60.6

[*]Cross-border SPA

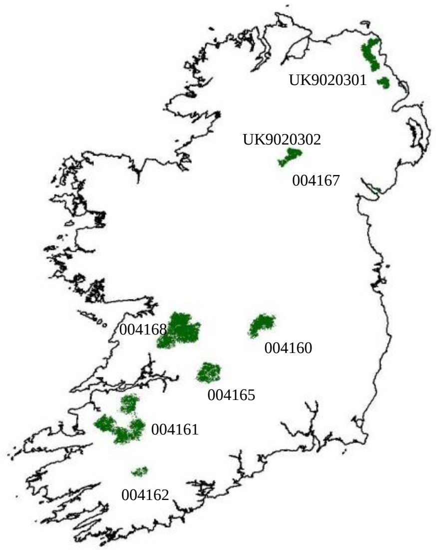

Figure 2.3. Locations of Irish Hen Harrier Special Protection Areas

Chapter Three

Prey

I have seen the heathers embrace
Close, concealing the plummeting lark
Fleeing the wild hawk's swoop
On a Kerry mountain

Dónal Ó Siodhacháin. Images. 2004.

In this chapter, the following research questions are addressed:

- What are Hen Harriers in Ireland feeding on?
- How important are various prey types and species in the diet?
- Does diet differ according to time and location?
- What habitats are most beneficial in terms of providing prey?
- How frequently is prey delivered to Hen Harrier nests?
- How do nest provisioning rates compare across regions?

The key objective of this chapter is to provide an understanding of Hen Harrier diet, which can be used to inform habitat management in a way which will increase the prey base of Hen Harriers.

3.1 INTRODUCTION

3.1.1 The Population in Question at the Time in Question

One of the most fundamental requirements to help maintain, support and conserve a predator species is a comprehensive understanding of its diet and prey (Taylor, 1994; Winterhalder and Lu, 1997; Barbosa *et al*., 2005; Sergio *et al*., 2005). Without sufficient or accessible prey resources, predators may experience declines in survival, productivity, or population. When changes occur in prey densities, predators may shift to other species available to them (Taylor, 1984; Olsen *et al*., 2008). The diet of the Hen Harrier (*Circus cyaneus*), as a generalist predator (Clarke *et al*., 1993; Redpath and Thirgood, 1999), is diverse (Table 1.2) and has been shown to vary both spatially and temporally, adapting to changes in populations of its prey (Randall, 1940; Hecht, 1951; Schipper *et al*., 1975; Picozzi and Cuthbert, 1982; Barnard *et al*., 1987; Martin, 1987; Redpath, 1992; Clarke *et al*., 1993; Simmons, 2000; Redpath *et al*., 2002a). Thus, it is essential to undertake a specific study dedicated to the population in question, at the time in question.

The only exploration of the Hen Harrier's diet in the Republic of Ireland to date was undertaken by O'Donoghue (2004). In that study, passerines were found to be the primary prey items, supplemented by small mammals and waders. However, O'Donoghue (2004) focussed almost exclusively on diet during the non-breeding season, at a limited number of sites, in one year only. Breeding season diet has never been studied in detail and feeding rates have never been investigated in Ireland. A more complete, comprehensive understanding of the Hen Harrier's diet in Ireland is needed. This is particularly true for the breeding season, as food is closely linked with breeding productivity (Newton, 1979 and 1998). This current study focuses on both the breeding and non-breeding season (namely the winters of 2006/7 and 2007/8 and the breeding seasons of 2007 and 2008), across a range of sites and regions. The results will help enlighten habitat maintenance and creation as part of conservation plans and possibly inform future population trends linked to prey and habitat.

3.1.2 Review of Dietary Analysis Techniques

Different techniques are available to analyse avian diet (Hartley, 1948; Ford *et al.*, 1982; Duffy and Jackson, 1986; Rosenberg and Cooper, 1990). Investigations of raptor diet have been completed on many species (e.g. Bavoux, 1990; Roulin, 1996; Avenant, 2005; Ruddock, 2006; Taylor, 2006; Olsen *et al.*, 2008; Rooney, 2008; Escala *et al.*, 2009; Simmons, 2010). The majority of studies on Hen Harrier diet (Table 1.2) have been undertaken using pellet analysis, with a number supplementing this method with prey remains. Pellet analysis is undertaken by collecting indigestible material such as feathers, fur, bones, bill parts, claws and teeth, which are regurgitated in a casting (Plate 3.1) and from which it can be determined what the bird has eaten. A harrier egests approximately one pellet every day Errington (1930). In addition to collecting pellets, prey remains can also be taken from plucking posts, perches, feeding stations, kill locations and nests.

Much information can be deduced from pellet analysis and prey remains including:

- Prey diversity and frequency of prey types in different areas and different habitats (Schipper, 1973; Clarke *et al.*, 1997; Redpath *et al.*, 2001b; Amar and Redpath, 2005);
- Differences between male and female diets (Schipper *et al.*, 1975; Marquiss, 1980);

- Trends in populations of prey and how this is manifested in diet composition (Schipper *et al*., 1975; Picozzi and Cuthbert, 1982; Madders, 1997; Redpath *et al*., 2002a);
- The diet of passerines preyed upon by harriers (Clarke *et al*., 2003);
- Differences between sympatric harrier diets (Schipper, 1973; Clarke *et al*., 1993).

Despite the various applications of pellet analysis and examination of prey remains, there are some disadvantages or inherent biases associated with each method. Not all kills are delivered to the nest as some may be eaten on capture (Sonerud, 1992; Rutz, 2003). Diagnostic parts of prey (e.g. some small mammal jawbones) may not be eaten (Simmons *et al*., 1991). Remains of some prey items are preserved longer than others, while remains of large and pale prey are easier to discover than remains of small and dark prey (Rutz, 2003). Some prey species may be underrepresented or not represented at all (Bildstein, 1987; Mersmann *et al*., 1992; Redpath *et al*., 2001b; Lewis *et al*., 2004), while large prey species may be overrepresented (Redpath *et al*., 2001b; Lewis *et al*., 2004; Margalida, 2005; Tornberg and Reif, 2007). Females can also remove pellets from the nest for nest sanitisation (MacWhirter and Bildstein, 1996; pers. obs.).

Simmons *et al.* (1991) reported that combining pellets and prey remains provides accurate results for harrier dietary analysis, while Collopy (1983) earlier advocated this for Golden Eagles (*Aquila chrysaetos*). However, Redpath *et al.* (2001b) stated that this might not fully eliminate biases and advised that direct observations should be used in association with pellet analysis and prey remains to give as accurate a picture of diet as possible (see also Marti, 1987; Koks *et al*., 2007; Tornberg and Reif, 2007). Direct observations however, are also not without biases. Redpath *et al.* (2001b) found direct observations gave the highest percentage of unidentified prey. Direct observations of prey taken to nests can also be most time-consuming and not suitable to study a population over a large sample of nests or regions (Tornberg and Reif, 2007). Pellets are more useful for detecting small prey species than direct observations, and for giving better estimates of prey diversity (Redpath *et al*., 2001b). In previous cases, prey remains and pellets have given results similar to direct observations of diet (Collopy, 1983; Simmons *et al*., 1991). Tornberg and Reif (2007), investigating the biases of prey analysis methods, found indirect methods to be satisfactory so long as a species is not specialising on one prey species or type. For a generalist predator like the Hen Harrier, data collected from a wide range of nest sites or non-breeding roost sites should give a reliable picture of diet (R. Tornberg, pers. comm.).

Direct observations of prey consumption are in reality only feasible during the breeding season, when harriers have a nucleus of activity to which they return with food – i.e. the nest. Given time restraints, direct observations can only be carried out at a subset of nests. Direct observations or indeed analysis of prey remains during the non-breeding season are not feasible, as most foraging is done away from the roost site and harriers do not generally bring food back to their roosts. Consequently, during the non-breeding season, pellet analysis is the only method available to investigate diet. This sole method of investigating non-breeding diet has been used by a number of authors (e.g. Dickson 1970; Schipper, 1973; Marquiss, 1980; Picozzi and Cuthbert, 1982; Clarke *et al*., 1993 and 1997).

3.2 METHODS

3.2.1 Study Areas, Data Collection and Techniques Employed

Breeding season diet was analysed using the combined techniques of pellet analysis, prey remains and direct observations at a total of 79 breeding sites across the five breeding areas of Kerry, West Clare, Boggeraghs, Ballyhouras and Slieve Aughties (Figure 1.3). Non-breeding diet was assessed using pellets collected at ten roost sites spread across the country. Pellets were collected when birds were away from roosts, and vegetation disturbance was kept to a minimum in order to protect the integrity of the roost sites.

Upon collection at each nest, perch, roost or kill site, pellets or prey remains were inserted into individual paper envelopes, labelled and filed according to site and date, to enable comparison of diet between sites and seasons. They were then fully air-dried. Prior to analysis, pellets were measured for length (mm) and breadth (mm). Pellets were broken up carefully by hand and the remains within were identified with the aid of Day (1966), Yalden (1977), Shawyer and Talbot (1989) and Yalden and Morriss (1990), along with a personal reference collection of bones and feathers and a specialist website (Klemann, 2009). For feathers which could not be distinguished using these resources, the Bird Remains Identification System (BRIS) (Prast and Shamoun, 2001) was used by examining feathers under light microscope and matching what was seen to microscopic images supplied in BRIS. More than one small mammal of the same species was recorded where left or right jaw bones, skulls or pairs of upper or lower incisors summed to more than one individual. More than one bird of the same species per pellet was recorded where there was more than one of the same bill part or gizzard. A small number of bone remains were measured and compared with Walsh (2005) to aid identification. In addition to scheduled visits during nest occupation at a subset of nests (Chapter 5, Breeding Ecology); all nests (including those previously unvisited) were visited at the end of the breeding season when birds had departed from the nest site, thereby allowing time for thorough pellet and prey searching. All prey items were identified to the lowest taxonomic level possible, usually to species level. Not all prey items could be identified to species level, particularly as the material within pellets was frequently degraded. For analysis of prey by type, bird prey was assigned to four categories (small (<35g) passerine[2]; large (≥35g) passerine; wader and game). Irish Hares (*Lepus timidus hibernicus*) and Rabbits (*Oryctolagus cuninculus*) were grouped as lagomorphs, while small mammals, Common Frog (*Rana temporaria*) and Viviparous Lizard (*Zootoca vivipara*) were listed by species.

3.2.2 Prey Delivery Rates

During the breeding seasons of 2007 and 2008, the number of prey deliveries to 79 nests within the four main study areas was recorded and divided by the amount of time spent observing these nests to determine the prey delivery rates in each of the areas. A total of 244hrs were spent observing nests in Kerry; 202.3hrs in West Clare; 150.6hrs in the Ballyhouras and 258.9hrs in the Slieve Aughties. Prey delivery rates were also related to stage of breeding (egg, nestling or fledgling), for those nests which were observed in all three stages. The time of each prey delivery was also recorded and times were grouped into eight two-hour periods, beginning at 0600hrs and ending at 2200hrs. The effort per two-hour period is summarised in Table 3.1.

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[2] Weights according to Robinson (2005).

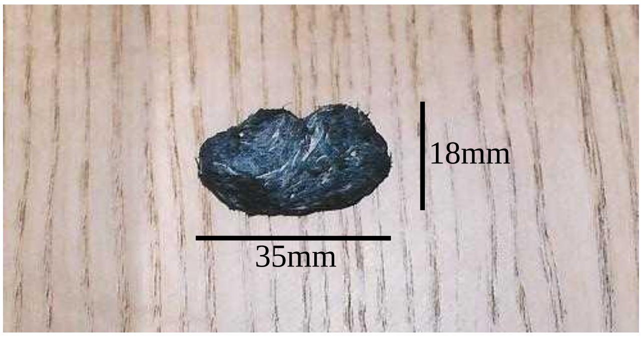

Plate 3.1. Typical Hen Harrier pellet collected from nest or non-breeding roost.

Table 3.1. Observation effort across all nests, per two-hour period.

Beginning	**0600**	**0800**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**
Effort (hrs)	7.48	33.20	54.95	81.50	72.45	62.42	36.37	13.17
Number of Nests	18	30	33	36	34	35	29	18

3.2.3 Presentation of Dietary Results

Results are presented according to the method by which they were derived (pellet analysis, prey remains and direct observations), as well as a combination of pellet analysis and prey remains (which gave results to both category and species level), and combination of all three methods (to broad category only). As per Clarke *et al.* (1993), prey items (species) are presented in terms of frequency of occurrence, by counting the total number of individuals, rather than the number of samples in which particular items (species) occurred. While estimated weights of prey can be found in Schipper (1973) and Yalden (1977), this study follows a number of other Hen Harrier winter diet studies (e.g. Marquiss, 1980; Clarke *et al*., 1993 and 1997) in not applying weights to the diet, as pellets are generally a poor measure of percent biomass (Redpath *et al*., 2001b).

3.2.4 Prey Availability Investigations

Schipper *et al.* (1975) showed how harrier foraging habitats are closely associated with prey habitats. In addition to discovering and analysing the Hen Harrier's actual diet, the abundance and availability of the main prey types were investigated within Hen Harrier territories, as a function of habitat. Ten habitat types relevant to Hen Harriers in Ireland were identified; namely heather/bog, turbary, riparian, scrub/hedgerow, rough grassland, intensive grassland and the commercial forest stages and features of pre-thicket first rotation; pre-thicket restock, clearfell and forest track. Post-thicket or mature forest was not sampled as this habitat is generally avoided by Hen Harriers for hunting (Madders, 2000; O'Donoghue, 2004).

Small mammal surveying was carried out by mark and recapture using 30 Longworth live traps baited with peanut butter, in a line transect of 300m, with trapping stations separated by 10m. This was repeated over a three night period in each habitat in the summer of 2007 and repeated at the same sites in the winter of 2007/8 and the summer of 2008. A total of 1800 trap nights were recorded for the breeding season, while 900 trap nights were conducted during the non-breeding season. While vole numbers in summer can be considerably higher than at the time when harrier breeding territories are established (Dijkstra *et al*., 1988), they are correlated with spring vole abundance (Butet and Leroux, 2001).

Relative bird abundance was estimated through point count methodology, as described by Hutto *et al.* (1986), but modified to suit the requirements and landscape of this study. According to Felley and Sogge (1997) point counts are also suited to surveying riparian habitats (even though they are linear in nature). Six points a minimum of 150m apart were sampled for eight minutes each in the respective habitats in the summer of 2008. A 50m radius from the observer was taken as the limit of observations. Bird surveys were conducted in dry, calm conditions, between 0600hrs and 0900hrs in accordance with Thirgood *et al*. (1995).

Surveys for other prey were carried out simultaneously to bird and small mammal surveys. This involved noting the presence or absence of lagomorphs, amphibians, and reptiles (lizards) at and between bird point counts and along small mammal transects. Signs such as droppings, burrows or forms, as well as direct observations were taken as confirmation of the presence of lagomorphs.

Prey abundance in each habitat was investigated towards relative abundance rather than absolute abundance. The method of trapping and use of indices of small mammal numbers has been used in previous studies on raptor diet (e.g. Glue, 1967; Hamilton and O'Neill, 1981; Taylor, 1994). Relative abundance is a good indicator of population size (Collier *et al.,* 2008). However abundance does not necessarily equate to availability (Royama, 1970; Baker and Brooks, 1981; Ontiveros *et al*., 2005), so the percentage of prey capture attempts in a given habitat which were successful was taken as a measure of the availability of prey in that habitat. A capture attempt was defined as a single strike, or closely repeated group of strikes at prey (Bildstein, 1987; Redpath, 1992).

3.2.5 Data Analysis

Simpson's indices and Shannon indices were calculated from dietary investigations and prey abundance investigations to measure the diversity of the Hen Harrier's diet.

Simpson's Index: $D = 1 - ((\sum n(n-1))/N(N-1)$

where n = number of individuals of a given species and N = total number of individuals of all species

Shannon Index: $H' = \sum p_i \ln(p_i)$

where $\boldsymbol{p_i}$ = the relative abundance of each group of organisms

Non-breeding season diet was compared across roosts and regions (see Chapter 6, Non-breeding Ecology for details on these roosts and regions). Unfortunately, no pellets were obtainable from roosts in the midlands, so comparisons could not be made between the non-breeding diet of that region and the other two regions. Breeding season diet was compared across the five breeding areas of Kerry, West Clare, Ballyhouras, Slieve Aughties and Boggeraghs (Figure 1.3). For bird counts, the software program DISTANCE was used to model estimates of true density by relating count data to the distribution of birds relative to the observer (Buckland *et al*., 2001). Kruskal-Wallis tests were used to compare diet between sites and regions, while ANOVA was used to compare bird density estimates derived from DISTANCE and chi-square tests were used to compare diet between seasons.

3.3 RESULTS

3.3.1 Data Resource Collected

A total of 481 pellets were found at 44 breeding sites; mainly at the nest, but also at perches (usually <100m from the nest). A further 397 pellets were collected at ten non-breeding roost sites. Pellets had a mean length of 35.2 ± 0.90mm, and mean breadth of 17.5 ± 0.31mm. While typically less than five pellets were found in roosting platforms at non-breeding roosts, in one case 15 pellets were collected. A total of 1190 items were identified from the 878 pellets ($\bar{x}$=1.36 ± 0.05 items per pellet), with 28.8% of pellets containing more than one item. A relatively large proportion of prey (28.6% in summer, 40% in winter), particularly passerine, could not be identified to species level given the deterioration of feather material that had been ingested and digested. This brought the number of nests from which ‘usable’ pellets were collected to 36, while the number of roosts from which ‘usable’ pellets were collected at remained at ten. Prey remains were found only during the breeding season and all of the 55 items were identified to one of 20 species. Prey was also identified from 77 observations of food deliveries, kills or harriers transporting food. However, from direct observations, prey was identified to species level on just two occasions and in most cases could only be attributed to broad categories of prey.

3.3.2 Prey Species and Prey Types in Diet

Five broad categories of prey were identified by all three methods of dietary analysis: avian, small mammal, lagomorph, lizard and frog. Avian prey was the most common prey type, accounting for 77.0% of all prey (Figure 3.1). Analysis by pellets and prey remains allowed a more detailed categorisation of prey and this is summarised in Figure 3.2, showing small passerines to be the most common group taken. Pellet analysis and prey remains enabled more comprehensive identification to species level, with 44 species identified by these two methods (Table 3.2). A Simpson's Index of Diversity (1-D) of 0.90 and Shannon Index (H′) of 18.10 were found using pellet analysis and prey remains.

Overall (incorporating all dietary analysis techniques), 45 species were recorded as part of the Hen Harrier's diet; including at least 24 species of small passerine, six species of large passerine, four species of wader, two game bird species, lagomorphs (young rabbit and hare), five small mammal species, one lizard species (*Zootoca vivipara*) and one frog species (*Rana temporaria*). In addition, invertebrates (mainly ground beetles) were found in 106 pellets. However, because it could not be determined with certainty if the harriers had preyed on these invertebrates, or actually ingested birds or small mammals that had already eaten the invertebrate prey, invertebrates were not factored into dietary analyses. A blue eggshell was also found in one pellet.

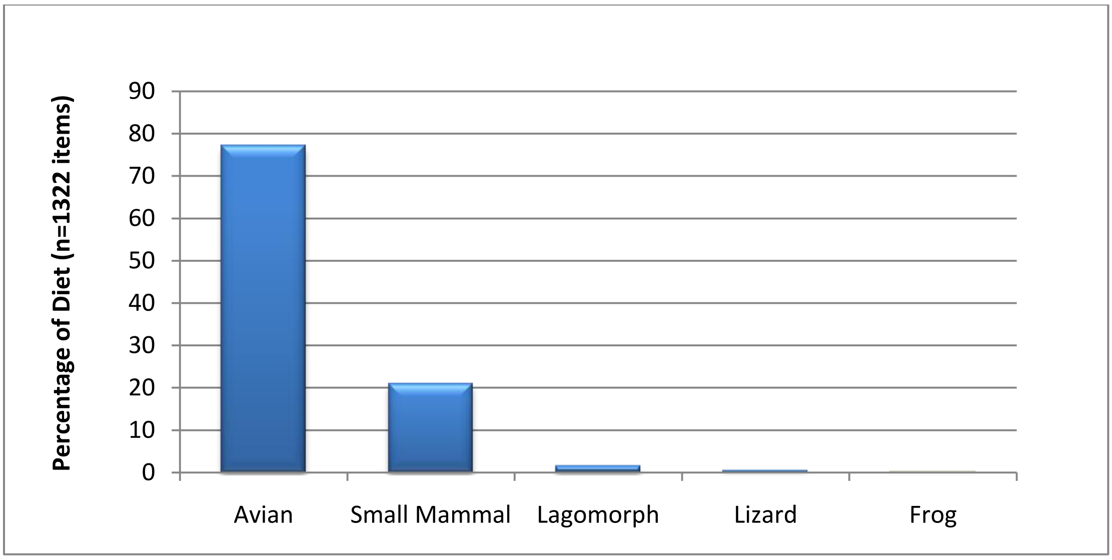

Figure 3.1. Contribution of broad prey types to breeding season diet as identified through combined techniques of pellet analysis, prey remains and direct observations.

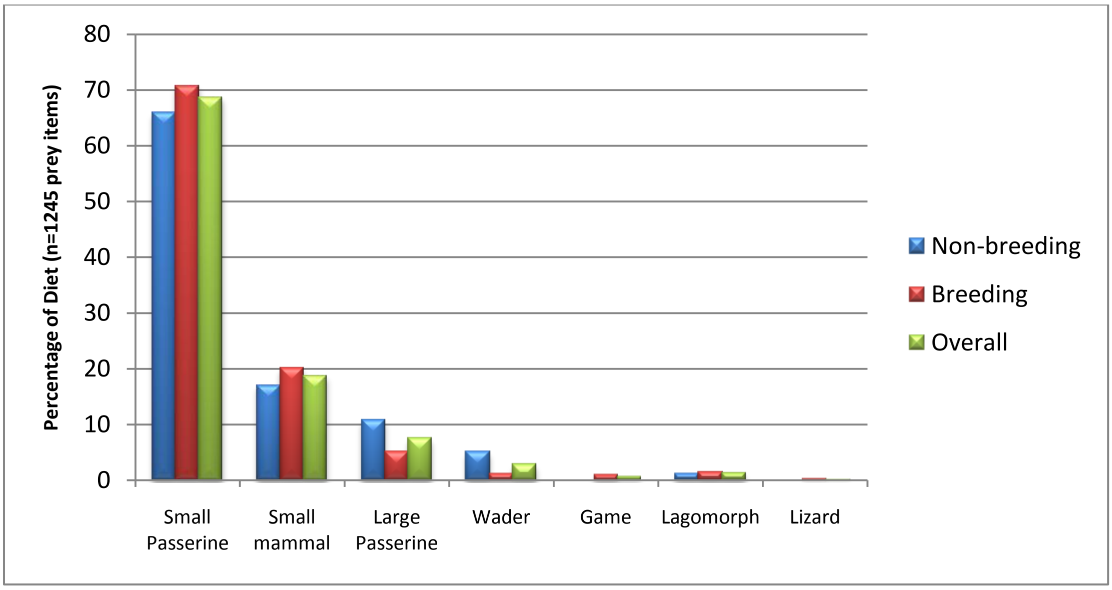

Figure 3.2. Contribution of prey types to breeding season diet as identified through the combined techniques of pellet analysis and prey remains. Note in comparison to Figure 3.1, direct observations are now not included, but more defined categories of prey are identified. Not all prey items were identified to species level.

Table 3.2. Prey species (identified by pellet analysis/prey remains) and respective contributions (%) to diet.

Prey	Non-breeding Diet	Breeding Diet	Combined/Overall Diet
Redshank (*Tringa totonus*)	2.44	-	0.94
Water Rail (*Rallus aquaticus*)	0.81	-	0.31
Woodcock (*Scalopax rusticola*)	0.41	-	0.16
Redwing (*Turdus iliacus*)	12.60	-	4.84
Fieldfare (*Turdus pilaris*)	2.44	-	0.94
Redpoll (*Carduelis flammeus*)	0.41	-	0.16
Bullfinch (*Pyrrhula pyrrhula*)	1.22	-	0.47
Coal Tit (*Parus ater*)	2.85	-	1.09
Pygmy Shrew (*Sorex minutus*)	0.41	-	0.16
Red Grouse (*Lagopus lagopus*)	-	0.25	0.16
Pheasant (*Phasianus colchicus*)	-	1.27	0.78
Blackbird (*Turdus merula*)	-	1.27	0.78
Song Thrush (*Turdus philomelos*)	-	0.76	0.47
Greenfinch (*Carduelis chloris*)	-	0.51	0.31
Siskin (*Carduelis spinus*)	-	0.76	0.47
Grey Wagtail (*Motacilla cinerea*)	-	0.25	0.16
House Sparrow (*Passer domesticus*)	-	0.25	0.16
Swallow (*Hirundo rustica*)	-	0.25	0.16
Wheatear (*Oenanthe oenanthe*)	-	1.02	0.63
Sedge Warbler (*Acrocephalus schoenobaenus*)	-	2.03	1.25
Willow Warbler (*Phylloscopus trochilus*)	-*	5.84†	3.59
Grasshopper Warbler (*Locustella naevia*)	-	0.51	0.31
Chiffchaff (*Phylloscopus collybita*)	-	0.51	0.31
Lizard (*Zootoca vivipara*)	-	0.51	0.31
Snipe (*Gallinago gallinago*)	5.28	1.78	3.13
Chaffinch (*Fringilla coelebs*)	6.50	4.06	5.00
Skylark (*Alauda arvensis*)	0.81	2.03	1.56
Goldfinch (*Carduelis carduelis*)	0.41	1.02	0.78
Pied Wagtail (*Motacilla alba*)	0.41	0.51	0.45
Starling (*Sturnus vulagris*)	0.41	1.78	1.25
Stonechat (*Saxicola turquata*)	3.25	4.06	3.75
Wren (*Troglodytes troglodytes*)	0.41*	7.87†	5.00
Robin (*Erithacus rubecula*)	0.41	0.51	0.45
Linnet (*Carduelis cannabina*)	1.63	0.51	0.94
Reed Bunting (*Emberiza schoeniclus*)	4.88	1.78	2.97
Meadow Pipit (*Anthus pratensis*)	18.29	24.87	22.34
Great Tit (*Parus major*)	0.81	0.76	0.78
Dunnock (*Prunella modularis*)	1.63	0.75	0.78
Bank Vole (*Myodes glareolus*)	13.41	16.00	15.00
Wood Mouse (*Apodemus sylvaticus*)	1.63*	11.68†	7.81
House Mouse (*Mus musculus*)	2.03	0.51	1.09
Rat (*Rattus norvegicus*)	12.20†	1.78*	5.78
Rabbit (*Oryctolagus cuninculus*)	0.81	1.27	1.09
Irish Hare (*Lepus timidus hibernicus*)	1.22	1.02	1.09
Shannon Index (H′)	14.61	13.82	18.10
Simpson's Index (1-D)	0.90	0.88	0.90

†significantly higher seasonally, *significantly lower seasonally.

3.3.3 Diet of the Hen Harrier according to Season

Certain species were found exclusively in either the breeding or non-breeding season diet. However the only confirmed prey category which differed between seasons was Large Passerine, whereby this category accounted for a significantly larger proportion of the diet during the non-breeding season than during the breeding season (χ^2=8.05, *df*=1, *P*=0.005). Small mammals increased in the breeding season diet, but did not account for a significantly higher proportion of diet than in the non-breeding diet (χ^2=1.32, *df*=1, *P*=0.25). Invertebrates featured more highly during the breeding season (accounting for 10.4% of items found in pellets) than during the non-breeding season (accounting for 3.33% of items found in pellets at that time). However as before, it is not known by which means invertebrates entered the diet. The median number of items found within pellets varied significantly (Mann-Whitney W=150260, *P*<0.001) between the non-breeding season (1.20 ± 0.02) and the breeding season (1.49 ± 0.03).

3.3.4 Diet of the Hen Harrier according to Location

3.3.4.1 Comparison of Diet between Non-breeding Sites

There was significant variation between roosts in terms of how frequently prey categories, including small passerine (Kruskal-Wallis H=109.91, *df*=9, *P*<0.001), large passerine (Kruskal-Wallis H=66.28, *df*=9, *P*<0.001), wader (Kruskal-Wallis H=36.75, *df*=9, *P*<0.001) and small mammal (Kruskal-Wallis H=129.60, *df*=9, *P*<0.001) occurred in the diet. With regard to region, small passerines were significantly more prevalent in the Western Seaboard diet than the South and East Region diet (Mann-Whitney W=6730, *P*<0.001). The occurrence of large passerines did not vary significantly between the two regions (Mann-Whitney W=5481, *P*=0.363). Significantly more waders (Mann-Whitney W=12243, *P*<0.045) and small mammals (Mann-Whitney W=16143, *P*<0.001), particularly Rats (Mann-Whitney W=10085, *P*<0.001) were taken in the South and East Region than in the Western Seaboard Region.

There was a significantly higher proportion of small mammals in the diet at roosts dominated by ringtails compared to those dominated by males (Mann-Whitney W=1688, *P*<0.001) and a significantly higher proportion of small passerines in the diet at roosts dominated by males (Mann-Whitney W=1290, *P*<0.001).

3.3.4.2 Comparison of Diet between Breeding Sites

The proportion of small passerines in the diet varied significantly between individual nest sites (Kruskal-Wallis H=141.97, $df=35$, $P<0.001$), though not between breeding areas (Kruskal-Wallis H=2.29, $df=4$, $P=0.682$). Large passerines did not vary significantly in the diet of individual nests (Kruskal-Wallis H=31.47, $df=35$, $P=0.639$) or breeding areas (Kruskal-Wallis H=6.30, $df=4$, $P=0.178$). Game species were almost negligible in the breeding season diet, with remains found in only two of 36 nests. The occurrence of waders in the breeding diet did not vary significantly for nests (Kruskal-Wallis H=24.87, $df=35$, $P=0.898$) or breeding area (Kruskal-Wallis H=1.34, $df=4$, $P=0.854$).

Small mammals accounted for 20% of the breeding season diet. The number of small mammals taken in the diet did not differ significantly across the five breeding areas (Kruskal-Wallis H=5.54, $df=4$, $P=0.237$), but did differ significantly across individual nests (Kruskal-Wallis H=69.39, $df=35$, $P<0.001$), with some nests recording no small mammals and others recording nothing but small mammals. Of the small mammals, the proportion of Bank Vole (*Myodes glareolus*) in the diet differed between breeding areas (Kruskal-Wallis H=20.79, $df=4$, $P<0.001$), with Kerry having the highest percentage (17.8%). The proportion of Bank Vole in the diet also differed between individual nest sites (Kruskal-Wallis H=108.98, $df=35$, $P<0.001$). The proportion of Wood Mouse (*Apodemus sylvaticus*) in the diet also differed significantly between nests (Kruskal-Wallis H=61.67, $df=35$, $P=0.004$), though not between breeding areas (Kruskal-Wallis H=9.05, $df=4$, $P=0.060$). The proportion of House Mouse (*Mus musculus*) in the diet also showed significant differences between individual sites (Kruskal-Wallis H=136.00, $df=35$, $P<0.001$), but not between breeding areas (Kruskal-Wallis H=2.41, $df=4$, $P=0.661$). Rat (*Rattus norvegicus*) did not differ between individual nest sites (Kruskal-Wallis H=37.52, $df=35$, $P=0.354$) or breeding areas (Kruskal-Wallis H=2.51, $df=4$, $P=0.644$). As with Rat, Lagomorphs did not differ between sites (Kruskal-Wallis H=49.48, $df=35$, $P=0.053$) or between breeding areas (Kruskal-Wallis H=4.35, $df=4$, $P=0.361$). The occurrence of Lizard (*Zootoca vivipara*) in the diet was site specific, varying significantly between nests (Kruskal-Wallis H=86.55, $df=35$, $P<0.001$) but not breeding areas (Kruskal-Wallis H=4.35, $df=4$, $P=0.361$).

3.3.5 Prey Abundance, Species Richness and Availability

In total, 35 species of bird were recorded during point counts across the ten habitat types surveyed (see Appendix I for details). Estimates of bird density generated from DISTANCE are summarised in Table 3.4. Significant differences existed between habitats in terms of birds density ($F_{9,50}$=15.22, P<0.001), with highest densities found in scrub/hedgerow and lowest densities in clearfell and intensive pasture. The density of birds in the other eight habitats did not vary significantly. Small mammal (Bank Vole, Wood Mouse and Pygmy Shrew) abundance was highest in scrub/hedgerows and restock forest (Figure 3.3). Significantly fewer small mammals were trapped in scrub/hedgerows during the non-breeding season compared to the breeding season (Kruskal-Wallis H=26.90, df=1, P<0.001 and H=25.23, df=1, P<0.001, respectively). The prey species richness of the habitats that constitute the Hen Harrier's breeding landscape in Ireland are summarised in descending order in Table 3.5. While 45 prey species were recorded during dietary analysis, 42 species were accounted for during surveys for prey, the majority of which were birds, given the relative paucity of Irish small mammal fauna.

Both aerial and ground capture attempts were observed on 74 occasions across all ten habitats studied. The observed frequencies of capture attempts per habitat are summarised in Table 3.6, but are not adjusted according to the amount of each habitat observed. There was no difference in the strike success rate between habitats (Kruskal-Wallis H=3.75, df=9, P=0.92).

Table 3.3. Contribution (%) of prey types to breeding season diet according to study area.

	Kerry	West Clare	Ballyhouras	Slieve Aughties	Boggeraghs
Small Passerine	69.6	69.3	74.6	80.4	76.9
Large Passerine	3.7	7.2	0	4.3	15.4
Game	2.6	0	0	0	0
Wader	1.6	1.1	0	2.2	0
Bank Vole	17.8	6.8	12.7	4.3	0
Wood Mouse	3.1	11	8.5	8.7	7.7
House Mouse	0	0.8	0	0	0
Rat	1	1.1	2.8	0	0
Lagomorph	0.5	2.7	1.4	0	0
Lizard	1	0	0	0	0
Shannon Index (H)	2.9	3.0	2.3	2.1	2.7
Simpson's Index (1-D)	0.5	0.5	0.4	0.3	0.5

Table 3.4. Mean (± s.e.) bird density according to habitat, presented in descending order.

Habitat	**Mean Density (No. ha.$^{-1}$)**
Scrub/Hedgerow	71.09 ± 5.90
Riparian	42.27 ± 3.84
Restock	40.35 ± 2.98
First Rotation	39.39 ± 2.75
Heather/Bog	38.43 ± 5.89
Turbary	38.43 ± 5.50
Rough Grass	37.47 ± 1.29
Forest Track	36.51 ± 4.63
Improved Grassland	17.29 ± 5.95
Clearfell	6.72 ± 0.96

Table 3.5. Prey species richness of habitats, presented in descending order.

Habitat	Bird	Small Mammal	Lagomorph	Amphibian	Lizard	Total species	Shannon Index
Scrub	29	3	2	0	0	34	26.94
Riparian	12	2	1	1	1	17	12.39
Restock	13	2	0	1	0	16	12.36
Rough Grass	10	2	2	0	0	14	10.37
Forest Track	13	1	0	0	0	14	10.62
First Rotation	11	2	1	1	0	14	10.89
Heather/Bog	8	1	1	1	1	12	9.88
Turbary	7	1	1	1	1	11	9.18
Intensive Grass	6	1	2	0	0	9	6.70
Clearfell	5	1	0	0	0	6	5.67
All Landscape	35	3	2	1	1	42	33.85

Table 3.6. Directly observed strikes at prey in Kerry and West Clare in 2007 and 2008, presented in order of descending frequency.

Habitat	Attempts	% of Total	Successful	Success Rate
Scrub	20	27.03%	10	50%
Heather/Bog	19	25.68%	8	42%
Riparian	10	13.51%	5	50%
Turbary	10	13.51%	5	50%
First Rotation	5	6.76%	2	40%
Restock	4	5.41%	2	50%
Rough Grass	3	4.05%	1	33%
Forest Track	1	1.35%	1	100%
Intensive Grass	1	1.35%	0	0%
Clearfell	1	1.35%	0	0%
All	74	100	34	46%

3.3.6 Prey Delivery Rates

In total, 458 prey deliveries to 79 nest sites were recorded in 2007 and 2008, with nests in Kerry (*n*=179) and West Clare (*n*=152) accounting for over 72% of all deliveries recorded. Food provisioning rates in each of the four studied areas are summarised in Figure 3.4.

Provisioning rate was lowest when the female was incubating (0.52 items hr^{-1} or one item every 1.9hrs), but increased after hatching, to a rate of 0.77 items hr^{-1} (or one item every 1.3hrs) for both the nestling and fledging stages individually. Considering a mean brood size of 3.13 (Chapter 5, Breeding Ecology), this represents a delivery rate of 0.25 items hr^{-1} per individual chick. Figure 3.5 summarises the provisioning rate on a daily time scale, and it shows provisioning rate to increase up to 0800hrs (2.5-3 hrs after sunrise) and remain constant at between 0.6 and 0.8 items hr^{-1} for the rest of the day, apart from a peak during the evening period between 1800 and 2000hrs (2-4 hrs before sunset). The earliest recorded prey delivery was at 0544hrs (20mins after sunrise) and the latest was at 2107hrs (37mins before sunset).

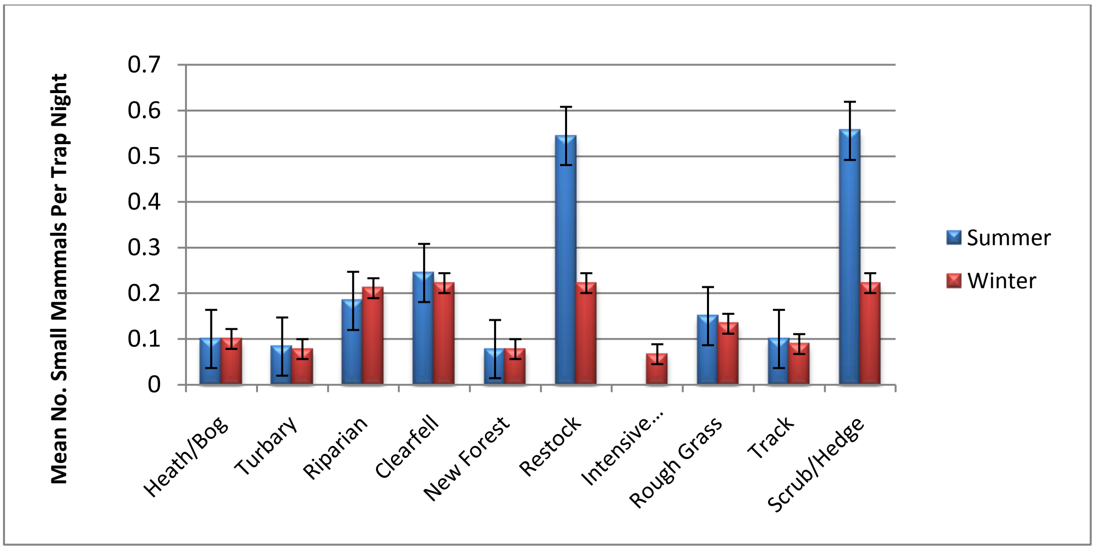

Figure 3.3. Small mammal relative abundance in nine key habitats in the Hen Harrier landscape of Ireland.

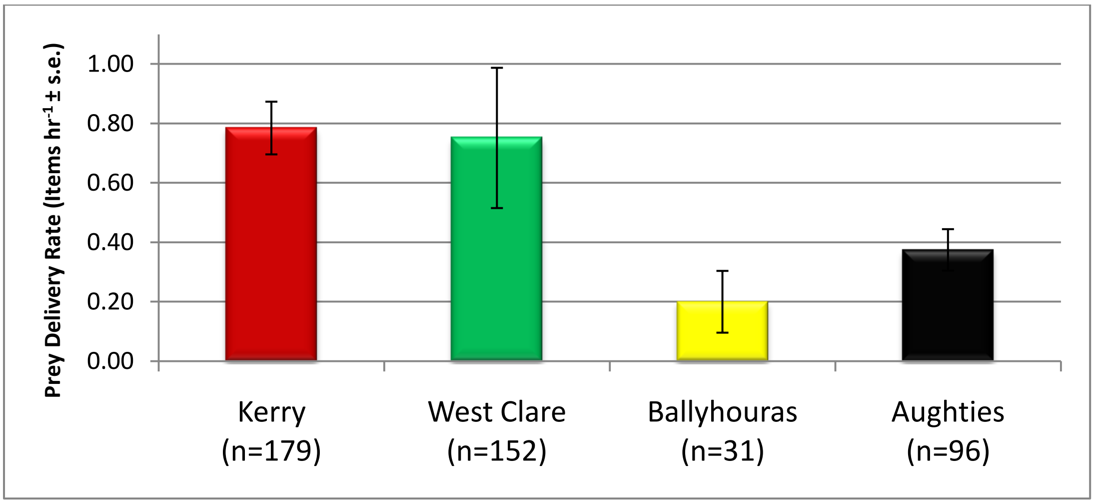

Figure 3.4. Mean (± s.e.) prey delivery rates (items hr^{-1}) to nests according to region.

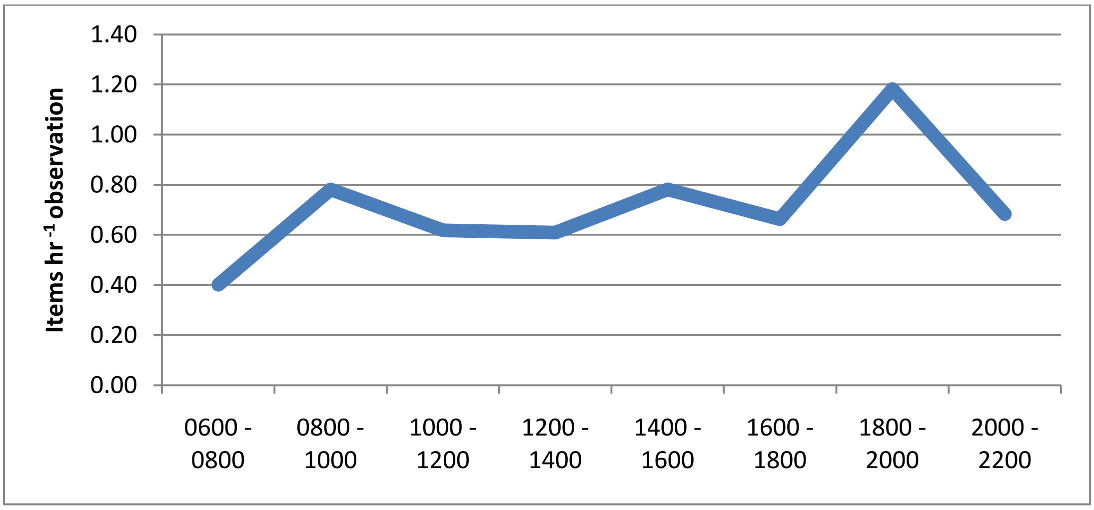

Figure 3.5. Daily nest provisioning rates (*n*=79 nests).

3.4 DISCUSSION

3.4.1 Prey Taken by Hen Harriers in Ireland

The findings of the current investigation are largely in agreement with O'Donoghue (2004), despite a four year gap between the studies and a larger area involved in the current study (Figure 3.6). The majority of the diet was found to be passerines, with the remainder composed mainly of small mammals along with lagomorphs and waders. In both studies, small mammals became more prevalent in the diet during the breeding season, though this increase was not statistically significant. Large passerines were the only confirmed prey category that showed significant differences between seasons, accounting for a higher proportion of the diet during the non-breeding season, as during this time Ireland plays host to significant numbers of migrants of the Thrush (*Turdus*) genus (Mullarney *et al*., 1999; Wernham *et al*., 2002). Meadow Pipit (*Anthus pratensis*) has been identified as the most common species taken by Hen Harriers in Ireland (Table 3.2). The present study has also accounted for Lizard (identified by remains) and Common Frog (identified by direct observation), whereas these were not recorded by O'Donoghue (2004).

3.4.1.1 Passerines and Other Birds

Passerines, whether large or small, constituted the greatest proportion of the Hen Harrier's diet throughout the year, both during the breeding and non-breeding seasons. This share (c.75% of the diet) is similar to the proportion that O'Donoghue (2004) in Ireland and Watson (1977) and Marquiss (1980) in Scotland reported. However, the prevalence of any prey type can vary by time and location, and there are as many studies showing passerines to be one of the least taken prey types (e.g. Schipper *et al*., 1975; Redpath *et al*., 2002a).

Small passerines accounted for a significantly higher proportion of the non-breeding season diet in the Western Region than in the South and Eastern Region. Conversely, significantly more waders and small mammals were found in the non-breeding diet of the South and Eastern region than in the Western Region. The Western Region has been found to have a significantly higher proportion of males over the winter period than the South and Eastern Region which has an influx of ringtails, particularly female ringtails (Chapter 6, Non-breeding Ecology). Previous studies (Schipper *et al*., 1975; Marquiss, 1980; Clarke *et al*., 1993 and 1997) have commented on the diverged selection of small passerine prey by males and larger prey by females and the findings of this study concur with this.

The fact that Meadow Pipit was the main prey species taken by Hen Harriers in Ireland highlights the importance of protecting and enhancing heather/bog and rough grassland within the Hen Harrier's range, given these habitats contain the greatest concentration of Meadow Pipits (Smith *et al.*, 2001; Vanhinsbergh and Chamberlain, 2001; Pearce-Higgins and Grant, 2002).

Predation of game was very much a rarity and fortunately, the harrier-game bird conflict which has been cited as the main reason for a below natural population in Britain (Etheridge *et al*., 1997; Potts, 1998; Natural England, 2008; Fielding *et al*., 2009), does not feature as much in Ireland.

3.4.1.2 Small Mammals and the Importance of Bank Voles

Small mammals were the next most common prey type taken by Hen Harriers after passerines, accounting for approximately 20% of prey throughout the year. Pygmy Shrew (*Sorex minutus*), Bank Vole (*Myodes glareolus*), Wood Mouse (*Apodemus sylvaticus*), House Mouse (*Mus musculus*) and Rat (*Rattus norvegicus*) were all taken, representing the entire suite of small mammals known in the study areas. Though the Greater White-toothed Shrew (*Crocidura russula*) has been found in the diet of Barn Owls (*Tyto alba*) less than 3km from the nearest Hen Harrier nest in the Ballyhouras (J. Lusby, pers. comm.), it was not found in Hen Harrier diet, but may feature in future as it continues to expand.

Small mammals are nutritionally rich prey (Rooney, 2008), but in both O'Donoghue (2004) and the current study, accounted for just 20-30% of the Hen Harrier's diet in Ireland. The small mammals of Ireland are not known to experience large cyclic fluctuations (P. Sleeman, pers. comm.) as with other species internationally (Hamerstrom, 1986; Brommer *et al*., 2010; Burthe *et al*., 2010) so there are unlikely to be 'plague' years in which small mammals become the main prey of Hen Harriers in Ireland. In addition, a large proportion of the Irish Hen Harrier's landscape (Chapter 1, Introduction) is under closed canopy forest, or restock forest in which small mammals may not be as accessible (Madders, 1997). Despite accounting for no more than a third of the diet, small mammals may be vital in providing nutrients and minerals unattainable from other prey.

The occurrence of Bank Vole as the primary small mammal in the Hen Harrier's diet is interesting, as both species' distributions overlap to a large extent (Figure 3.7). Investigations of Hen Harrier diet outside of the Bank Vole's range were undertaken at non-breeding sites only. There, Bank Vole was compensated either by Brown Rat or passerines. Further research into the diet of breeding Hen Harriers outside the Bank Vole's current distribution would reveal what harriers in those areas feed on in the absence of the Bank Vole, and indicate the importance of this small mammal in terms of breeding productivity. Furthermore, it would indicate what the Hen Harrier's diet in the south may have been like before the arrival of the Bank Vole. It is important to note at this point however, that the Isle of Man Hen Harrier population is apparently enjoying resurgence (Sim *et al.*, 2007), despite the island being devoid of voles (Manx Wildlife Trust, 2005). There, Hen Harriers feed chiefly on Brown Rats (S. Murphy, pers. comm.).

Brown Rats increased in importance during the non-breeding season in Ireland, most likely due to a shift in location by harriers to areas such as the south and east, where they are regularly seen to catch rats in the more common horticultural and tillage fields during the non-breeding season. Wood Mice decreased in importance from the breeding to non-breeding season, probably because they are less active and abundant during the winter (Hayden and Harrington, 2000).

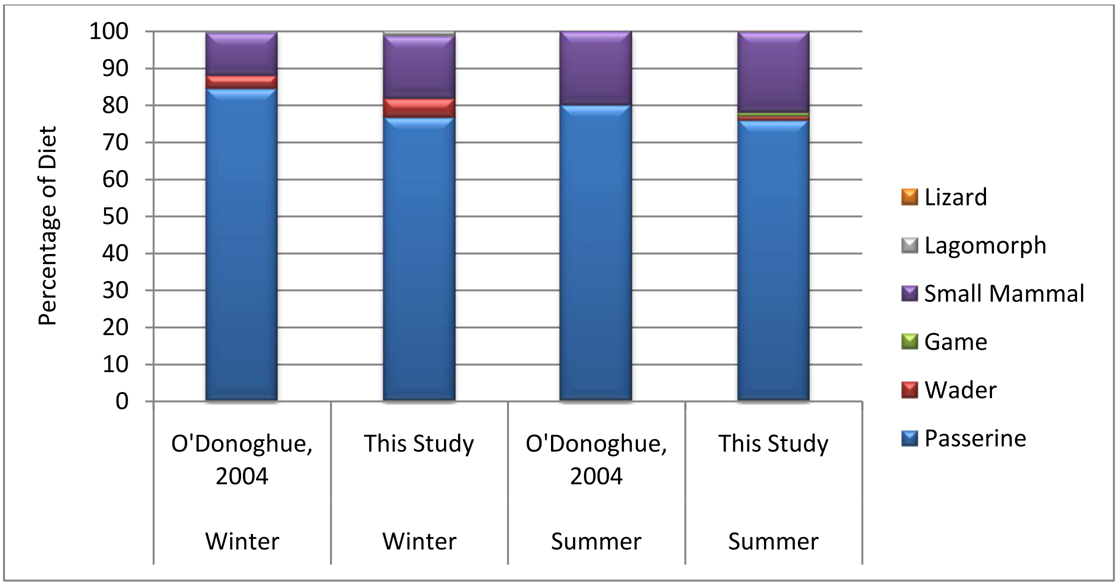

Figure 3.6. Comparison of diet (identified by analysis of pellets and prey remains) between this study and O'Donoghue (2004).

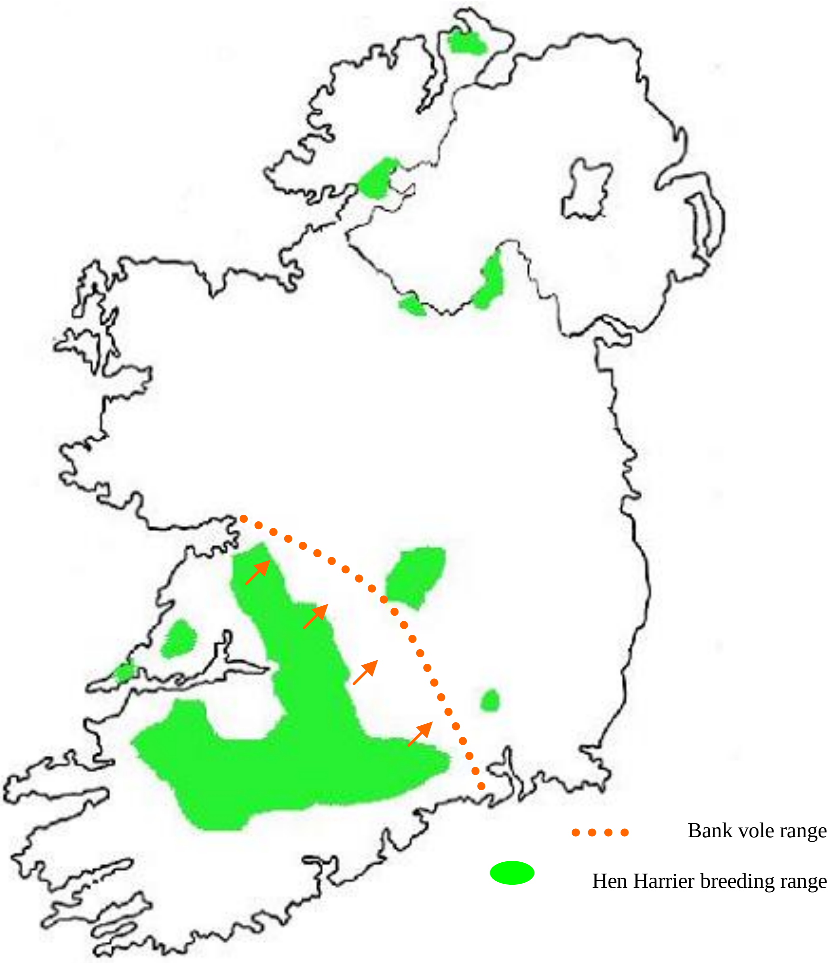

Figure 3.7. Bank Vole and Hen Harrier breeding distribution in Ireland (adapted from O'Donoghue, 2004 and Meehan, 2004).

3.4.1.3 Other Prey

While invertebrates were found in the diet, they are thought to contribute only in a very small way towards the biomass intake of Hen Harriers. Nevertheless, they may possibly provide essential nutrients otherwise unattainable from other prey. The most peculiar item found in the diet was a blue eggshell matching that of a Blackbird's. A literature search has produced four other records of eggs in the diet; Bittera (1914), Uttendörfer (1939), Dementiev *et al.* (1951) and Klaassen *et al.* (2006). Montagu's Harrier (*Circus pygargus*) has also been noted to take eggs (Arroyo, 1997; García and Arroyo, 2005).

3.4.2 Comparison of Dietary Analysis Techniques

Pellets provided by far the largest sample size for dietary analysis and 33 of the 35 species recorded in the breeding season diet were found in pellets. However, due to weathering, 28-40% of pellets could not be used for identification to species level. While less species (*n*=20) were found in prey remains than in pellet analysis (due to a smaller sample, a natural bias (Simmons *et al.*, 1991)), all prey remains were identified to species level. Similar diversity indices were calculated from both pellet analysis (1-D=0.88; H=14.42) and prey remains (1-D=0.89; H=13.57). Direct observations were the least useful in identifying prey to species level (or even category) and often prey could not be identified at all, resulting in a low sample size, as per Redpath (1991). Nevertheless, direct observations did show a prey species (Common Frog) to be taken, which was otherwise unrecorded by pellet analysis or prey remains. Amphibians are commonly underrepresented by pellet analysis (Schipper, 1973; Selås, 2001; Tornberg and Reif, 2007), so direct observations proved useful in this regard. Overall it can be concluded, that as per Redpath *et al.* (2001b), the three methods of pellet analysis, prey remains and direct observations provided a better picture of diet when combined, than if used in isolation.

3.4.3 Change in Diet According to Season

The adaptable nature of the Hen Harrier as a generalist predator was evident in the fact that a number of prey types and over half the species found in the diet were taken exclusively in either the breeding or non-breeding season. Swallow (*Hirundo rustica*), Wheatear (*Oenanthe oenanthe*); Sedge Warbler (*Acrocephalus schoenobaenus*); Willow Warbler (*Phylloscopus trochilus*); Grasshopper Warbler (*Locustella naevia*) and Chiffchaff (*Phylloscopus collybita*), as summer migrants featured in the breeding season diet only. Redwing (*Turdus iliacus*), Fieldfare (*Turdus pilaris*), Redpoll (*Carduelis flammeus*) and Woodcock (*Scalopax rusticola*) are all winter migrants and were thus present in the winter diet but were absent from the breeding season diet. Prey species whose numbers were seasonally inflated accounted for 23.3% of the winter diet, and 10.7% of the summer diet.

Of resident species (present all year round), it is not surprising that Viviparous Lizard and Common Frog were found as part of the breeding season diet only, as they hibernate during the winter. Pheasant (*Phasianus colchicus*) and Red Grouse (*Lagopus lagopus*) (albeit accounting for less than 1% of overall diet) were taken during summer and not winter because harriers would be more likely to take small juveniles (Redpath and Thirgood, 1999; Redpath *et al*., 2001b). Redshank (*Tringa totonus*) numbers in Ireland are increased by migrants during the winter (Crowe *et al*., 2005). The proportion of Wren (*Troglodytes troglodytes*) in the diet varied significantly between summer and winter, accounting for a proportion of diet 19 times higher in summer than winter. As Wrens are virtually ubiquitous (Coombes *et al*., 2009; British Trust for Ornithology, 2009b) and could be found at harrier winter or summer grounds, a likely source of this variation is the fact that Wren numbers can drop significantly during the winter, as well as the fact that harriers may raid Wren nests during the breeding season, thereby taking significant numbers of young Wrens. The reason why Water Rail (*Rallus aquaticus*), Bullfinch (*Pyrrhula pyrrhula*), Coal Tit (*Parus ater*) and Pygmy Shrew (*Sorex minutus*) were part of the winter diet but not summer may be related to location (although all species are known to occur on the landscape in which Hen Harriers breed). In any case, they occurred in negligible numbers. The fact that a higher mean number of items were found in pellets during the breeding season than during the non-breeding season may indicate that harriers make more captures each day during the summer, when there is more prey and daylight.

3.4.4 Prey Delivery Rates

It was understandable that the prey delivery rate to nests would increase after eggs had hatched. In this case, it increased by a factor of 1.5, similar to Simmons *et al.* (1987). While deliveries to nests occurred over a wide time frame of almost 15.5hrs (0544-2107hrs), food provisioning rate was relatively consistent throughout the day, between a lull in the early morning, and a peak in the evening time, most likely to see the female and/or chicks through until the following morning. This is not dissimilar to what Watson (1977) and Redpath and Thirgood (1997) found for Hen Harriers in Scotland.

The rate at which a harrier catches prey should be directly proportional to the rate of nest provisioning (Picozzi, 1978). Ultimately the amount of food delivered to a nest is a product of the abundance and availability of prey (Newton, 1979; Redpath, 1991). This in turn is related to availability and quality of habitat (Gorman and Reynolds, 1993; Smith *et al.*, 2001; Vanhinsbergh and Chamberlain, 2001; Pearce-Higgins and Grant, 2002; Madders, 2003; Amar *et al*., 2003a,b; Amar and Redpath, 2005). Kerry and West Clare, the two most productive areas in terms of breeding (Chapter 5, Breeding Ecology), had higher prey delivery rates than the Ballyhouras or Slieve Aughties. The Ballyhouras had a particularly low provisioning rate, with an average of five hours between deliveries to nests observed. The prey taken in the four areas was found to be similar, so there is no evidence to suggest the lower prey delivery rate in the Ballyhouras is related to larger items or higher quality prey being delivered to nests there.

Food delivery rates to nests during this study (0.77 items hr^{-1}) are similar or at the lower end of the scale when compared to international studies by Balfour and MacDonald (1970) (0.80 items hr^{-1}) and Schipper (1973) (0.82 items hr^{-1}), Picozzi (1978) (0.78 - 1.12 items hr^{-1}) and Redpath (1991) (0.59 - 0.82 items hr^{-1}), whereas Picozzi (1980a) recorded a prey delivery rate of 0.36 items hr^{-1} (where most of the prey was rabbit).

3.4.5 Habitat Value and Suggested Habitat Management

While prey indices may or may not be correlated with diet for species such as Common Buzzard (*Buteo buteo*) (Graham *et al*., 2005), Hen Harriers have been shown to follow optimal foraging theory (Krebs *et al*., 1983), by foraging in habitats where they derive greatest return from their efforts (Redpath, 1992; Madders, 2000). As with this study, Bildstein (1987) and Madders (2000) found no difference in strike success rate between the habitats they studied. Thus, the abundance of prey may be generally associated with its availability to the Hen Harrier in Ireland. Moreover, a prey abundance estimate at any site (except a closed canopy forest plantation) can be used as an indicator of the profitability of that site for foraging Hen Harriers. However, it is possible that nuances exist within and between habitats, which were not noticed during foraging studies, that make prey easier or harder to catch (e.g. small mammals may be inaccessible under brash). An overall foraging success rate of 46% matches that of Redpath (1992) in eastern Scotland, and compares favourably to Thirgood *et al.* (2002) in southern Scotland (36.3%); Redpath *et al.* (2002b) throughout Scotland (32.3% success rate); Madders (2000) in SW Scotland (17% success rate) and Bildstein (1987) in Ohio (24% success rate).

Clearfelled forest was found to be relatively poor in terms of providing prey. Otherwise, young (pre-thicket) forest has been shown to be among the best in terms of providing prey species, and has been shown to be among the most favoured foraging habitats of Hen Harriers in Ireland (O'Donoghue, 2004) and elsewhere (Madders, 2000 and 2003). Small mammal species composition and densities change as a result of vegetation changes after clearfelling (Tevis, 1956; Hooven, 1973; Ramirez and Hornocker, 1981), in addition to concurrent changes in songbird communities (Wardell-Johnson and Williams, 2000; Wilson *et al*., 2006b; Lefort and Grove, 2009). Pre-thicket forest has a limited timeline of usefulness to Hen Harriers before it closes to thicket stage again (O'Donoghue, 2004). If the ground was left for an extended period before replanting (while allowing ground vegetation to regenerate), this would extend the window of opportunity for Hen Harriers (and other fauna). From a commercial forestry point of view, this may also mitigate the negative impact of the Pine Weevil (*Hylobius abietis*), which tends to die out when forest ground is left fallow (Nordenhem, 1989).

The habitat which Hen Harriers hunt most regularly in Ireland is heather/bog (O'Donoghue, 2004). The fact that the current study found Meadow Pipit to be the main prey species supports this observation. In general, heather/bog is of high conservation value for birds (Bracken *et al*., 2008). Retention of such a habitat for Hen Harriers is critical, given that it is virtually irreplaceable if lost.

At least 34 of the 45 species found to make up the Hen Harrier's diet were associated with scrub and hedgerows, which provided the highest density and diversity of prey. The importance of scrub and hedgerows to Hen Harriers has previously been highlighted by O'Flynn (1983); Dickson (1997); O'Donoghue (2004); Tapia *et al.* (2004) and Klaassen *et al.* (2006) and linear habitat features (such as hedgerows) are known to be used by hunting harriers (Schipper, 1977; Thompson-Hanson, 1984; Martin, 1987; Clarke, 1990; Redpath, 1992; Thorpe, 1994; Madders, 1997; Madders, 2003; O'Donoghue, 2004). O'Donoghue (2004) suggested the attraction to such features was likely to be related to the element of surprise which they afford to foraging harriers (being irregular and bushy in nature). Prey might be at a higher risk of being caught in such settings, where they cannot see the predator approaching (Whittingham *et al.*, 2004); vulnerability of prey being an important consideration in predation mechanics (Quinn and Cresswell, 2004). The fact that scrub/hedgerows hold some of the highest densities of prey on the Hen Harrier landscape can now also be offered as an explanation of their attractiveness. Of particular importance in Ireland are Willow (*Salix* spp.); Gorse (*Ulex europaeus*); Alder (*Alnus glutinosa*); Whitethorn (*Crataegus monogyna*); and Blackthorn (*Prunus spinosa*).

Improved grassland could be made more amenable and useful to Hen Harriers by the introduction and tailoring of hedgerows which can generally be lacking from such habitats. Rough Grassland in Ireland is often associated with infrequently cut hedgerows, irregular and bushy by nature, in effect tailor-made for hunting harriers. Watson (1977) and O'Donoghue (2004) recognised that hill and valley farmland in Scotland and Ireland respectively were integral parts of many harrier's territories. The importance and necessity of rough grassland and suitable farming practices for foraging harriers has been highlighted by research internationally (Millon *et al.*, 2002; Amar *et al.*, 2003a,b; Arroyo *et al.*, 2003; Tapia *et al.*, 2004; Amar and Redpath, 2005; Massey *et al.*, 2009).

3.5 SUMMARY

Hen Harrier diet was investigated by means of pellet analysis, prey remains and direct observations. Hen Harriers in Ireland were found to have a diverse diet, which can vary between areas and seasons. Small mammals, lagomorphs, waders, amphibians and reptiles were all taken but small birds were the most numerous. Meadow Pipit (*Anthus pratensis*) was found to be the single most popular prey item. Hedgerows and scrub were found to be the most important features on the landscape for Hen Harrier prey, while clearfelled forest and improved grassland were found to be the least important (in addition to mature forests which are essentially avoided by foraging harriers). Mean prey delivery rate to active nests was calculated as once every 1.9hrs in the incubation period and once every 1.3hrs thereafter. Prey delivery rates were highest in the two most successful breeding areas, Kerry and West Clare, while lowest in the Ballyhouras, which has the smallest mean fledged brood size.

Chapter Four

Nest Sites

In trying to preserve harrier habitat we must not forget that many harriers – as well as other species – are often not nesting in the best places.

Frances Hamerstrom. Harrier, Hawk of the Marshes: The Hawk That Is Ruled by a Mouse. 1986.

In this chapter, the following research questions are addressed:

- What are the physical attributes of Hen Harrier nest sites, at large and fine scales, in terms of habitat and location?
- Do these attributes differ regionally?
- Are there particular features which attract or deter nesting?
- How do nest sites in Ireland compare to those elsewhere?

The main aim of this chapter is to provide a detailed account of Hen Harrier nesting sites, a central consideration in any future conservation planning or assessment of population trends. Such knowledge can also be used in assessing other aspects of harrier ecology including diet (in terms of nest location) and breeding success (in terms of nest site properties which influence breeding success).

4.1 INTRODUCTION

The Hen Harrier (*Circus cyaneus*) is a loosely colonial breeder with a distribution pattern that can be clustered, while large tracts of land will have no breeding harriers at all (Watson, 1977; Newton, 1979; Hamerstrom, 1986; Potts, 1998; Millon *et al*., 2002; Barton *et al*., 2006). This is usually in response to habitat availability and quality (including prey availability) (Craighead and Craighead, 1956; Picozzi, 1978; Bekhuis and Zijlstra, 1991; Grant *et al*., 1991; Redpath *et al*., 1998; Millon *et al*., 2002; Amar and Redpath, 2005; Arroyo *et al*., 2005; Fielding *et al*., 2009) or other factors such as persecution (Blake, 1976; Etheridge *et al*., 1997; Potts, 1998; Stott, 1998; Thirgood *et al*., 2000; Summers *et al*., 2003; Natural England, 2008; Whitfield *et al*., 2008); climate (García and Arroyo, 2001; Redpath *et al*., 2002c) or human habitation (Tapia *et al*., 2004; Massey *et al*., 2008). Studies of Hen Harrier breeding distribution have chiefly taken a landscape-scale approach and have directly highlighted and informed conservation issues such as the effects of forest maturation (e.g. O'Flynn, 1983; Bibby and Etheridge, 1993; Clarke and Watson, 1997) or loss of traditional farming practices or natural habitats (e.g. Hamerstrom, 1986; Amar and Redpath, 2005). As pointed out by Cormier *et al.* (2008), studies of nesting habitat used by harriers have also focussed largely on the landscape scale (e.g. Schipper, 1978; Amar and Redpath, 2005; Wilson *et al*., 2009) and less effort has been invested in the finer-scale details of the nest site (but see Redpath *et al*., 1998). However, it is clearly important to identify the precise set of nest site characteristics where survival and breeding success are maximised, contributing to long-term viability of the population (Mosher and White, 1976; Skutch, 1976; Newton, 1979; Simmons and Smith, 1985; Mearns and Newton, 1988).

As with many aspects of Hen Harrier ecology in Ireland, nest site selection has not previously been examined to any great extent. Historical accounts of Hen Harriers in Ireland (e.g. Watters, 1853; Ussher and Warren, 1900) associate the bird's breeding habits closely with heather moorland. Doran (1976) reported all nests he found were in heather, while Gorse (*Ulex* spp.), straw (of unnamed species), Birch (*Betula* spp.), Larch (*Larix* spp.), Sitka Spruce (*Picea sitchensis*), Bracken (*Pteridium* spp.) and grass (of unnamed species) were found as nest materials. Watson (1977) reported moorland to be the preferred habitat for nesting in Ireland. However, O'Flynn (1983) documented acquiescence by many harriers in Ireland to young forest habitats when large tracts of that natural heather moorland were converted to commercial plantations in the middle decades of the 20th century. In the two published Irish Hen Harrier breeding surveys to date (Norriss *et al*., 2002; Barton *et al*., 2006), the most frequently recorded nesting habitat was second rotation pre-thicket forest plantation (hereafter referred to as restock), accounting for approximately 40% of all reported nesting sites. Similar surveys in neighbouring Britain showed restock forest to be a seldom-used nesting habitat (Sim *et al*., 2001 and 2007). Indeed, in Scotland, a shift away from forest nesting has been noted (Fielding *et al*., 2009). Barton *et al.* (2006) reported heather to be the most frequently recorded habitat in the vicinity of nests within plantations, and the most commonly used substrate for nesting in all habitats. The two Irish census studies (Norriss *et al*., 2002; Barton *et al*., 2006) were focussed on determining breeding numbers rather than investigating nest locations and habitats, so this study set out to fill a gap in our understanding of Hen Harrier breeding in Ireland. Without such a study, the importance of certain habitats and features on the landscape for Hen Harriers may not be fully understood. Without specific knowledge of nest sites, it would not be possible to relate where Hen Harriers are nesting to the outcome of their nesting attempt.

4.2 METHODS

4.2.1 Finding Territories and Nests

The nest locations of Hen Harriers were investigated in each of five distinct breeding areas during the breeding seasons of 2007 and 2008. The main study areas involved were Kerry, West Clare, Ballyhouras and Slieve Aughties, with supplementary information from the Boggeragh Mountains of County Cork in 2008 (Figure 1.3). A description of each of these study areas can be found in Section 1.10. Territories and nests were located by visual observations of harriers from selected vantage points. Observations of activity began on breeding grounds from as early as mid-February, progressing to sky-dancing activity from mid-March, which acts as a guide to intended nesting sites (Watson, 1977), and later to adults carrying nest material or food. Observations of 'stooping' or defensive behaviour were also used to identify nest locations (Hamerstrom, 1969; Hardey *et al*., 2006). A nest was confirmed when a female was seen to 'drop into' a specific patch of ground and remain there for a period of at least ten minutes on more than one occasion. In cases of pairs building multiple nests, the final and utilised location was taken as the nest site. The method by which territories and nests were located was recorded, as well as the stage of the breeding season in which they were located.

4.2.2 Data Collection

Certain features of the nest site could be determined while breeding was still active (e.g. directional exposure of the nest (aspect) and macrohabitat), but to minimise disturbance, detailed nest site investigations were not undertaken until the end of the breeding attempt, when the nest area had been vacated. In addition, Ordnance Survey Ireland 1:50,000 maps and the most recent (2005) colour ortho-photographs were utilised in ArcView GIS 3.2 Geographical Information System (Environmental Systems Research Institute, 2004) to enable identification of further variables (such as hill height, slope and distance to human activities or neighbouring nests) that were not readily determinable in the field. The features of nest sites which were measured are set out below:

4.2.2.1 Nest Location

Global Positioning System (GPS) readings were taken at all nests, using Garmin handheld GPS units. Grid references were recorded in the Irish Grid format and plotted on ArcView GIS 3.2.

4.2.2.2 Macrohabitat

This feature identified the predominant and distinct habitat type/patch within which the nest was situated. In accordance with previous Hen Harrier research in Ireland (Norriss *et al.*, 2002; O'Donoghue *et al.*, 2004; Barton *et al.*, 2006; Wilson *et al.*, 2009), the main macrohabitats identified on the landscape were (a) heather/bog, (b) pre-thicket first rotation forest, (c) mature forest, (d) pre-thicket restock forest, (e) intensive grassland, (f) rough grassland and (g) scrub (Table 4.1). For nests that occurred within plantations, details such as sub-compartment (forest stand) size (ha) and age (years after planting) were recorded using up-to-date (2009) Forest Inventory and Planning System (FIPS) and Coillte GIS data. For adjoining sub-compartments which were felled and replanted in the same year, or for sub-compartments which were only partially felled and replanted in one year, the coupe size (ha) was calculated manually in ArcView GIS 3.2 using ortho-photographs to get an accurate value for the contiguous area of restock. For comparison, the size (ha) of the sub-compartment immediately adjacent (to the east) was measured. Distance to the edge of the forest was measured in ArcView GIS 3.2.

4.2.2.3 Microhabitat

Vegetation type within a 2m radius of the nest was recorded, as well as percentage cover accounted for by these vegetation types (estimated by eye). This was repeated at four points, ten metres north, south, east and west of the nest for comparison and to identify any special features which may have influenced the bird's selection of the exact nest site. A microhabitat category was assigned to a nest depending on what vegetation dominated the 2m core nesting zone.

Table 4.1. Description of macrohabitat types used in the study of Hen Harrier nest sites in Ireland.

Habitat Type	Fossitt (2000) code	Hen Harrier Habitat Code	Description
Heather/Bog	HH1-2, PB2-4	HB	‘Open Habitat’. Peat substrate. Vegetation dominated by Heather (*Calluna* spp., *Erica* spp.), Purple Moor-grass (*Molinia caerulea*), Bilberry (*Vaccinium myrtillus*), Cottongrass (*Eriophorum* spp.), Bog-myrtle (*Myrica gale*), mosses (*Sphagnum* spp.) or other peatland species. Consists of a range of peatland habitats ranging from intact to degraded. Scrub such as Willow bushes (*Salix* spp.) and Bracken (*Pteridium* spp.) can be present in parts of this habitat.
Pre-thicket First Rotation Forest	WD4	NF	‘Time-limited Open Habitat’. Peat or mineral substrate. Surrounded by stock-proof fencing. The first time the land has been planted with trees (in most cases with Sitka Spruce *Picea sitchensis*) and before it has reached thicket stage, when the branches of neighbouring trees meet, usually at 12-14 years (O’Donoghue, 2004). In most cases drainage has been carried out and fertiliser has been applied.
Mature Forest	WD4	MF	‘Closed Habitat’. Peat or mineral substrate. Any forest in post-thicket or closed canopy stage, remaining so for up to 60 years in the case of commercial conifer plantations and longer for deciduous plantations.
Pre-thicket Restock Forest	WD4	RS	‘Time-limited Open Habitat’. Peat or mineral substrate. Restock forest replaces the previous ‘rotation’ which has been harvested as part of the commercial forestry cycle. Most restock forests in Ireland today are second rotation, but there are third rotation forests and these will soon be more popular than second rotation forests. Typified by brashings/cuttings and stumps from the previous harvest. Possesses generally greater diversity of plant species than pre-thicket first rotation forest. Of more limited time availability (6-9.5yrs of opportunity for hunting/nesting) for Hen Harriers than pre-thicket first rotation, given a period of scant vegetation after harvesting and a quicker succession to thicket stage (O’Donoghue, 2004).
Intensive Grassland	GA1	IG	‘Open Habitat’. Mineral or rocky substrate, occasionally on peat substrate. Intensively managed grassland, predominated by Rye-grasses (*Lolium* spp.) in most cases, often in association with nitrogen fixing White Clover (*Trifolium repens*). Such habitat is usually grazed by livestock or saved for silage or hay, cut during the summer, in most cases once or twice. Intensive grassland fields are often surrounded by neatly trimmed hedgerows or no hedgerows at all, to maximise the area under production.
Rough Grassland	GS4, GM1	RG	‘Open Habitat’. Peat, mineral or rocky substrate. Similar to Intensive Grassland in that it is often dominated by grasses, but in the case of rough grassland, other species, particularly Rushes (*Juncus* spp.) are plentiful (>33.3% cover) or dominant and the fields are usually surrounded by bushy and irregular hedgerows. Grazing pressure is less than that on Intensive Grassland and silage or hay is not normally harvested from Rough Grassland fields.
Scrub	HD1, WN7, WS1	SC	‘Semi-open Habitat’. Peat, mineral or rocky substrate. Structurally diverse. Composed of species such as Willow (*Salix* spp.), Gorse (*Ulex* spp.), Alder (*Alnus* spp.), Birch (*Betula* spp.), Bramble (*Rubus* spp.) and Bracken (*Pteridium* spp.).

4.2.2.4 Vegetation Height, Canopy Cover and Nest Exposure

As with microhabitat, the height (m) of vegetation was recorded within a 2m radius of the nest and repeated at four cardinal points 10m from the nest. A measure of canopy closure was taken to determine the level of nest concealment, particularly from aerial predators, but also in relation to shelter from the elements. Hemispherical photographs (as per Walsberg, 1981) were taken by placing the camera lens vertically upwards and reviewing the percentage of vegetation cover/open space within the photograph using Gap Light Analyser 2.0 (Simon Fraser University, 1999). Nest exposure (or nest concealment) is believed to be an important factor in determining harrier breeding success (Watson, 1977; Sutherland, 1987). The exposure of a nest was categorised as low, medium or high to give a measure of the risk of attack from predators, taking account of nest location, visibility and accessibility, as well as abundance and proximity of predators recorded during fieldwork.

4.2.2.5 Elevation, Hill Height and Hill Height Fraction

Nest site elevation (m ASL) was recorded using a '3-D' function on the handheld GPS units. Readings from the GPS were double-checked with the nest's location on 1:50,000 O.S.I. maps, which display elevation contour lines. The summit height of the hill or mountain on which a nest was made was identified on 1:50,000 O.S.I. maps. The 'hill height fraction', as a measure of how far up the hill the harriers nested (in percentage terms), was then calculated by dividing the elevation of the nest, by the height of the hill (or mountain) and multiplying by 100.

4.2.2.6 Nesting Slope

This variable refers to the gradient upon which the nest site was located and was measured by taking two adjacent elevation contour lines on the 1:50,000 O.S.I. maps at opposite sides of the nest (constituting an incline of 20m) and determining the distance between these lines. This 20m incline, divided by the distance between the contour lines, provided the slope.

4.2.2.7 Directional Exposure of Nest (Aspect)

The direction in which the nest location faced (if any) was recorded. Aspect categories were north, south, east, west, north-east, north-west, south-east, south-west and neutral (i.e. flat ground or ground with a slope <5%).

4.2.2.8 Glen Nesting

Whether or not the nest occurred in a glen (mountain valley) was recorded.

4.2.2.9 Distance to Nearest Watercourse

The distance (m) from the nest to the nearest watercourse was identified. Watercourses included all rivers, streams and water-carrying drains.

4.2.2.10 Distance to Nearest Track

This distance (m) was measured in the same way as that for watercourses. Tracks included all road types, walking paths and forest fire-breaks.

4.2.2.11 Distance to Nearest Significant 'On-site' Human Operations

Human 'on-site' activities which were frequent, sustained and concentrated in nature were considered and their distance (m) from the nests was measured. Such activities included turf-cutting and saving, human habitation, working farmyards, on-site forest operations, wind farm construction, quarrying and any other sustained work or leisure activities.

4.2.2.12 Dryness of site

After Simmons and Smith (1985), a categorical scoring was given to the ground within the core nesting zone, as to whether it was dry, damp or wet under-foot.

4.2.2.13 Nesting Material

The materials used in nest building were recorded and categorised according to type or species.

4.2.2.14 Breeding Density and Distribution (including Nearest Neighbour Distance and Overlapping Territories)

A core area, which represented the maximum number of nests within a 10x10km ($100km^2$) square, was identified for each of the four main study areas. The number of nests within this 10x10km square was taken as the maximum breeding density of each study area. The distribution of nests in each study area was assessed by plotting nest locations on ArcView GIS 3.2. The distance of a given nest to its nearest neighbouring nest was measured on ArcView GIS 3.2, to the nearest 10m. As Hen Harrier territories often overlap (Balfour, 1962b; Watson, 1977; Redpath, 1991; Arroyo *et al*., 2004 and 2005; pers. obs.), with male harriers capable of travelling distances of 6km (and more) on foraging bouts (Arroyo *et al*., 2005; Hardey *et al*., 2006), the number of nests that occurred within 6km of a given nest was identified on ArcView GIS 3.2 to give a measure of the likelihood of territory overlap.

4.2.2.15 Breeding Dispersal and Fidelity to Territory and Nesting Habitat

As the study spanned two consecutive breeding seasons, continuity of territory use was assessed by re-surveying in 2008, territories that were occupied in 2007. If a territory was 're-occupied', the habitat in which birds nested was compared between years. The distance between a given territory's nest locations in 2007 and 2008 was recorded as a measure of breeding dispersal across years.

4.2.3 Data Analysis

Random control or dummy nest sites were detailed in order to compare sites where harriers nested to sites where harriers did not nest (after Redpath *et al.* 1998; Kelleher and O'Halloran, 2007; Cormier *et al*., 2008). In this study, as many dummy nest sites as real nests were created by generating random grid references which were constrained to lie within a 3km radius of each real nest in order to make comparisons more relevant to the landscape in question. Comparisons between habitat attributes at actual and random control nests were performed using Mann-Whitney U-tests in Minitab 15 (Minitab Inc., 2007) and chi-square tests. Comparisons of nesting variables between study areas were performed by Kruskal-Wallis tests in Minitab 15 (Minitab Inc., 2007).

To determine which variables were most influential on nest site selection, variables collected at actual nests and dummy nests were analysed by means of a Generalized Linear Model (GLM) with a binomial distribution and log-link function, performed using R software (R Development Core Team, 2008). Covariates included macrohabitat, elevation, hill height, hill height fraction, nesting slope, directional exposure of nest (aspect), glen nesting, dryness of site, number of neighbours, number of neighbours that successfully reared young, distance to stream, distance to track and distance to nearest neighbour. Territory was entered as a random explanatory factor in the model in order to control for any possible non-independence of data from the same territory (Ruddock *et al.*, 2008). Microhabitat, canopy openness and nest exposure were not measured at dummy nests due to constraints on time and resources. Data were first explored by checking all explanatory variables for outliers and colinearity (Zuur *et al*., 2009). Variables expressing distances (to nearest stream, track, human activity and nearest neighbour) were square-root transformed to deal with a small number of outliers. The number of neighbours a pair had and the number of successful neighbours a pair had, proved to be co-linear. The number of successful neighbours variable was then removed from the analysis, as the number of neighbours variable accounted for a longer time period. In addition, hill height, hill height fraction and elevation (of nest) proved to be co-linear, so hill height and hill height fraction were removed from analyses as elevation is a variable more commonly used in Hen Harrier studies (e.g. Redpath *et al*., 1998; Tapia *et al*., 2004).

The models were compared using the Akaike's Information Criterion (AIC), a tool to measure the goodness-of-fit of an estimated statistical model and model complexity. If competing models are ranked according to their AIC, the one having the lowest AIC is the best (Akaike, 1974). The step function in R was used to carry out a preliminary model selection, followed by the systematic removal of non-significant variables. This is because the step function relies only on AIC to make its selection, and can therefore be conservative in what it deletes (Zuur *et al*., 2009).

4.3 RESULTS

4.3.1 Finding Territories and Nests

Across the four main study areas of Kerry, West Clare, Ballyhouras and Slieve Aughties, 134 breeding territories were confirmed and 105 nests were pin-pointed during the breeding seasons of 2007 and 2008, with an additional two nests located in the Boggeragh Mountains in 2008. Therefore, a total of 136 breeding territories and 107 nests were located and available for analysis. The majority (83.7%) of territories were confirmed at the earliest stage of the breeding season (the pre-egg laying stage), while 95.2% were confirmed before hatching had commenced. Nests were pin-pointed before completion of hatching in 78.0% of cases, while 96.1% of all nests were located prior to fledging. The methods by which territories and nests were located are summarised in Table 4.2.

4.3.2 Nest Site Details

4.3.2.1 Macrohabitat

The habitats used by Hen Harriers for nesting across the five study areas are summarised in Table 4.3, while Plates 4.1 to 4.3 provide views of these habitats. While over half of all nests were located in non-afforested habitats, restock forest was the single most commonly used habitat type for nesting. The use of scrub (χ^2=18.42, df=4, P=0.001) and restock (χ^2=25.63, df=4, P<0.001) varied significantly between study areas (Table 4.3). However, the proportion of nests in heather did not differ significantly between study areas (χ^2=4.17, df=4, P=0.386).

Table 4.2. Percentage frequency (%) of methods by which territories and nests were first confirmed/located.

	Territories (*n*=136)	**Nests (*n*=107)**
Sky Dancing/Nuptial Flights	72.9	-
Food Pass/Food Delivery	13.1	59.8
Carrying Nest Material/Nest Building	4.7	10.3
Female's Presence (including Nest Duties)	5.6	27.1
Information from Public	3.7	0.9
Defensive Behaviour	-	1.9

Table 4.3. Habitats used for nesting (in percentage terms), according to study area and overall.

	Overall (*n*=107)	**Kerry (*n*=37)**	**West Clare (*n*=22)**	**Ballyhouras (*n*=25)**	**Slieve Aughties (*n*=21)**	**Boggeraghs (*n*=2)**
Scrub	23.4	43.2	18.5	0.0	14.3	50.0
Heather/Bog	29.9	37.8	40.7	24.0	19.0	50.0
Restock	46.7	18.9	40.7	76.0	66.7	0.0

Plate 4.1. Nest in scrub (macrohabitat). 2m core nesting zone (microhabitat) is dominated by Bramble (*Rubus fruticosus*).

Plate 4.2. Nest in glen of heather/bog (macrohabitat). 2m core nesting zone (microhabitat) is dominated by Bell Heather (*Erica cinerea*).

Plate 4.3. Nest in restock forest (macrohabitat). 2m core nesting zone (microhabitat) is dominated by Bramble (*Rubus fruticosus*).

For those nests located in forest stands, the mean sub-compartment size was 19.02 ± 2.80ha (range 1.5-103ha). The size of forest stand occupied by harriers did not vary significantly across study areas ($F_{3,41}$=0.56, P=0.648) and did not differ significantly from the size of adjacent forest stands ($F_{1,83}$=2.55, P=0.114). Pre-thicket forest stands that harriers occupied ranged in age from three to twelve years. The median age was six years after planting, while >80% of all forest nesting attempts occurred in plantations aged four to eight years (Figure 4.1). The age of forest stand used by harriers for nesting differed significantly across regions ($F_{3,41}$=4.11, P=0.013) with harriers in the Slieve Aughties occupying generally older restock plantations ($\bar{x}$=7.8yrs). The average distance from nests to the edge of the compartment in which they were found was 81.7 ± 9.1m, and did not differ significantly between regions ($F_{3,41}$=0.91, P=0.443).

The primary tree species of commercial plantations across the ranges studied was Sitka Spruce (*Picea sitchensis*) and this was reflected in the fact that 97.6% of nests in plantations were in sub-compartments which contained this conifer. Other species included Japanese Larch (*Larix kaempferi*) and Lodgepole Pine (*Pinus contorta*) (both present at 21.4% of nesting sub-compartments respectively), Birch (*Betula* spp.) (in 11.9% of sub-compartments) and Oak (*Quercus* spp.) (in 4.8% of sub-compartments). Willow (*Salix* spp.) was found in the majority of restock forests as a colonist or through natural regeneration.

The use of habitats for nesting differed significantly between actual nests and random control nests (χ^2=126.9, df=6, P<0.001). The observed (actual) and expected (random) frequencies are presented in Table 4.4. While at least seven different macrohabitats existed within 3km of nests, just three were used; restock forest, heather, and scrub, all chosen more than would have been expected if selection had been random, particularly heather and scrub which would have been expected to hold just 2 nests, but in reality held 57 nests. Harriers (early, mid and late nesters) did not display a temporal trend in terms of nesting habitat selection (Kruskal-Wallis H=1.21, df=2, P=0.545).

4.3.2.2 Microhabitat

At least seventeen different vegetation types were found within 2m of nests. Of these, five vegetation types dominated the 2m core nesting zone to varying degrees, and thus, five principle microhabitats were recorded: Bramble (*Rubus* sp.), Heather (*Erica* spp. and *Calluna* sp.), Rush (*Juncus* spp.), Gorse (*Ulex* spp.) and Bracken (*Pteridium* spp.). The overall frequency occurrence of each vegetation type is displayed in Figure 4.2, while the frequency occurrence of each microhabitat at nests is given in Table 4.5.

Bramble was found to be the most common vegetation type and microhabitat for Hen Harriers to nest in, particularly at nests based in scrub and restock forest (Figure 4.2; Tables 4.5 and 4.6). Bramble was the only vegetation type that occurred more often at the nests than at the four cardinal points 10m from the nests (Mann-Whitney $W=28095$, $P=0.019$). While heather was present at nests in 54% of cases, it dominated at almost a quarter of nests. The remainder of nests were found in microhabitats of Rush (*Juncus* spp.), Gorse (*Ulex* spp.) and Bracken (*Pteridium* spp.). Purple Moor-grass (*Molinia caerulea*) was present at approximately half the nests found (though it was never dominant).

The prevalence of Bramble and Heather as microhabitats, did not vary significantly across study areas (Kruskal-Wallis $H=4.69$, $df=4$, $P=0.321$ and $H=7.49$, $df=4$, $P=0.112$, respectively). However, the percentage of rush at nests did significantly differ between study areas (Kruskal-Wallis $H=15.45$, $df=4$, $P=0.004$), as rush was the microhabitat type at 38.1% of nests in the Slieve Aughties; significantly more than in Kerry (Mann-Whitney $W=964$, $P=0.002$) and the Ballyhouras (Mann-Whitney $W=427$, $P=0.004$), though not significantly greater than West Clare (Mann-Whitney $W=498$, $P=0.072$). Dwarf Gorse (*Ulex gallii* or *U. Minor*) was a dominant habitat at one nest in Kerry and three nests in the Ballyhouras. Bracken was the dominant vegetation type at two nests, one in the Boggeraghs and one in the Ballyhouras.

Figure 4.1. Ages of forest plantations used for nesting in 2007 and 2008.

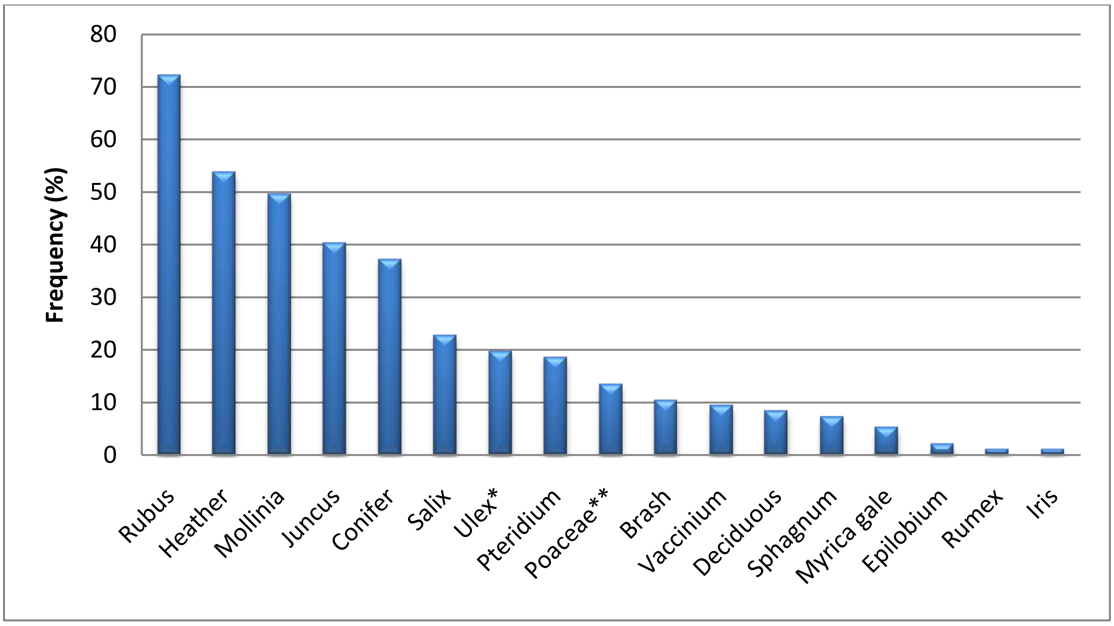

Figure 4.2. Vegetation in the immediate nest area (*n*=97 nests).

*Dwarf Gorse of the kind *Ulex gallii* or *U. minor* which are virtually similar species overlapping in range (Stokes *et al.*, 2003). **Other than *Molinia*, which is listed separately.

Table 4.4. Frequency occurrence of actual and random control nests in various macrohabitats.

	Restock	**Heather**	**Scrub**	**Mature Forest**	**First Rotation**	**Intensive Grassland**	**Rough Grassland**
Actual	50	32	25	0	0	0	0
Random	23	2	0	36	16	16	14

Table 4.5. Percentage frequency occurrence of each microhabitat.

	Overall	**Kerry**	**W. Clare**	**Ballyhouras**	**Aughties**	**Boggeraghs**
Bramble	57.9	64.9	63.6	56.0	47.6	0.0
Heather	24.3	27.0	22.7	24.0	14.3	50.0
Rush	13.2	5.4	13.6	4.0	38.1	0.0
Gorse	3.6	2.7	0.0	12.0	0.0	0.0
Bracken	1.8	0.0	0.0	4.0	0.0	50.0

Table 4.6. Relationship between macrohabitats and microhabitats, summarised as percentage occurrence of microhabitat (rows) within macrohabitat category (columns).

	Scrub	**Heather/Bog**	**Restock**
Bramble	84.0	13.9	72.5
Heather	0.0	58.3	7.8
Rush	16.0	8.3	13.7
Gorse	0.0	13.9	3.9
Bracken	0.0	5.6	2.0

4.3.2.3 Vegetation Height, Canopy Cover and Nest Exposure

The height of ground vegetation within 2m of the nest ranged from 0.2m to 1.5m, with a mean of 0.64 ± 0.04m. No significant difference was found when vegetation at nest locations was compared to that at four points sampled 10m north, south, east and west of each nest (Mann Whitney W=15253, $P=0.364$). Ground vegetation height did not differ significantly across the microhabitat types (Kruskal-Wallis H=2.62, $df=4$, $P=0.794$). At nests within restock plantations, the average tree height was 1.59 ± 0.10cm.

The Gap Light Analyser program, operating on hemispherical photographs (e.g. Plate 4.4), showed that the average canopy cover at nests was 69.5 ± 0.8% (range 46.8 - 86.7%). However, this differed significantly across the main study areas (Kruskal-Wallis H=9.11, $df=3$, $P=0.028$), with West Clare ($\bar{x}$=74.65 ± 2.5%) and Kerry ($\bar{x}$=70.62 ± 1.6%) having greater canopy cover than the Ballyhouras ($\bar{x}$=65.8 ± 2.3%) and the Slieve Aughties ($\bar{x}$=56.2 ± 9.4%). As well as being similar in terms of vegetation height, the different microhabitat types each provided similar levels of canopy cover (Kruskal-Wallis H=1.46, $df=4$, $P=0.833$). Of nests to which exposure scores were assigned, 66.7% occurred in low exposure situations, while 25.9% were in medium exposure and 7.5% were in high exposure situations.

Plate 4.4. Hemispherical photograph taken at a nest site.

4.3.2.4 *Elevation, Hill Height and Hill Height Fraction*

Hen Harriers in West Clare generally nested on the lowest hills or mountains of the five study areas (median hill height of 211m ASL), whereas Hen Harriers in the Ballyhouras were generally found on the highest elevations (median hill height of 363m ASL). The median hill height of Kerry nests was 302m ASL and that of the Slieve Aughties was 290m ASL. Harriers were found to nest from as low as 36m ASL to as high as 385m ASL. The median nesting elevation was 199m ASL ($\bar{x}$=209 ± 7.4m ASL). When grouped into elevation categories (Figure 4.3), the least occupied categories were those at high and low extremes, with seven nesting attempts below 100m ASL and six nesting attempts above 350m ASL. The most frequently occupied elevation category was that between 150 and 199m ASL, while over half (50.5%) of all nests existed between 150 and 249m ASL.

Harriers in the study areas nested at significantly higher altitudes (median = 199 ± 7.4m ASL) than the series of random control nests that were generated (median = 176 ± 6.9m ASL) (Mann-Whitney W=12365, P=0.042), though not to the extent that this dictated nesting location overall. The mean hill height fraction was 70.1 ± 1.7% (i.e. harriers nested on average, 70.1% up the slope of a hill or mountain). Harriers did not nest on hills or mountains which were any higher or lower than expected by chance (Mann-Whitney W=11099, P=0.671), but they did nest significantly further up those hills and mountains than was expected with random control nests (Mann-Whitney W=12691, P=0.002).

4.3.2.5 *Nesting Slope*

Over 80% of nests were found on a slope (n=86). The average slope was 12.2 ± 1.4% (11.0 ± 1.6°). The steepest slope on which a nest was built measured 60% or 54°. Slopes which harriers nested on were apparently steeper than slopes which random control nests were on (9.2 ± 1.1% or 8.3 ± 0.9°), though any difference was not statistically significant (Mann-Whitney W=11139, P=0.889).

4.3.2.6 *Directional Exposure of Nests*

Harriers were found to nest on ground facing all potential directions. A summary of nesting aspects is given in Table 4.7. The most common aspect was in fact neutral, perhaps incongruously, given the majority of nests were on a slope. Of those nests facing in a particular direction, south facing slopes were the predominant choice

(Figure 4.4), although they were not chosen significantly more than was recorded with random control nests (χ^2=0.671, *df*=1, *P*=0.412). North-east facing slopes were the rarest choice, and were in fact avoided compared to what was recorded with random control nests (χ^2=4.326, *df*=1, *P*=0.037). Grouping south-east and south-west facing nests with those facing due south amounted to a total of 35% of nests with a generally southerly orientation, while grouping generally northerly facing nests accounted for 21% of all nests. A similar 35% of random control nests were generally southerly facing, while 23% of random control nests were generally north facing random nests.

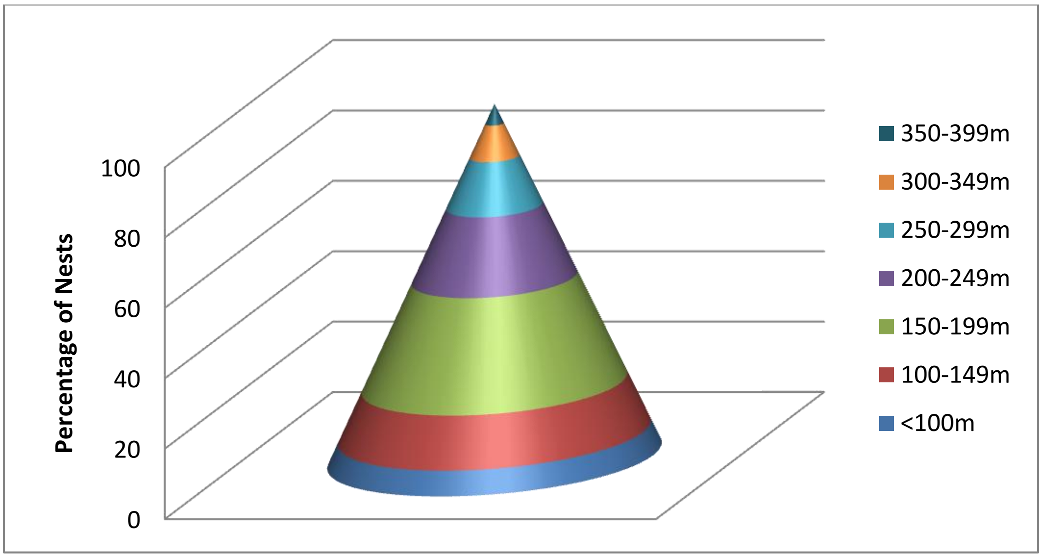

Figure 4.3. Proportion of nests per elevation categories (*n* = 107 nests).

Table 4.7. Directional exposure (aspect) of nests, including nests which had ‘neutral aspects’.

Aspect	**N**	**S**	**E**	**W**	**NE***	**NW**	**SE**	**SW**	**0†**
Actual Nests	17	27	9	7	2	3	5	5	32
% of total	16	25	8	7	2	3	5	5	30
Random Nests	10	21	9	7	10	5	6	10	29

*used significantly less than in random control nests, † Neutral aspect (not facing any direction).

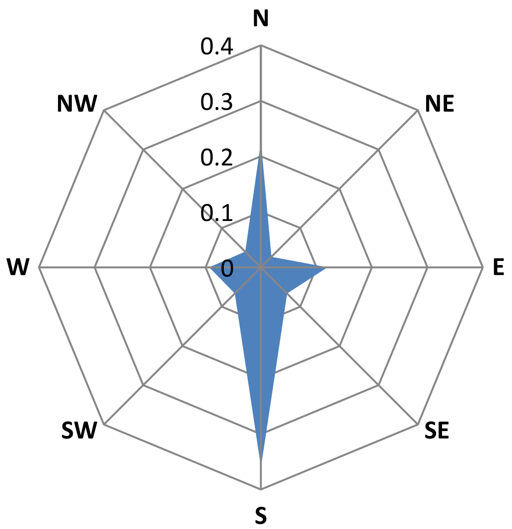

Figure 4.4. Directional exposure of nests. Values refer to proportion of all nests other than those with ‘neutral aspects’ (*n* = 75 nests).

4.3.2.7 Glen Nesting

A total of 26 nests were found in glen locations and a chi-square test showed that glen nesting occurred significantly more often than would have been expected if harriers occupied random sites (χ^2=14.23, *df*=1, *P*<0.001).

4.3.2.8 Distance to Nearest Watercourse

The average distance between Hen Harrier nests and watercourses was 244.5 ± 23.5m (range 0-1040m). There was a significant difference among the study areas (Kruskal-Wallis H=25.68, *df*=4, *P*<0.001) in terms of distance from nest to watercourse. Bonferroni corrected *post hoc* Mann-Whitney tests showed this difference to lie with the Ballyhouras, where a significantly greater (*P*<0.005) distance to nearest watercourse was recorded. Ballyhouras nests were also the only nests positioned significantly further from watercourses than was recorded at random control nests (Mann-Whitney W=785, *P*=0.004). Conversely, nests in West Clare were positioned closer to watercourses than the random control nests (Mann-Whitney W=367, *P*=0.003). When all nests across all regions were considered, Hen Harriers were not found to nest closer to or further from streams than was the case with random control nests (Mann-Whitney W=10435, *P*=0.144).

4.3.2.9 Distance to Nearest Track

Hen Harrier nests were found to lie 7 - 930m from the nearest track (median = 108.4 ± 12.5m). In all but a few cases, the nearest track was rarely used by humans and traffic. Hen Harriers were found to nest significantly further from tracks than was the case with randomly generated nests (Mann-Whitney W=12010, *P*=0.034). The distance from nest to nearest track did not differ significantly between study areas (Kruskal-Wallis H=2.95, *df*=4, *P*=0.400). A difference across the habitats in which the harriers chose to nest was initially indicated by a Kruskal-Wallis test (Kruskal-Wallis H=6.23, *df*=2, *P*=0.044) but Bonferroni corrected *post hoc* Mann-Whitney tests showed no significant difference between individual habitats (*P*>0.016).

4.3.2.10 Distance to Nearest Significant 'On-site' Human Operations

The distance between nests and human activities ranged from 7m to 3510m, with a median distance of 813 ± 68.3m and varied significantly between study areas (Kruskal-Wallis H=33.73, df=4, P<0.001). Hen Harriers in Kerry were the most closely associated with human operations (median distance 290m). West Clare nests were also closely situated to human activities (median distance 490m), with the Slieve Aughties (median distance 770m) and Boggeraghs (median distance 850m) being more isolated. Mann-Whitney tests (with a Bonferroni correction factor) revealed nests in the Ballyhouras to be significantly further removed from human activities than those in the other main study areas (P<0.005), with a median distance of 1,400m.

Dwelling houses or farmyards (42.1% of cases), followed by turbary (32.7% of cases) were the most common human activity nearest to harrier nests and together accounted for almost 75% of the human activities closest to Hen Harrier nests. Other activities included forest operations (14.0%), recreation (6.5%), construction (1.9%), quarrying (1.9%) and landfill (0.9%).

While eleven nests were found at distances of less than 100m from human activity, Hen Harriers nested significantly further from human activities than was the case with random control nests (Mann-Whitney W=12435, P=0.040). A difference was found in terms of nesting habitat and distance to nearest human activity, whereby nests in scrub were significantly closer to human activity than those in either heather/bog (Mann-Whitney W=443, P<0.001) or forest plantations (Mann-Whitney W=531, P<0.001).

4.3.2.11 Dryness of Nest Site

All nests were situated on dry ground, with little or no standing water at the nest site. Even within sites, which at the larger scale may have been damp or wet, nests were located in dry patches, at times raised 10-15cm above ground level.

4.3.2.12 Nesting Material

Ten different vegetation types were noted to be used in nest building, namely grass (virtually all of which was Purple Moor-grass *Molinia caerulea*), Heather (Ling *Calluna vulgaris*, Cross-leaved Heath *Erica tetralix* and Bell Heather *Erica cinerea*), Rush (virtually all of which was Soft Rush *Juncus effusus*), coniferous twigs (predominantly from clearfell brashings), Bramble (*Rubus* spp.), deciduous twigs (mostly Alder (*Alnus* spp.), Birch (*Betula* spp.) and Willow (*Salix* spp.)), mosses (mainly *Sphagmum* spp.), Bracken (*Pteridium* spp.), Nettle (*Urtica dioica*) and Bog-myrtle (*Myrica gale*). Grass and Heather were the most frequently used materials, occurring in 94.0% and 82.6% of nests respectively, and in combination together in 78.3% of nests. The next most common vegetation was Rush, which was found in almost half of all nests. A combination of grass, Heather and Rush was used in 35.9% of all nests. Some nests were constructed solely of one vegetation type, while others had up to six materials added to them. The most common number of materials used in building a nest was three (in 41.3% of nests).

4.3.2.13 Breeding Density and Distribution

The core breeding densities of each study area are compared in Table 4.8. The mean nearest neighbour distance for all nests studied was 3.11 ± 0.20km, ranging from 0.38km to 12.23km. When the core $100km^2$ of each range was considered, a mean nearest neighbour distance of 2.47 ± 0.16km was calculated. Nest spacing differed significantly between study areas (Kruskal-Wallis H=17.30, df=4, P=0.002), and $100km^2$ cores of the four main study areas (Kruskal-Wallis H=17.36, df=3, P=0.001). The Ballyhouras had smaller nearest neighbour distances than the other areas (Mann-Whitney tests with Bonferroni correction factor, $P \leq 0.015$). Nearest neighbour distance did not differ from that recorded with random control nests (Mann-Whitney W=11016, P=0.8237).

At least 91.5% of nesting pairs found during this study were within 6km of their nearest neighbour's nest (i.e. there was likely to have been a high degree of territory overlap). The number of pairs potentially sharing a territory (of 6km radius) ranged from 0 to 11, with a mean of 4.4 ± 0.26 pairs. The number of neighbours potentially sharing territory differed significantly between the four main study areas (Kruskal-Wallis H=28.15, df=3, $P<0.001$). *Post hoc* Mann-Whitney tests (with a Bonferroni correction factor applied) showed this variation to lie primarily with the Slieve Aughties, which had a lower potential number of overlapping territories than all other areas ($P<0.005$). Kerry was also shown to have significantly less pairs within 6km of each other than the Ballyhouras (Mann-Whitney W=918, P=0.004).

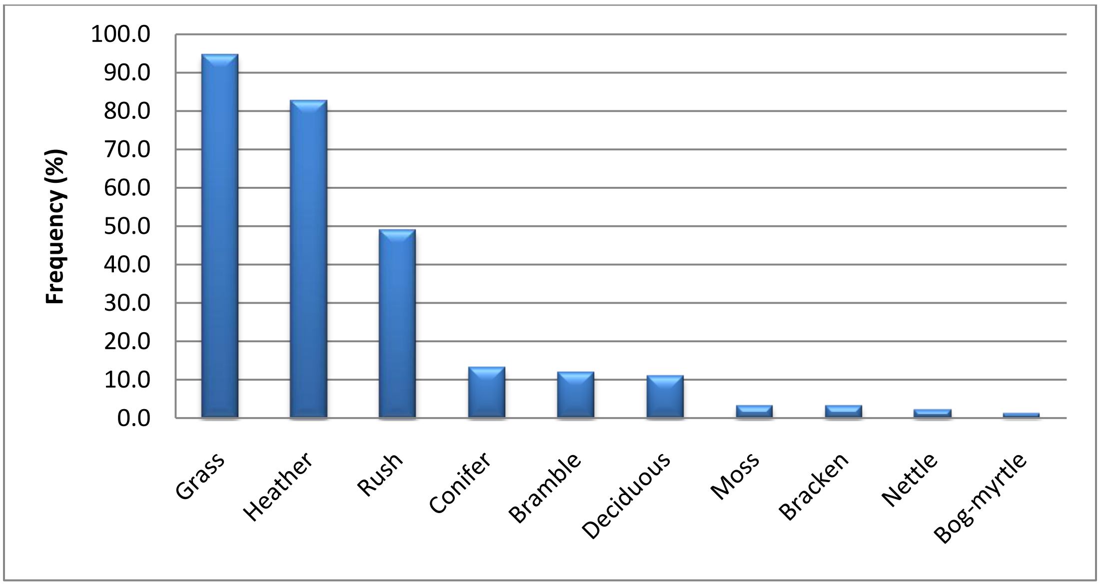

Figure 4.5. Materials used by Hen Harriers in nest building (*n*=97 nests).

Table 4.8. Maximum breeding densities in 100km^2 core areas according to study area.

	Kerry	West Clare	Ballyhouras	Slieve Aughties
Maximum Nesting Density (nests/100km^2)	10	10	11	5

4.3.2.14 Breeding Dispersal and Fidelity to Territory and Nesting Habitat

Of 45 territories with nests found in 2007, 37 (82%) had breeding attempts in 2008. Re-occupation rates across the study areas did not vary significantly (Kruskal-Wallis H=0.80, *df*=3, *P*=0.849). Of territories that were successful in 2007, 89.6% were re-occupied in 2008, compared to a re-occupation rate of 66.7% for territories which failed in 2007, though these re-occupation rates were just short of being significantly different (χ^2=3.15, *df*=1, *P*=0.061). The majority (62.5%) of territories that were abandoned were those that failed in the preceding year. With regard to nesting habitat, for any given territory occupied in both years, the same habitat type was used for nesting in both years on 78.4% of occasions. Of 21 territories in which restock forests were used for nesting in 2007, 76.2% utilised this habitat again in 2008, with 14.3% switching to scrub and 9.5% changing to heather/bog. With heather nesting territories in 2007, 81.8% utilised this habitat in 2008, while 18.2% switched to forests. 20% of scrub nests in 2007 changed to heather in 2008. Of territories that were successful in 2007, 84.6% used the same habitat in 2008; while conversely, just 60% of nests that failed in 2007 used the same nesting habitat for 2008. However, no significant difference was found between failed territories and successful territories in terms of habitat fidelity between years (Kruskal-Wallis H=1.19, *df*=1, *P*=0.275).

Nests were never found in the same position in successive years, and ranged from as close as 0.01km to as far 2.70km from the location of the preceding year. The median distance moved was 0.25km ($\bar{x}$=0.56km) and did not differ significantly between nests at the core of the range (within the 100km^2 core area) and those at the extremities of the range (Mann-Whitney W=654, *P*=0.918). Furthermore, this distance did not differ significantly across the main study areas (Kruskal-Wallis H=0.32, *df*= 3, *P*=0.955).

4.3.2.15 Model Selection Regarding Factors Most Influential on Nest Site Selection

While a number of variables differed from what was recorded at random control nests, the final model describing the most influential variables on nest sites was found to be:

Nest Site ~ Macrohabitat + Elevation + Glen Nesting

Table 4.9. A summary of available explanatory variables for modelling presence/absence of nest sites and the stepwise deletion of the least significant variable with the corresponding AIC values.

Step	Model	AIC
Start model	elevation + macrohabitat + aspect + slope + distance to track + distance to stream + distance to human activity + distance to nearest neighbour + glen nesting	114.89
Remove distance to stream	elevation + macrohabitat + aspect + slope + distance to track + distance to human activity + distance to nearest neighbour + glen nesting	112.89
Remove slope	elevation + macrohabitat + aspect + distance to track + distance to human activity + distance to nearest neighbour + glen nesting	111.04
Remove distance to track	elevation + macrohabitat + aspect + distance to human activity + distance to nearest neighbour + glen nesting	109.71
Remove distance to human activity	elevation + macrohabitat + aspect + distance to nearest neighbour + glen nesting	108.64
Remove distance to nearest neighbour	elevation + macrohabitat + aspect + glen nesting	107.29
Remove aspect	elevation + macrohabitat + glen nesting	107.19

Table 4.10. Results (or numerical output) of the model selection for nest sites using a binomial Generalized Linear Model (GLM). Final AIC = 107.2. Null deviance = 289.7; residual deviance = 99.19).

	Estimate	Std. Error	z value	***P***
Intercept	10.55	2.35	4.49	<0.001
Macrohabitat	-3.91	0.77	-5.09	<0.001
Elevation	0.03	0.01	2.15	0.032
Glen Nesting	1.97	0.83	2.37	0.018

4.4 DISCUSSION

4.4.1 Finding Nests and Territories

The most fruitful methods employed in finding Hen Harrier territories and nests are important to highlight, in order to advise future research. The majority of territories were confirmed via sky dancing and nuptial flights. Surveying for breeding Hen Harriers in Ireland should thus begin as soon as possible in the months of March and April. Locating a territory at these early stages allows ample time in which to pin-point the nest, and sky dancing usually indicates the favoured or most likely nest site location (Watson, 1977). While Watson (1977) said the incubation period was *"much the most difficult time to locate a Hen Harrier's nest"*, it proved the most common stage to pin-point nests in the current study, because the territory had in most cases already been located in the pre-egg laying stage. Without knowledge of harrier activity in an area prior to egg laying, determining the presence of harriers during the incubation stage, at a time when they are less active or conspicuous, will be more difficult. The present study shows that over 95% of territories can be confirmed prior to hatching by surveying at early stages, thus allowing relatively accurate calculations of the breeding success and productivity of given breeding areas.

4.4.2 Nest Sites

4.4.2.1 Nesting Habitats

Three macrohabitats were used for nesting: pre-thicket restock forests (46.7%), heather/bog (29.9%), and scrub (23.4%). In Northern Ireland, Ruddock *et al.* (2008) found only two macrohabitats to be used: heather/bog (53.4%) and restock forest (46.6%). Despite holding the most random control nests, mature forests were avoided, due to their closed canopies and lack of dense ground vegetation. Other habitats that were avoided for nesting included intensive grassland and rough grassland (which again do not have the dense vegetation associated with harrier nests), and perhaps most interestingly, first rotation forest. Ruddock *et al.* (2008) also recorded a lack of nests in first rotation forest in Northern Ireland. The breeding censuses by Norriss *et al.* (2002) and Barton *et al.* (2006) respectively reported 23.5% and 21.9% of nests to occur in this habitat. There are still large areas of pre-thicket first rotation available in the study areas (in fact at least 15% of nests would have been expected at random to occur in new plantations) so succession to thicket stage forest or restock does not fully explain the shift away from first rotation. It is possible that Norriss *et al.* (2002) and Barton *et al.* (2006) overestimated the use of first rotation forests by misidentifying certain amounts of restock (volunteers were not trained in habitat recognition or provided with habitat definitions). Another explanation may be that modern forestry tends to avoid heather/bog which is relatively unproductive for tree growth (Fahy and Foley, 2002) and mainly targets grassland. While forests planted on heather would have had ground vegetation automatically suitable for nesting (i.e. heather), ground vegetation in grassland may only become tall or dense enough for nesting just prior to thicket stage, if at all. The fact that macrohabitat was found to be a major influence on whether harriers nested at a site or not, highlights the importance of pre-thicket restock forests, heather/bog and scrub in providing nesting sites. Without these habitats, Hen Harriers in Ireland would have little, if any, places to nest.

Nesting on ground which has been planted with trees is not unique to Ireland (Hamerstrom, 1969; Cormier, 1984; Bibby and Etheridge, 1993; Redpath *et al*., 1998; Sim *et al*., 2001 and 2007). However, the frequency with which harriers here nest in forest plantations (46.7% of nests in this study and 46.6% of nests in Northern Ireland), is higher than elsewhere and thus young forestry is of great importance to Irish Hen Harriers for nesting. This reflects the large amounts of forest plantation across the Hen Harrier landscape in Ireland (48% of Hen Harrier SPAs in Ireland). The ability of restock forest stands to host nesting is relatively short-lived, even less so than first rotation, due to a period of scant vegetation for 2-3 years after clearfelling and a faster progression to thicket stage (Hart, 1994; O'Donoghue, 2004). In this study, the youngest plantation holding a nest was three years old, while harriers were not found to use plantations any older than 12 years old (approximately 3m high), with the majority (80%) found in plantations aged four to eight years. In Northern Ireland, 96% of forest stands used for ground nesting were aged two to six years (range 2-12yrs) (Ruddock *et al*., 2008). In terms of nests located in forest stands, it was the associated ground cover of Bramble, Heather or Rush rather than the trees that the harriers were selecting.

Use of a given habitat for nesting does not necessarily mean that habitat is 'preferred' or optimal, but may simply reflect a lack of other suitable nesting habitats in an area (Hamerstrom, 1986). For example, nesting in restock forests may reflect the fact that forestry has replaced what was previously heather/bog or scrub, which otherwise appears to be used when present (Watson, 1977; Jones, 1981; Petty and

Anderson, 1986; Bibby and Etheridge, 1993; Redpath *et al*., 1998; Sim *et al*., 2001 and 2007; Massey *et al*., 2008; Ruddock *et al*., 2008). Nevertheless, pre-thicket restock forest at least provides nesting potential (if only for a limited amount of time), whereas if heather/bog or scrub had been transformed into grassland for agricultural purposes or overgrazed, it is likely that there would be no nesting potential at all (although remedial works would be possible in the aftermath of overgrazing). Nesting in certain habitats or locations out of necessity, can present an 'ecological trap' in terms of breeding success and population viability (Hamerstrom and Kopeny, 1981; Hamerstrom, 1986; MacWhirter and Bildstein, 1996; Corbacho *et al*., 1997; Koks *et al*., 2001; Arroyo *et al*., 2002; Millon *et al*., 2002; Robertson and Hutto, 2007; Scott and Clarke, 2007; Wilson *et al*., in review).

Heather/bog, which hosted almost a third of all nesting attempts, is arguably the most sensitive and vulnerable habitat for Hen Harriers and upland wildlife in general. Quality moorland habitat in Ireland has been and continues to be lost through conversion to intensive grassland, nutrient enrichment, burning, peat extraction, heather beetle (*Lochmaea suturalis*), overgrazing, afforestation and wind farm development (Hobbs and Gimingham, 1987; Scandrett and Gimingham, 1991; Thompson *et al.*, 1995; Hope *et al.*, 1996; Bleasdale, 1998; Scott, 2000; Alonso *et al*., 2001; Foss *et al*., 2001; Phillips, 2005; Evans *et al.* 2006; Feehan and O'Donovan, 2006; Nayak *et al*., 2008; pers. obs.). Scrub, another important nesting habitat, is also threatened by conversion to grassland, burning and development. Scrub is a regular nesting habitat of Hen Harriers throughout the species' range (Watson, 1977; O'Flynn, 1983; Shepel, 1992; Klaassen *et al*., 2006; Sim *et al*., 2007; Klaassen *et al*., 2007; Massey *et al*., 2008). In the case of Irish Hen Harriers, there was a propensity towards nesting in Bramble (*Rubus fruticosus*). It was the only vegetation type found more often at nests than around nests and so Hen Harriers apparently selected to nest in Bramble, presumably for the shelter and protection which this dense and thorny shrub provides. Its prevalence at Irish nests is particularly noteworthy given that the vast majority of Western European literature pertaining to Hen Harrier nesting habitats makes no reference to Bramble (e.g. Balfour, 1962a; Doran, 1976; Watson 1977; Picozzi, 1984b; Schipper, 1978; Redpath *et al*., 1998; Millon *et al*., 2002; Norriss *et al*., 2002; Arroyo *et al*., 2004; Tapia *et al*., 2004; Mellon *et al*., 2005; Barton *et al*., 2006; Hardey *et al*., 2006; Cormier *et al*., 2008; Ruddock *et al*., 2008), while consulted experts have not witnessed Bramble nesting in other areas where the plant is known to occur (A. Amar, B. Arroyo, B. Etheridge, S. Murphy, S. Redpath, B. van Hecke and I. Williams, pers. comm.). Nesting in Bramble was however recorded in 29% of Hen Harrier nests in Holland (Klaassen *et al.*, 2007) and Toland (1986) had previously recorded Northern Harriers (*Circus hudsonius*) in south-western Missouri to nest in Bramble.

4.4.2.2 Vegetation Height, Canopy Cover and Nest Exposure

Hen Harriers nested in low exposure situations, which helped conceal the nest or made access for potential predators more difficult. As per Kantrud and Higgins (1992) and Hansell (2000), habitat structure was of great importance at the nest site. Vegetation was invariably tall and dense (as per Watson, 1977; Redpath *et al.*, 1998) and on average, almost 70% of the nest was concealed. Olfactory and auditory cues from the nest are important in terms of ground predation (Taylor, 1984), so choosing to nest in areas of dense vegetation up to at least 10m from the nest, is likely to be an adaptation preventing/mitigating such events. The benefits of nesting in concealed, low exposure situations had been suggested by Balfour (1962a), Hamerstrom and Kopeny (1981) and Sutherland (1987), although Simmons and Smith (1985) found nest concealment had no significant effect on breeding success.

4.4.2.3 Elevation, Hill Height and Hill Height Fraction

Hen Harriers nested across a range of elevations (36-385m ASL), but were largely confined to upland locations (>100m ASL). Nesting elevations generally resembled that reported by Watson (1977), Redpath *et al.* (1998) and Ruddock *et al.* (2008). However, none of those studies reported nesting at elevations below 100m ASL, while this study found seven nests at such elevations. As suggested by Watson (1977) with regard to Northern Harriers in North America, which have no competition from sympatric harriers, perhaps Hen Harriers in Ireland can nest in lowland locations for similar reasons, where circumstances allow. However, as with Tapia *et al.* (2004), the fact that overall, nesting occurred at altitudes higher than might have otherwise been expected, and further up hills than might have been expected, suggests the population has been exiled to the extremities of the landscape on which they survive.

4.4.2.4 Nesting Slope

The fact that over 80% of nests were located on slopes is perhaps not surprising given Hen Harriers in Ireland primarily frequent rolling uplands for breeding. Nesting slopes used by Hen Harriers in this study (average 12.2 ± 1.4%) were shallower than those reported by Ruddock *et al.* (2008) in Northern Ireland, where the average nesting slope was 35.2 ± 3.7%. Tapia *et al.* (2004) found Hen Harriers in Spain opted for slopes which were shallower than that recorded at random control sites. In Ireland, nesting on gradients may be useful in avoiding water-logging at the nest.

4.4.2.5 Directional Exposure of Nests

Hen Harriers nested on north-east facing slopes significantly fewer times than was recorded at random control nests. Neither Redpath *et al.* (1998) nor the current research (Chapter 5, Breeding Ecology) found the direction a nest faced in, to influence breeding success. However it is possible that north-east facing slopes are generally avoided because they receive a low amount of sunlight and may be among the coldest slopes, which would not be conducive to egg or chick thermo-regulation. Conversely, Ruddock *et al.* (2008) found 14% of Hen Harrier nests in Northern Ireland to face north-easterly and Ruddock (2006) reported north-eastern facing cliffs were particularly successful for Peregrine Falcons (*Falco peregrinus*), possibly for the shelter provided from prevailing south-westerly winds.

4.4.2.6 Glen Nesting

Hen Harriers were shown to nest in glens more often than was the case with random control nests. Glens may be attractive for the shelter and seclusion they provide, or for the tall, dense vegetation which typically grows on the slopes. In some cases, glens may represent the only suitable nesting location if overgrazing, burning, conversion to intensive grassland or forest maturation have left little else to choose from.

4.4.2.7 Distance to Nearest Watercourse and Nearest Track

While Redpath *et al.* (1998) found nests in Scotland were situated closer to streams than expected; no effect of stream location was recorded in the current study. It can thus be deduced that it was not an attraction to watercourses which led to the relatively high incidence of glen nesting. Hen Harriers tended to nest further away from tracks or roads than was the case with randomly generated nests. Tapia *et al.* (2004) mentioned roads as one of the most significant threats to harriers in Spain, while Massey *et al.* (2008) found a general avoidance of roads by Northern Harriers on Nantucket Island. The majority of tracks in this study were seldom used by humans, but would nevertheless have provided easy passage for ground predators (see also Ruddock and Whitfield, 2007).

4.4.2.8 Distance to Nearest Significant 'On-site' Human Operations

Human activities have shaped the modern Hen Harrier distribution of Ireland (e.g. O'Flynn, 1983; Barton *et al*., 2006) and Europe (Potts, 1998; Millon *et al*., 2002, Tapia *et al*., 2004; Fielding *et al*., 2009). While Tapia *et al.* (2004) and Massey *et al.* (2008) reveal human settlement to be one of the main factors of dissuading harrier nesting and Combs-Beattie (1993) and Hardey *et al.* (2006) state that nests will not be found close to dwelling houses, this study found a number of nests were found within 100m of houses, the closest just 14m away from an occupied dwelling in West Clare in 2007 (Plate 4.5). In addition, Hardey *et al.* (2006) state that Hen Harriers will not be found breeding within 100m of hill farms, yet in the course of this study at least ten nests were located on hill farms, principally in fields which had become overgrown with Rush and Bramble. In such cases, the landowners were made aware of harriers' presence and were asked not to cultivate the fields until the harriers left. Nine of these ten nests successfully fledged young. The closest recorded distance to human activity was just 7m, when a nest in Kerry was situated at the end of an active turbary bank.

Anomalies such as nesting extremely close to active turf banks or dwelling houses should not be taken to say such activities are invariably compatible at such close distances. Respect must be afforded to the sensitive nature of a harrier's nest site with regard to disturbance/human operations (Ruddock and Whitfield, 2007). Human activities which were most disturbing to Hen Harriers included forestry operations such as harvesting; forest thinning; aerial fertilisation and road making (Chapter 5, Breeding Ecology). Watson (1977) had previously referred to forest operations as of disturbance to breeding harriers. Nest failures in Northern Ireland have also been attributed to forestry operations (Scott and McHaffie, 2003; Mellon *et al*., 2005; Scott, 2008). At three traditional sites observed during the current study, Hen Harriers did not settle to build nests until the use of off-road vehicles for recreational purposes ceased.

4.4.2.9 Dryness of Site

The statement by Hardey *et al.* (2006) that wet sites are avoided for nesting was supported by the current study. While Thompson-Hanson (1984) and Simmons and Smith (1985) found that Northern Harriers in North America often nested in wet sites (for protection from predators), protection from flooding and/or chilling of eggs/nestlings may be more pertinent in Britain and Ireland.

4.4.2.10 Nesting Materials

The materials that harriers used to construct their nests were all indigenous to the localities in which the nests were found. Forays by harriers travelling up to 300m to gather nesting material were observed. Heavy materials were carried in the legs, with lighter pieces often carried in the beak. Twigs of Heather and trees served the purpose of nest rigidity and support, while Rush aided dryness and lining of grasses, mosses or leafy material provided softness and a degree of insulation. Grasses and Heather were by far the most common and abundant material in nests, even in macrohabitats such as forests reflecting the traditional moorland nesting habits of the species. One of the most unusual items found within a Hen Harrier nest was a rusted piece of barbed wire, 40cm in length, 24.5g in weight and visually resembling a heather twig.

Plate 4.5. Nest location (outlined in white), 14m from occupied dwelling house.

Plate 4.6. Nest location (outlined in white), 10m from active turbary (turf) bank. Another nest was just 7m from an active turbary bank.

4.4.2.11 Breeding Density and Distribution (including Nearest Neighbour Distance and Overlapping Territories)

The nesting density of harriers at the core of the study areas ranged from 5-11 nests per 100km^2, with the Slieve Aughties having just half the density of other areas. In the most recent national census of Ireland (Barton *et al*., 2006), the density of territorial pairs per breeding area varied between 0.7 and 14.8 pairs per 100km^2. Published densities from studies covering at least 100km^2 in the UK ranged between 4 and 16 nests per 100km^2 (Potts, 1998).

The mean distance between neighbouring nests was 3.11 ± 0.20km across the wider breeding area and 2.47 ± 0.16km within the core 100km^2 of each area. David Scott (in Watson, 1977) stated that the nearest harrier nests in Ireland were generally 1km apart when in sight of one another, and closer if separated by a ridge. Scott's observations related to a period when there were more harriers and higher quality, less fragmented habitat than is the case today (cf. O'Flynn, 1983). Watson (1977) himself reported regular, but unequal, spacing between nests of 2-3km in south-west Scotland. Picozzi (1978) recorded a mean nearest neighbour distance of 1.52km, while Balfour and Cadbury found this distance to be 1.10km.

Following from having the lowest breeding density, the Slieve Aughties range was found to have the lowest number of potentially overlapping territories throughout the two breeding seasons. The fact that the Ballyhouras had the highest number of pairs sharing a 6km radius does not necessarily point to a superior quality of habitat in this range. The distribution was clumped, with large tracts of the range unoccupied, and most pairs were situated along the fringes of the heavily afforested upland massif. Inter-nest distances and distribution can be highly variable between and within populations, usually dictated by degree of polygyny, availability of nesting habitat and abundance of prey (Picozzi, 1984b; MacWhirter and Bildstein, 1996). As polygyny was not noted in the Ballyhouras, and there were large areas of restock forest available for nesting right across the range, it appears prey availability may be a major determinant of nesting distribution in the Ballyhouras.

4.4.2.12 Breeding Dispersal, Site and Habitat Fidelity

A median breeding dispersal distance (within individual territories) of 0.25km was recorded. Etheridge *et al.* (1997) found a median breeding dispersal between years of 0.71km in Scotland, while Whitfield and Fielding (2009) in Wales reported a median dispersal of 0.0km (*sic*). The fact that the same habitat was used in both years in a given territory in 78.4% of cases may suggest a degree of specialism or preference by harriers which claim these territories. In other words, there may be harriers which are 'heather-nesters', 'scrub nesters' or 'forest nesters'. Nesting habitat choice may be imprinted on birds from the natal site (Hilden, 1965; Watson, 1977; Etheridge *et al*., 1997; Teuschl *et al*., 1998; Davis and Stamps, 2004; Scott, 2007). Further evidence for this hypothesis is presented in Chapter 7 (Movements and Survival). Unfortunately only three individuals were wing-tagged prior to 2007, so there were no observations of breeding harriers in both 2007 and 2008 to inform whether it was the same birds breeding in these cases. As more wing-tagged individuals enter the Irish breeding population (Chapter 7, Movements and Survival), the fidelity of individual birds to territories should become more apparent.

4.5 SUMMARY

Nest sites were investigated at large and fine scales, exploring vegetative, topographical and community aspects among others, in a bid to understand the nesting ecology of harriers in Ireland. The four main study areas were compared and contrasted in terms of nesting ecology. Scrub, heather/bog and restock forest were all used for nesting at the larger scale, with Bramble (*Rubus* spp.), Heather (*Erica* spp. and *Calluna* spp.), Rush (*Juncus* spp.), Gorse (*Ulex* spp.) and Bracken (*Pteridium* spp.) as the dominant ground vegetation within these habitats. Restock forest and Bramble are used more frequently in Ireland than anywhere else in the Hen Harrier's range. Hen Harriers in Ireland are functioning in a landscape which bears much influence from humans; though nest further from human activity than might be expected. The key factors determining nest site location were found to be habitat, elevation and glens. While some nests were found in lowland locations, Hen Harriers in Ireland have been generally confined to a restricted upland niche in terms of breeding distribution and further loss of potential nest sites (and indeed foraging sites) is likely to have further detrimental effects on the population and its distribution.

Chapter Five

Breeding Ecology

Samhradh, samhradh, bainne na gamhna,
Thugamair féin and samhradh linn!
Thugamair linn é is cé bhainfeadh dínn é,
Is thugamair féin an samhradh linn!

Eamonn Kelly. May Morning. 1998.

Towards investigating the breeding ecology of Hen Harriers in Ireland, the following research questions are addressed:

- When do Hen Harriers in Ireland begin to lay eggs, hatch and fledge young, and depart from their breeding sites?
- What percentage of breeding attempts are successful?
- Of those that are successful, how many fledglings are produced?
- Of those that are not successful, why do they fail?
- What are the main determinants of breeding success?
- Do breeding success and productivity differ regionally?
- How does the breeding fecundity of Hen Harriers in Ireland compare to that elsewhere?

The primary aim of this chapter is to provide qualitative assessment of Hen Harrier breeding ecology in Ireland, particularly in terms of the population's ability to reproduce. Such information is imperative in evaluating whether the population is capable of achieving favourable conservation status and whether action needs to be taken on matters affecting breeding performance.

5.1 INTRODUCTION

Breeding ecology, and particularly breeding performance and productivity, are of fundamental importance to the status and wellbeing of bird populations at both local and national levels (Newton, 1979; Whitfield *et al*., 2008; Fielding *et al*., 2009). Knowledge and understanding of these parameters and the factors which influence them are essential towards informing effective conservation measures (Sutherland *et al*., 2004). Across the Hen Harrier's (*Circus cyaneus*) range, a number of studies have been undertaken to gather such information (e.g. Etheridge *et al*., 1997; García and Arroyo, 2001; Redpath *et al*., 2002b; Millon *et al*., 2002; Amar *et al*., 2003a,b; Whitfield *et al*., 2008). However, relatively little is known about Hen Harrier breeding ecology in Ireland and what has been found elsewhere does not automatically correspond to the Irish population. Norriss *et al.* (2002) and Barton *et al.* (2006)

referred to breeding success, but this was not a focus of those national censuses, and the outcome of many nests went unrecorded. In the absence of specific research, the conservation status of Irish Hen Harriers cannot be assessed; the factors driving breeding productivity cannot be known and effective action cannot be taken to maintain and enhance the breeding population. The present study is aimed at describing the breeding ecology of Hen Harriers here. Breeding chronology, success, productivity and the factors driving breeding performance are all investigated. In doing so, a new understanding of a native Irish raptor is achieved, while data gathered can be used in projections of the future status of Hen Harriers in Ireland.

5.2 METHODS

5.2.1 Surveying

The study areas in which this research was carried out (Kerry, West Clare, Ballyhouras and Slieve Aughties) are described in Chapter 1 (Introduction). While two nests in the Boggeraghs were referred to in Chapter 4 (Nest Sites), these are not included in the current chapter, because they were found during intermittent surveying of the area in 2008, whereas the four main study areas were surveyed thoroughly throughout the breeding seasons of 2007 and 2008, following a prescribed methodology (Hardey *et al.*, 2006). Scanning for harriers was done using both naked eye and binoculars (8x30WB Swarovski and 10x40 Leica with laser range finder). Early parts of the season were spent using multiple vantage points (e.g. up to 80 individual vantage points in Kerry) when birds had not yet fully settled on one particular point. When a nest site was selected, intensive observations from a more limited number of vantage points were undertaken, with emphasis on remaining out of sight of the birds and the general public. Observations were undertaken between 0500hrs and 2225hrs (but mostly between 0800hrs and 1900hrs). Vantage point watches ranged in duration between 0.02 and 7.75hrs continuous monitoring and averaged 1.06 ± 0.03hrs. Activities noted during watches were recorded by dictaphone and later transferred to template MS Excel files (Appendix II) for records and analysis. While nests in all areas were typically observed until the outcome of the breeding effort was confirmed, 43 successful breeding sites in Kerry and West Clare were observed until the harriers (male, female and juveniles) ceased to use the nesting area (a radius within 1km of the nest site) as a focal point for the breeding season.

The minimum evidence needed to satisfy the title of breeding female was that of a female settling on a nest. A territory was considered to be occupied if a pair was seen with any of the following traits:

- Courtship display or nuptial flight on more than one occasion;
- Territorial aggression/behaviour;
- Nest building or visiting a probable or known nest site;
- Food pass between two adults.

5.2.2 Nest Visits

To collect data on clutch size, laying and hatching dates, sex ratio, brood size and development, a limited number of visits to selected active nests were undertaken. Special consideration was given to the risk pertaining to nest visits (carried out under licence from the National Parks and Wildlife Service). A precautionary protocol was implemented in the interests of nest security. A green, amber and red classification was assigned to each individual nest, taking account of a number and combination of factors, including accuracy of nest location, likelihood of leaving tracks traceable by humans or predators, location with regard to predators and humans, and judgement of each individual female's temperament (some were observed to be more sensitive to human activity than others). Green nests were those judged to be relatively safe to visit, amber nests were those judged to require particular mitigating action if visited, and red nests were those to which a visit would have posed unacceptable risks. Only green and amber nests were visited. Nests were not visited until at least seven days after clutch laying had been completed (considering a maximum of six eggs laid over 12 days, this was taken to be 19 days after the female first began to spend extended periods on the nest). To minimise the time spent at nests, egg dimensions were not measured. Where clutch size was not counted during the incubation phase, it was estimated by visiting the nest soon after or during hatching, and adding the number of young chicks and unhatched eggs. Unhatched Hen Harrier eggs are left within the nest; in most cases even after the brood has fully fledged (Watson, 1977; Millon *et al.*, 2002; pers. obs.), and this method of estimating clutch size has been shown to be accurate (Millon *et al.*, 2002).

Nests were generally visited during dry and mild or warm weather, to minimise tracks and scent left on vegetation and to ensure the nest was not left without the shelter of a female in rainy or cold conditions. Nest visits were not carried out until at least mid-morning so that the female and/or chicks would have received food before the visit. In the majority of cases, a nest was not visited until a food pass or delivery had been witnessed and the food had been ingested and the parent bird had departed the nest area. Nest visits were not carried out late in the evening to avoid leaving 'fresh' scent trails for ground predators which are mostly crepuscular and nocturnal (Hayden and Harrington, 2000). Impenetrable vegetation such as Gorse (*Ulex europaeus*) was regularly placed along the route to the nest to deter predators following this path. The number of visits to active nests ranged from one to three in most cases, depending on which stage the nest was first visited at and how far the breeding attempt progressed.

When a breeding attempt was suspected to have failed (usually after multiple or prolonged observation periods without sightings of harriers), the nest was visited and its contents were recorded. An area immediately around the nest was searched for evidence of the cause of failure. Ground mammals were identified as the predator where harrier carcasses were found with evidence of teeth marks, or if scattered/chewed feathers, tracks, scent or droppings were found in or near the nest. Corvids were identified as the cause of failure if eggs were found with distinctive signs of being opened by bill, or if prior observations showed frequent and persistent attacks on the nest by corvids (while not direct evidence, believed to have been the most likely cause of failure given prior observations involved corvids which were intent on predating the nest).

5.2.3 Laying and Hatching Date Estimation

Few nests were visited on the day of hatching, so the commonly used method of backdating the age of the eldest chick was employed to determine hatching date (after Hamerstrom, 1969; Schipper, 1978; Kantrud and Higgins, 1992; Scharf, 1992; Arroyo, 1996; Etheridge *et al*., 1997; Millon *et al*., 2002). Most nests were visited within a few days of the first egg hatching, after watching for the female's behaviour upon receiving food passes. The first time she was observed to bring food to the nest was taken as a sign that at least one chick had hatched out. Newly hatched chicks are easy to identify from their short pinkish-white down, showing skin for the first 2-3 days, while one day old chicks have their eyes closed (Watson, 1977). Identifying the age of chicks which were any older was done by wing length and feather growth (Picozzi, 1980a; Bijlsma, 1997). In addition, experience and a photographic profile of chicks aged 0-56 days (including every day from Day 1 – 39) were used (Appendix III). The date on which the first egg was laid was calculated by subtracting 32 days from the date on which the first chick hatched, assuming a 30 day incubation period which began when two eggs were laid (48 hours apart).

5.2.4 Data Analysis

Breeding success is expressed as the proportion of breeding females that were successful in fledging at least one chick. Breeding productivity is expressed twofold: (1) as the number of chicks fledged per all attempts and (2) as the number of fledglings produced per successful breeding attempt. Fledging was confirmed when offspring were seen flying. As per Hamerstrom (1969) and Hardey *et al.* (2006), values for fledged chicks are minima, i.e. the number of chicks which were confirmed to have fledged. Suspected or potential numbers of chicks fledged (though not very dissimilar) are not deemed reliable. In many instances, chicks can die just short of fledging, particularly in the case of young chicks in relatively large broods, where their older, flying siblings are able to accost the parents before food is delivered directly to the nest. Male desertion towards the end of the season has also been shown to result in a high incidence of late-stage nestling starvation (Simmons *et al.*, 1987).

Comparisons of breeding success and productivity between nests, years or individual regions were performed using Mann-Whitney U-tests or chi-square tests in Minitab 15 (Minitab Inc., 2007). Comparisons of such data as a response to a given explanatory variable were performed by Kruskal-Wallis tests in Minitab 15 (Minitab Inc., 2007). In analysing which factors had greatest influence on the outcome of a breeding attempt in terms of success or failure, a Generalized Linear Model (GLM) was applied with a binomial distribution and logit-link function on data. For those nests that were successful, to determine which factors had greatest influence on the number of young produced, a Generalized Linear Model (GLM) was applied with a Gamma distribution and an inverse-link function on data. Calculations were carried out using R software (R Development Core Team, 2008). The covariates included in

GLM analyses were year, breeding area, nesting date, early season prey delivery rate (as determined in Chapter 3, Diet), whether the nest was visited, whether the nest was visited during egg stage, how many times the nest was visited, nest site variables (determined in Chapter 4, Nest Sites) including microhabitat, macrohabitat, elevation, hill height, hill height fraction, nesting slope, directional exposure of nest (aspect), glen nesting, number of neighbours, number of neighbours that successfully reared young, distance to stream, distance to track, and distance to nearest neighbour. Canopy openness and nest exposure were not included in the analysis as they were recorded at too small a subset of nests, in 2008 only. The dryness of a site was not included as all sites were found to be similarly dry (Chapter 4, Nest Sites).

Before analysis proceeded, data were explored by checking all variables for outliers and colinearity (Zuur *et al.*, 2009). Outliers were found with the distance variables (distance to nearest stream, track, human activity and nearest neighbour) and so were square-root transformed. This adequately dealt with the outliers. The number of neighbours a pair had and the number of successful neighbours a pair had, proved to be co-linear. The number of successful neighbours variable was then removed from the analysis, as the number of neighbours variable involved a larger sample size. Elevation, hill height and hill height fraction were found to be co-linear. Therefore hill height and hill height fraction were removed from analysis given elevation has been referred to in previous Hen Harrier studies (e.g. Redpath *et al*., 1998; Tapia *et al*., 2004). Whether a nest was visited and the number of visits a nest received proved to be co-linear. Whether a nest was visited or not was retained as a variable expected to be of more interest to future studies involving potential nest visits. The models were compared using the Akaike's Information Criterion (AIC), a tool to measure the goodness-of-fit of an estimated statistical model and model complexity: if competing models are ranked according to their AIC, the one having the lowest AIC is the best. The step function in R was used to carry out a preliminary model selection, followed by the systematic removal of non-significant variables. This is because the step function relies only on AIC to make its selection, and can therefore be conservative in what it deletes (Zuur *et al*., 2009).

Once the optimal model had been found, for fledging numbers model validation was applied by plotting residuals against fitted values to assess homogeneity, as well as assessing the model for influential observations using the Cook’s distance function. No discernable patterns were seen in the scatterplot, and no influential observations were noted using the Cook's distance function so the model was considered valid. For nesting success, model validation was applied by plotting the residuals of the binomial model against each explanatory variable used in the model. No patterns were apparent. While year did not appear as significant in the model, residuals were also plotted against year to make sure there was no influence on nesting success from this variable. No discernable pattern was seen so it was taken that year did not exert any influence on breeding success and the model was considered valid.

5.3 RESULTS

5.3.1 Breeding Numbers, Densities, Territories and Nests

A total of 134 breeding territories were confirmed and 105 nests pin-pointed across the four areas of Kerry, West Clare, Ballyhouras and Slieve Aughties over the two breeding seasons of 2007 and 2008 (Table 5.1). More territories and nests were found in the second year of the study than in the first, as a result of an increased working knowledge of the study areas.

5.3.2 Egg Stage

The clutch sizes from 65 nests were recorded (Kerry n=22; West Clare n=13; Ballyhouras n=13; Aughties n=17). The overall mean clutch size was 3.94 ± 0.14 eggs (range 1-6 eggs) and is summarised for each region in Figure 5.4. Clutch size did not significantly differ between areas (Kruskal-Wallis H=0.23, df=3, P=0.973), nor between years, (Mann-Whitney W=829, P=0.189). No significant differences in clutch size were found between those nests in scrub, heather/bog and restock (Kruskal-Wallis H=3.10, df=2, P=0.212; Mann-Whitney tests P>0.10).

Lay date was recorded or backdated for a total of 86 clutches. The median laying date for these nests was 5 May, with little variation between years (Mann-Whitney W=1600, P=0.648) (02 May 2007, 05 May 2008). The earliest laying date was at a nest in Kerry in 2008 (16 April) and the latest was in the Slieve Aughties the same year (10 June). Over half (55.8%) of all egg laying began in the two week period of 29 April – 13 May (Figure 5.1), while the month of May saw the initiation of 68.6% clutches. Median clutch initiation date did not differ significantly between areas (Kruskal-Wallis $H=3.78$, $df=3$, $P=0.286$), although it did approach significance between the earliest (Ballyhouras) and latest (Slieve Aughties) areas (Mann-Whitney $W=253$, $P=0.0567$).

Only the relatively early week of 22-28 April differed significantly from all others ($P<0.05$), whereby clutches laid at that stage were smaller than in other weeks (apart from the week of 4-10 June, during which time just one clutch was laid). Throughout the month of May, clutch sizes remained relatively constant. Clutch sizes derived from actual counts at egg stage did not differ significantly from clutch size estimates based on the number of hatched and unhatched eggs (Kruskal-Wallis $H=0.21$, $df=1$, $P=0.648$).

Table 5.1. Number of confirmed territories and nests in the four main study areas during 2007 and 2008. Note the Boggeragh Mountains study area is not included as this area provided supplementary information in terms of diet and nest sites only.

	Kerry	***West Clare***	***Ballyhouras***	***Slieve Aughties***	***Total***
Territories 2007	15	10	11	17	53
Territories 2008	24	12	21	24	81
Territories All Years	**39**	**22**	**32**	**41**	**134**
Nests 2007	15*	10	11	9	45
Nests 2008	22	12	14	12	60
Nests All Years	**37**	**22**	**25**	**21**	**105***

* one nest with unconfirmed outcome.

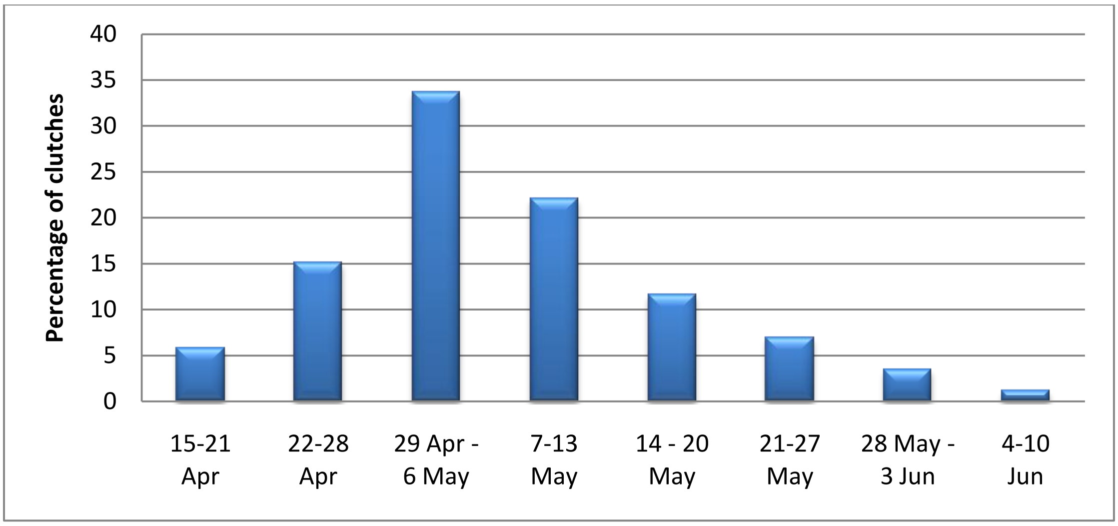

Figure 5.1. Proportion of clutches initiated in a given week (2007 and 2008 breeding seasons combined) (*n*=86 nests).

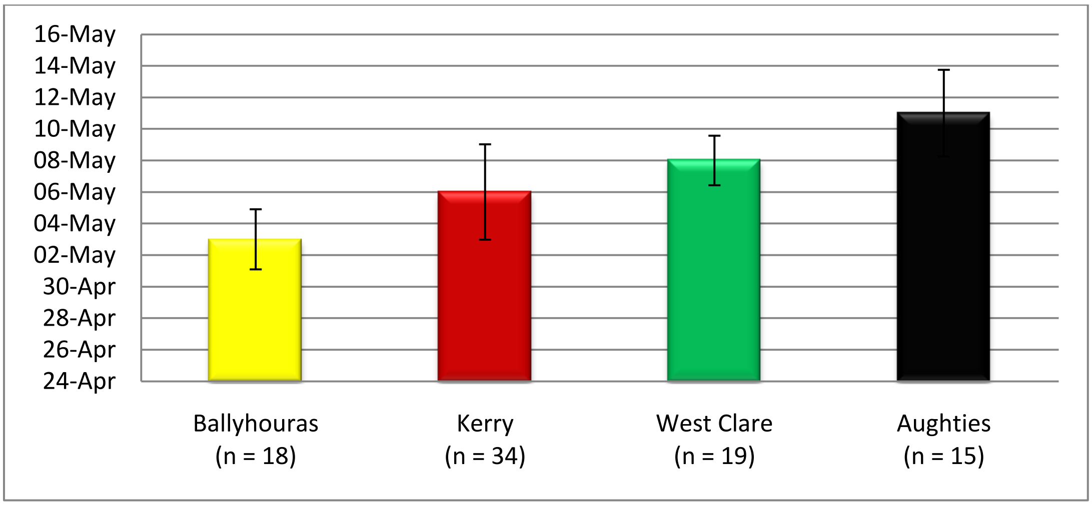

Figure 5.2. Mean (± s.e.) lay date per study area.

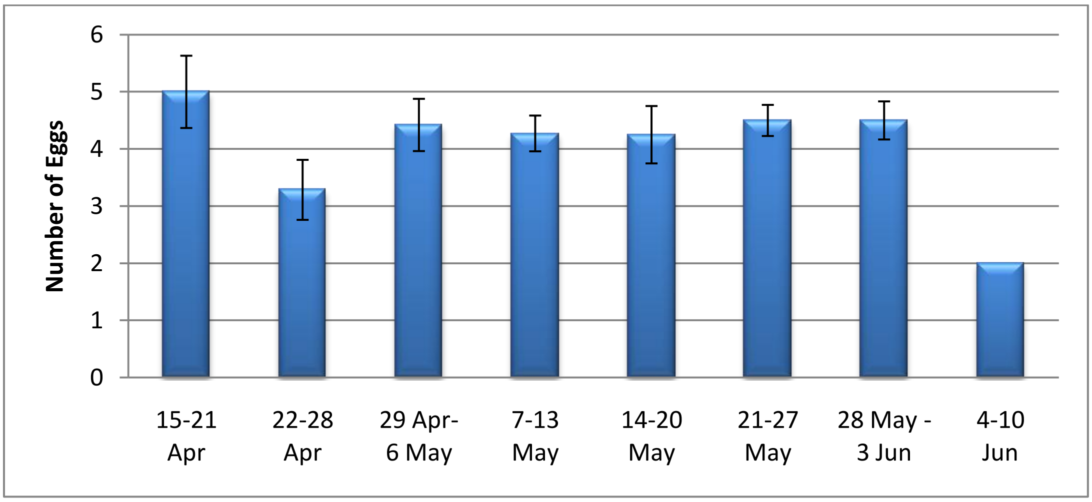

Figure 5.3. Mean (± s.e.) clutch size according to week of laying.

5.3.3 Hatching Success

A proportion of nests (15.4%) failed to hatch any young. The proportion of clutches that hatched varied significantly between breeding areas (Kruskal-Wallis H=12.65, *df*=3, *P*=0.005), ranging from the Slieve Aughties where 61.9% of clutches hatched, to Kerry where 97.2% of clutches hatched. Overall, 84.6% of all clutches hatched at least one egg. In terms of the total number of eggs (*n*=256), 66.8% of these hatched, with this proportion varying between study areas (H=12.15, *df*=3, *P*=0.007). *Post hoc* Mann-Whitney tests, with a Bonferroni correction factor applied, showed a significantly lower proportion of eggs hatched in the Ballyhouras and Slieve Aughties compared to Kerry and West Clare (*P*<0.01). For example, 48.1% of eggs in the Ballyhouras hatched, while 79.2% of eggs in West Clare hatched. There was a higher egg hatching rate in 2008 (71.2%) than in 2007 (61.3%), though any difference was not statistically significant (Mann-Whitney W=823, *P*=0.235). The proportion of clutches which hatched at least one egg did not differ between years (Mann-Whitney W=2246, *P*=0.504). A summary of hatching success is given in Table 5.2.

A greater proportion of eggs laid in scrub habitats hatched (95.8% of clutches and 79.7% of all eggs hatched), compared to those in heather/bog (81.8% of clutches and 64.2% of eggs hatched) and restock (81.6% of clutches and 63.1% of eggs hatched). However any apparent differences between nesting habitats in terms of hatching success of clutches and total number of eggs were not significant (χ^2=2.89, *df*=2, p=0.236 and χ^2=5.43, *df*=2, p=0.066, respectively). Of clutches that hatched, 89% did so between 20 May and 20 June (15 days either side of the mean hatching date, 5 June).

5.3.4 Nestling Stage

5.3.4.1 Brood Size

The mean brood size was 3.13 ± 0.12 chicks (range 1-6 chicks). It was lowest in the Ballyhouras ($\bar{x}$=2.83 ± 0.22), whereas this area had the highest mean clutch size (Figure 5.4). Brood size did not however vary significantly across study areas (Kruskal-Wallis H=2.35, *df*=3, *P*=0.503). No significant difference was found in terms of brood size in different macrohabitats (Kruskal-Wallis H=3.12, *df*=2, *P*=0.210). Mean brood size appeared larger in 2008 ($\bar{x}$=3.33 ± 0.16) than it was in 2007 ($\bar{x}$=2.87 ± 0.18), though any difference in median was short of significance (Mann-Whitney W=919, *P*=0.067). In late July at a nest in West Clare, a fledgling from one nest became associated with another nest and was fed by the 'surrogate' parents.

5.3.4.2 Sex Ratio of Chicks

Of 116 chicks that were sexed, 66 (56.9%) were female, meaning an overall ratio of 1.32 females : 1 male. Sex ratio ranged from 0.83 females : 1 male in the Slieve Aughties in 2008 to 2.00 females : 1 male in West Clare the same year. Kerry, West Clare and the Ballyhouras produced more females than males, while the Slieve Aughties was the only area that had more male chicks than female chicks (Figure 5.5). In 2008 overall, there was less of a bias in favour of female chicks (1.22:1) than was recorded in 2007 (1.5:1), though this adjustment was not significant (Mann-Whitney W=2713, P=0.595). Overall, sex ratio did not differ significantly from a parity (1:1) ratio (χ^2=0.849, df=1, P=0.356).

5.3.4.3 Fledging Date

In total, the first fledging dates of 63 broods were ascertained to within one week. Fledging occurred from as early as the week of 18 – 24 June, to as late as the week of 6 – 12 August, and peaked during the week of 9 – 15 July, while over half (57.1%) of successful attempts fledged their first young in the two week period of 9-22 July. Figure 5.6 outlines the frequency of fledging according to week. The week in which a brood fledged its first young did not vary significantly between study areas (Kruskal-Wallis H=1.64, df=3, P=0.651). The number of young which fledged did not vary significantly between weeks (Kruskal-Wallis H=5.88, df=7, P=0.554). Males on average fledged 33.5 ± 1.1 days after hatching, whereas females on average fledged at 36.0 ± 1.1 days of age. The youngest age that a male fledged at was 28 days, while the oldest a male fledged at was 40 days. Females took between 30 and 42 days to fledge. Any difference between the sexes in terms of fledging age was not significant (Mann-Whitney W=126.5, P=0.132).

5.3.5 Breeding Success and Productivity

In total, 104 nests had confirmed outcomes[3], and 68 of these were successful, meaning an overall breeding success rate of 65.4%. A confirmed 168 chicks fledged

[3] One of the 105 nests had an unconfirmed outcome.

successfully, giving breeding productivity values of 1.62 ± 0.14 fledglings per all females which bred and 2.47 ± 0.13 fledglings per successful females. Breeding productivity between years was relatively similar (1.61/2.45 in 2007 and 1.62/2.49 in 2008), and in terms of individual breeding areas, did not vary significantly between years (Mann-Whitney tests, $P>0.10$). The breeding success rates of the study areas are given in Table 5.3, while respective breeding productivity values are presented in Figure 5.7.

The percentage of chicks reared to fledging varied significantly across breeding areas (Kruskal-Wallis H=9.59, $df=3$, $P=0.022$), from 38.1% (in the case of the Slieve Aughties) to 76.1% (in the case of West Clare). Just 38.7% of chicks in the Ballyhouras made it to fledging, while 68.8% of chicks in Kerry were fully reared. Overall, 59.2% of all chicks which were accounted for as nestlings fledged.

Table 5.2. Hatching success according to study area and overall. Clutches hatched (%) refers to the percentage of clutches that hatched at least one egg. Eggs hatched (%) refers to the percentage of all eggs that hatched.

	Kerry	**W. Clare**	**Ballyhouras**	**Aughties**	**Overall**
Clutches Hatched (%)	97.2	86.4	84.0	61.9	84.6
Eggs Hatched (%)	78.9	79.2	48.1	54.2	66. 8

Table 5.3. Breeding success (% of females which were successful in breeding attempts) according to study area and overall.

Area	**Confirmed Breeding Results**	**Breeding Success (%)**
Kerry	36	80.6
West Clare	22	77.3
Ballyhouras	25	60.0
Slieve Aughties	21	33.3
Overall	*104*	*65.4*

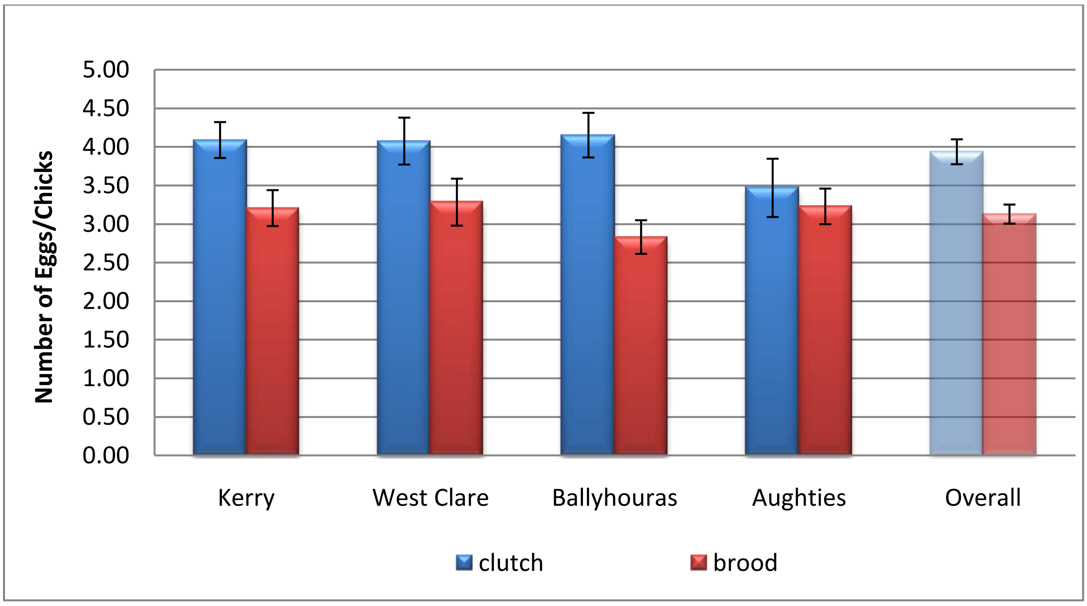

Figure 5.4. Mean (± s.e.) clutch and brood size of the study areas and overall.

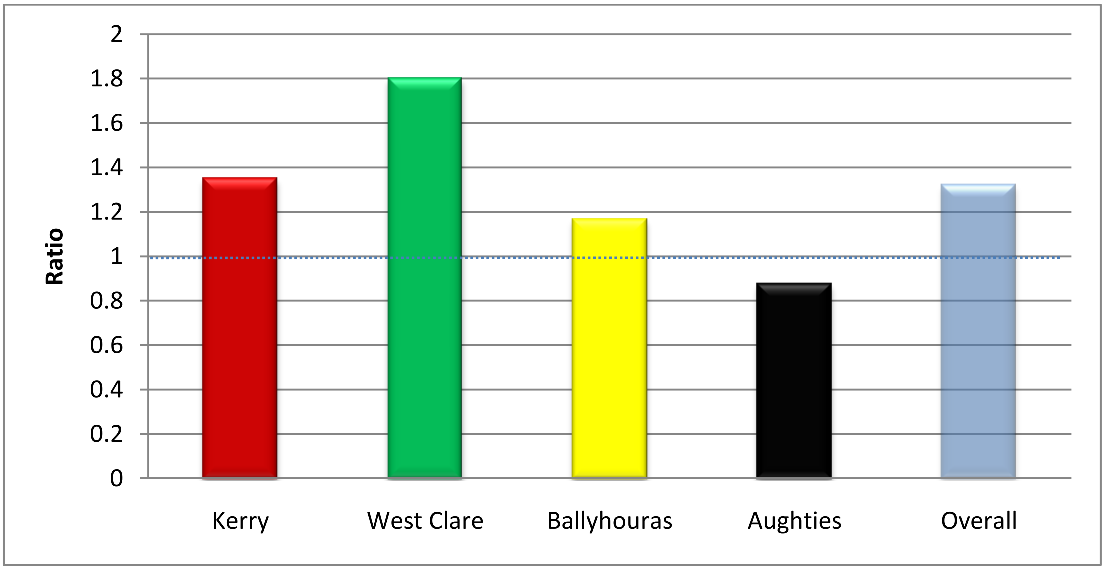

Figure 5.5. Brood sex ratio (female:male) according to study area and overall (dotted line represents parity).

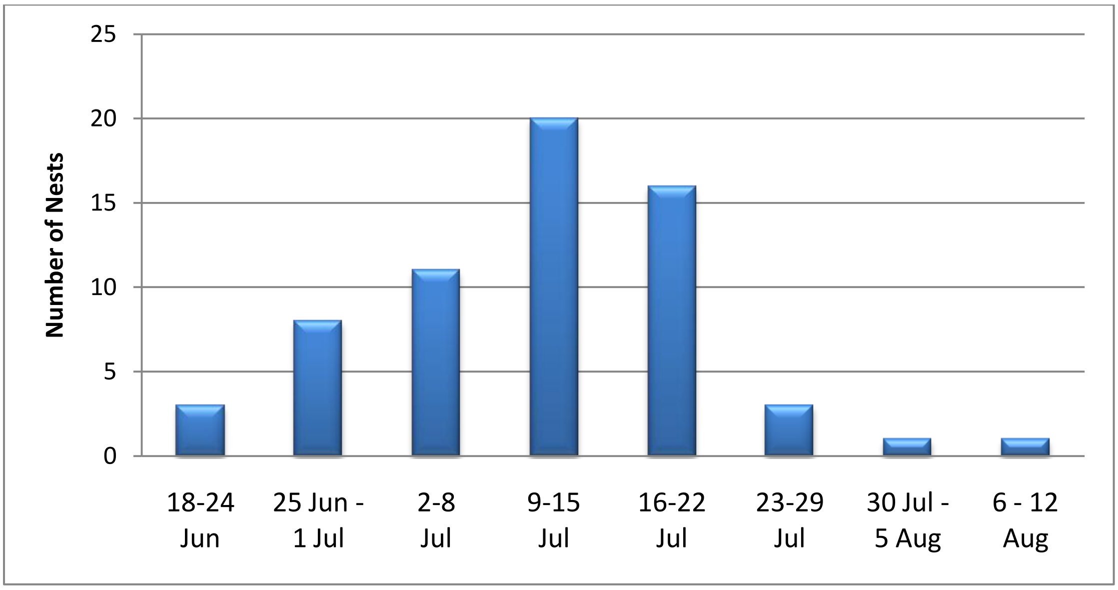

Figure 5.6. Number of nests fledged according to week during 2007 and 2008.

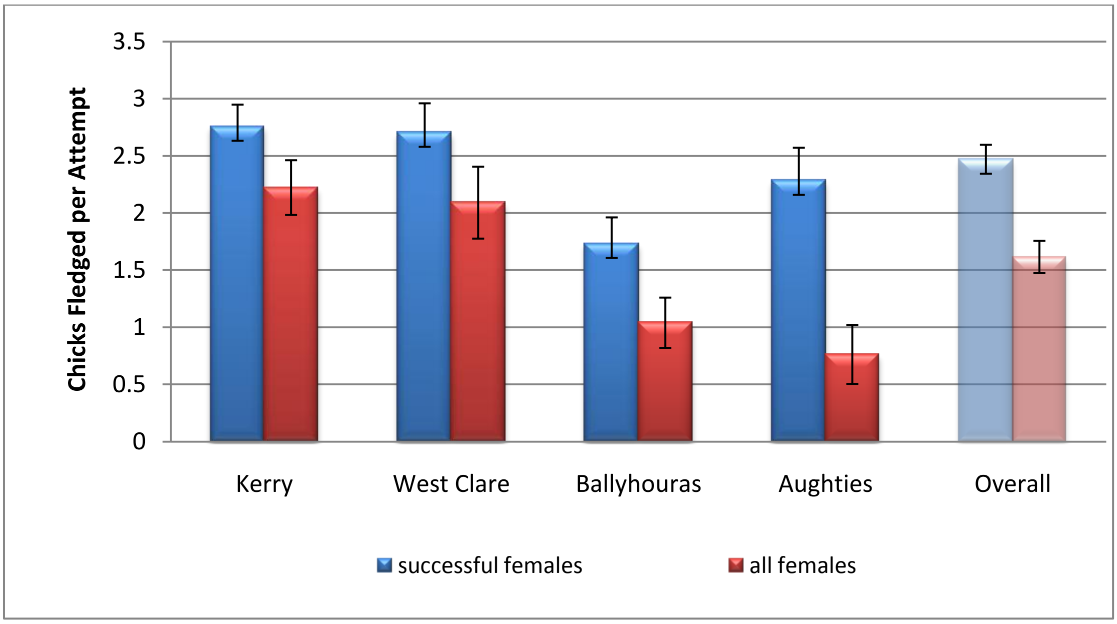

Figure 5.7. Breeding productivity (both in terms of successful females and all females) according to study area and overall.

5.3.5.1 Model Selection Regarding Factors Most Influential on Breeding Success and Breeding Productivity

Breeding area was found to be the most important factor affecting whether a nest was successful or not, with a gradient from most successful to least successful as per Table 5.3. The distances a nest lay from the nearest track, or nearest stream, were also found to be influential in whether that nest was successful or not, with nests closer to these features being more prone to failure.

Thus, the final model predicting breeding success was as follows:

Breeding success ~
Breeding Area + Distance to Nearest Track + Distance to Nearest Stream

Table 5.4 summarises the model selection process while Table 5.5 summarises the final model.

Breeding productivity was found to be influenced most highly by the prey delivery rate in the early parts of the season, with higher provisioning rates resulting in higher numbers fledged. Whether or not a nest was in a glen was also found to influence the number of young which fledged. Thus, the final model predicting breeding productivity was as follows:

Breeding productivity ~
Early Season Prey Delivery + Glen Nesting

Table 5.6 summarises the model selection process, while Table 5.7 summarises the final model.

Table 5.4. Summary of available explanatory variables for modelling breeding success and the stepwise deletion of the least significant variable with the corresponding AIC values.

Step	Model	AIC
Start model	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + breeding area + year + microhabitat + macrohabitat + aspect + glen nesting + nesting date + visited + egg visit	113.37
Remove aspect	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + breeding area + year + microhabitat + macrohabitat + glen nesting + nesting date + visited + egg visit	105.71
Remove microhabitat	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + breeding area + year + macrohabitat + glen nesting + nesting date + visited + egg visit	103.59
Remove number of neighbours within 6km	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + early season prey delivery rate + region + year + macrohabitat + glen nesting + nesting date + visited + egg visit	101.79
Remove year	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + early season prey delivery rate + breeding area + macrohabitat + glen nesting + nesting date + visited + egg visit	100.30
Remove glen nesting	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + early season prey delivery rate + breeding area + macrohabitat + nesting date + visited + egg visit	99.03
Remove macrohabitat	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + early season prey delivery rate + breeding area + nesting date + visited + egg visit	97.5
Remove early season prey delivery	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + breeding area + nesting date + visited + egg visit	96.29
Remove nesting date	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + breeding area + visited + egg visit	95.51
Remove egg visit	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + breeding area + visited	94.77
Remove slope	elevation + distance to stream + distance to track + distance to nearest neighbour + breeding area + visited	94.80
Remove distance to nearest neighbour	elevation + distance to stream + distance to track + breeding area + visited	95.04
Remove visited	elevation + distance to stream + distance to track + breeding area	95.08
Remove elevation	distance to stream + distance to track + breeding area	95.63

Table 5.5. Results (or numerical output) of the model selection for breeding success using a binomial Generalized Linear Model (GLM). (Final AIC=95.63. Null deviance = 103.8; residual deviance = 83.63).

	Estimate	**Std. Error**	**z value**	***P***
Intercept	-1.303	0.975	-1.337	0.181
West Clare	0.378	0.791	0.477	0.633
Ballyhouras	-0.906	0.812	-1.115	0.265
Aughties	-2.178	0.757	-2.875	0.004
Distance to Stream	0.076	0.038	1.977	0.048
Distance to Track	0.168	0.074	2.259	0.024

Table 5.6. Results (or numerical output) of the model selection for breeding productivity using a Generalized Linear Model (GLM) with a Gamma distribution.

Step	Model	AIC
Start model	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + breeding area + year + microhabitat + macrohabitat + aspect + glen nesting + nesting date	143.1
Remove aspect	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + breeding area + year + microhabitat + macrohabitat + glen nesting + nesting date	133.98
Remove breeding area	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + microhabitat + macrohabitat + glen nesting + nesting date	130.62
Remove microhabitat	elevation + slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + macrohabitat + glen nesting + nesting date	127.37
Remove elevation	slope + distance to stream + distance to track + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + macrohabitat + glen nesting + nesting date	125.4
Remove distance to track	slope + distance to stream + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + macrohabitat + glen nesting + nesting date	123.7
Remove distance to stream	slope + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + macrohabitat + glen nesting + nesting date	122.42
Remove nesting date	slope + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + macrohabitat + glen nesting	122.26
Remove macrohabitat	slope + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + year + glen nesting	123.00
Remove year	slope + distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + glen nesting	123.46
Remove slope	distance to nearest neighbour + number of neighbours within 6km + early season prey delivery rate + glen nesting	124.28
Remove number of neighbours within 6km	distance to nearest neighbour + early season prey delivery rate + glen nesting	124.68
Remove distance to nearest neighbour	early season prey delivery rate + glen nesting	124.86

Table 5.7. Summary of available explanatory variables for modelling breeding productivity and the stepwise deletion of the least significant variable with the corresponding AIC values. (Final AIC=124.86. Null deviance = 10.76; residual deviance = 6.38).

	Estimate	**Std. Error**	**t value**	***P***
Intercept	0.531	0.041	13.071	<0.001
Prey Delivery	-0.181	0.034	-5.369	<0.001
Glen Nesting	0.186	0.061	3.062	0.037

5.3.6 Dispersal dates

Fledgling Hen Harriers were observed to remain within 1km of the nest until as late as 26 August ($\bar{x}$ = 5 August) and on average until 56.2 ± 1.7 days after hatching (range 40-70 days after hatching), or 10 to 42 days after fledging. Parents were observed to provision the young from between just 15 days of age (in the case of one male), until 62 days of age (in the case of one female) and on average until 46.8 ± 1.8 days of age. Males generally (in 87% of cases) departed prior to females, on average 7.5 days earlier (38.4 ± 2.8 days after hatching *vs.* 45.9 ± 1.8 days after hatching), though this difference in terms of timing was not significant (Mann-Whitney W=562, P=0.086).

5.3.7 Nest Failures

The stage and cause of failures are presented in Figures 5.8 and 5.9. Of the 36 nests that failed, the causes of failure for 30 (83.3%) were identified and divided into nine categories as seen in Figure 5.9. Predation accounted for 66.7% of known cases of failure, with at least 55% of failed attempts and 19.2% of all breeding attempts terminated by predators (ground and avian). Of the five nests that were abandoned; three were deserted at egg stage and two before any eggs were laid. Disease (*Trichomoniasis*) was responsible for the failure of at least two nests in 2008. Sixty-one percent of confirmed nest failures occurred during the chick stage, with 33% happening at the egg stage and 6% at the hatching stage (Figure 5.8).

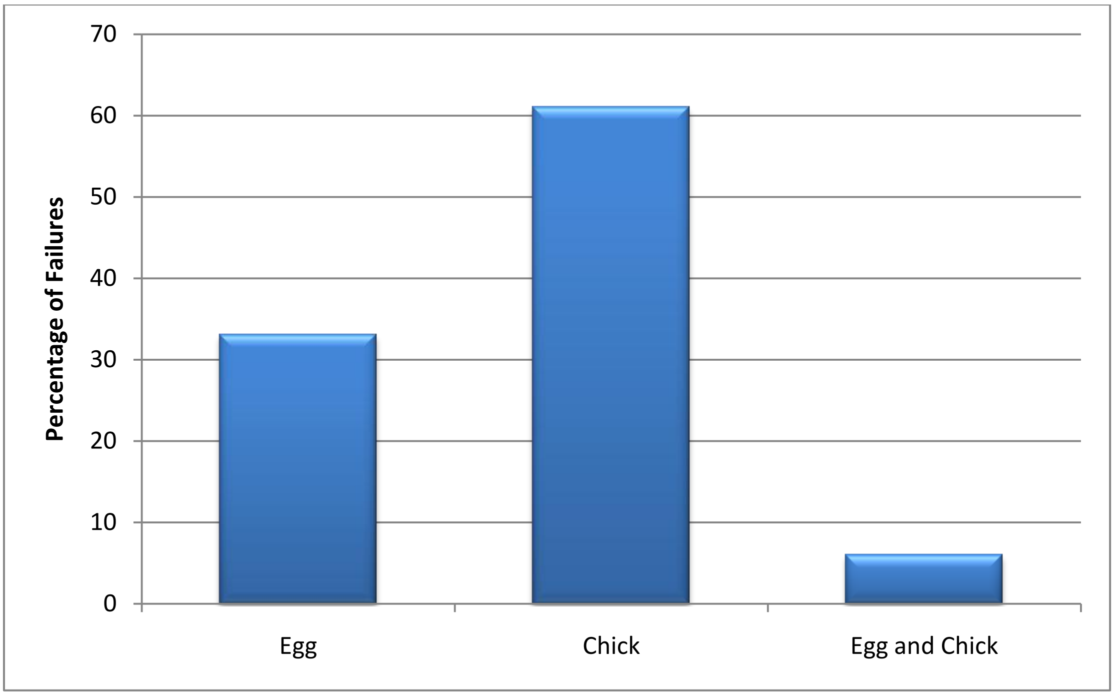

Figure 5.8. Stages of breeding attempt during which failures occurred (*n*=36 nests).

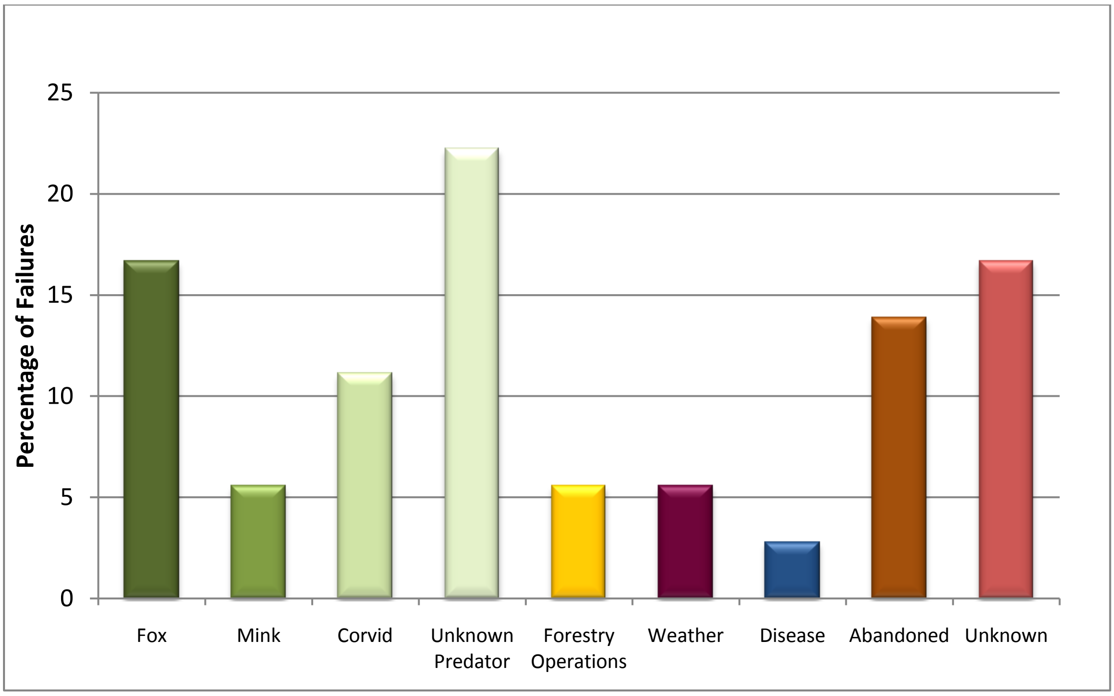

Figure 5.9. Causes of nest failures in 2007 and 2008 (*n*=30 nests).

5.3.8 Territory Occupation and Success

Of territories that were successful in 2007, 89.6% were re-occupied in 2008, compared to a re-occupation rate of 66.7% for territories which failed in 2007, though this difference was not significant (χ^2=3.15, *df*=1, *P*=0.061). Over half (54%) of territories which were re-occupied experienced the same outcome of success or failure in both years, where 61.5% of nests which were successful in 2007 were successful in 2008, and 15.4% of nests which failed in 2007 failed again in 2008. Failure followed success in 19% of re-occupied territories, whereas success followed failure in re-occupied territories on 27% of attempts.

5.3.9 Effect of Nest Visits

The success rate of unvisited and visited nests did not differ significantly (Mann-Whitney W=1591, *P*=0.552). In addition, the number of times a nest was visited (generally no more than three) did not have a significant impact on nest success (Kruskal-Wallis H=4.38, *df*=3, *P*=0.223). While the GLM predicted breeding success to be most influenced by region, distance to nearest stream and distance to nearest track, nests that were visited during egg stage were more likely to fail than those visited only from chick stage onwards (Mann-Whitney W=922, *P*=0.005), or not visited at all (Mann-Whitney W=788, *P*=0.05).

5.4 DISCUSSION

5.4.1 Breeding Populations

While it was not an objective of the study to find all breeding territories in the respective study areas, comparing the number of territories identified in each breeding area to that published by Barton *et al.* (2006), as well as the author's unpublished data for Kerry and West Clare, it appears that this was achieved or was very close to being achieved. A breeding territory in which a nest was not found did not necessarily mean the harriers there did not nest, but overall this statistic (21.6%) is believed to be representative of the proportion of females which did not breed. Picozzi (1984a) found up to 26% of females he observed on Orkney did not breed. As well as having the poorest breeding success rates, the Slieve Aughties may have had as many as 49%

of females not nesting at all. In contrast, nesting was recorded at 95% and 100% of territories confirmed in Kerry and West Clare respectively.

5.4.2 Egg Stage

5.4.2.1 Clutch Size

The mean clutch size of 3.94 ± 0.14 eggs is lower than that found in any population outside of Ireland (Table 5.8). The only studies presenting lower clutch sizes are those from the North of Ireland, by Scott and Clarke (2007) ($\bar{x}$ = 3.58 eggs) and Ruddock *et al*. (2008) ($\bar{x}$ = 3.50 eggs). Low clutch size in the current study cannot be attributed to density-dependence, as the mean distance between nests was greater than that found elsewhere (Chapter 4, Nest Sites). Survival rates in Ireland do not appear to be higher than elsewhere (Chapter 7, Movements and Survival), so again, cannot be offered as an explanation for lower clutch sizes.

Clutch size reflects the investment of the female in egg production, and ultimately the investment both parents will have to make to rear the young. As clutch size is closely correlated to and is essentially an index of food supply (Simmons *et al*., 1986b; Salamolard *et al*., 2000; Redpath *et al*., 2001a and 2002a; Amar *et al*., 2003a; Whitfield *et al*., 2008), the landscape in which Hen Harriers in Ireland are breeding may be less productive than elsewhere. Picozzi (1984b) and Daan *et al.* (1990) found that females which laid the most eggs reared the most young. Small clutch sizes essentially limit Irish Hen Harriers from the beginning, restricting potential brood sizes and fledging numbers.

Table 5.8. Mean clutch sizes of studied Hen Harrier (and Northern Harrier) populations.

Publication	**Study Population**	**Mean Clutch Size**
Balfour (1957)	Orkney, Scotland	4.16
Hamerstrom (1969)	Wisconsin, U.S.A.*	4.5
Balfour and Cadbury (1975)	Orkney, Scotland	4.60
Picozzi (1978)	Orkney, Scotland	4.70
Schipper (1978)	Northern Holland	4.56
Picozzi (1984b)	Orkney, Scotland	4.39 - 5.04
Simmons *et al.* (1986a)	New Brunswick, Canada*	4.57
Bibby and Etheridge (1993)	Scotland	4.00 - 5.20
Green and Etheridge (1999)	Scotland	4.44 - 6.00
García and Arroyo (2001)	Central Spain	4.37
Redpath *et al.* (2001a)	Langholm, Scotland	5.00
Redpath *et al.* (2002c)	Scotland	4.13 - 5.16
Millon *et al.* (2002)	Eastern France	4.15
Amar *et al.* (2003a)	Orkney and Langholm, Scotland	4.58 - 5.00
Amar *et al.* (2005)	Orkney, Scotland	4.68 - 5.15
Whitfield *et al.* (2008)	Wales	4.63 - 4.93
This Study	**Southern Ireland**	**3.94**
Scott and Clarke (2007)	Northern Ireland	3.58
Ruddock *et al.* (2008)	Northern Ireland	3.50

* Northern Harrier (*Circus hudsonius*)

5.4.2.2 Egg Lay Date

The median lay initiation date of 5 May for Ireland is slightly later than that found by Etheridge *et al.* (1997) for Scotland (2 May), Arroyo (1996) for Spain (4 May) and Millon *et al.* (2002) for France (2 May). England appears to have the earliest clutch initiations, with a median first lay date of 19 April (with one clutch beginning as early as 3 April) (S. Murphy, unpubl. data). Ireland is earlier than Orkney off the North Coast of Scotland, where median lay dates of 16 May (Redpath *et al*., 2002c) and 11 May (Amar *et al*., 2005) have been reported**.** Irish harriers are also earlier than those in North America where Northern Harriers (*Circus hudsonius*) generally don't lay until later in May (Simmons *et al*., 1986a; Kantrud and Higgins, 1992). In raptors, clutches laid earlier generally produce more young (and larger clutches which can produce more young) (Schipper, 1978; Newton, 1979; Etheridge *et al*., 1997; Daan *et al*., 1990; Olsent and Cockburn, 1990; Millon *et al*., 2002; Koks *et al*., 2007). A late median clutch initiation date may even be indicative of a population in decline. Scott (in Watson, 1977) reported that most clutches in Wicklow, which was a harrier population on the east coast in decline at the time and soon to become extinct, were not laid until mid-May. Orkney, a population which has declined substantially (Meek *et al*, 1998; Amar *et al*., 2003a,b, 2005 and 2008) has the latest clutch initiation dates and productivity of various regions studied in Scotland (Etheridge *et al*., 1997). Caution should be exercised however in comparing lay dates between studies carried out in different years, as even within the same regions, this can vary between years (e.g. Etheridge *et al*., 1997; Redpath *et al*., 2001a).

While no significant difference was recorded between the study areas of the current research, the earliest settling area had the largest mean clutch size (4.15 ± 0.19 eggs), while the latest settling area had the smallest mean clutch size (3.47 ± 0.39 eggs), a pattern which agrees with findings of Picozzi (1984b); Simmons *et al.* (1986b); Sutherland (1987); Kantrud and Higgins (1992); Etheridge *et al.* (1997) and Koks *et al.* (2007). The onset of harrier laying has been shown to be earlier in good prey abundance years (Simmons *et al.* 1986; Koks *et al*., 2007); a relationship that has also been observed in other vole-eating raptors such as Kestrel (*Falco tinnunculus*) (Meijer *et al*., 1988) and several owl species (Wijnandts, 1984; Hörnfeldt *et al*., 1990; Taylor, 1994). It is possible that a generally later clutch initiation date in Ireland than most other Western European populations is linked with lower prey abundance or availability here. Poor weather may also delay clutch initiation dates (Nethersole-

Thompson, 1933; Balfour, 1957; Schipper, 1978; Arroyo, 1996), though the months of April and May in both 2007 and 2008 were particularly warm and dry (Met Éireann 2007a,b and 2008a,b).

5.4.3 Hatching Success

The majority (84.6%) of clutches survived to chick stage. This hatching success rate was generally higher than that recorded in Britain (Balfour and Cadbury, 1975; Redpath *et al.*, 2002b; Amar *et al.*, 2003a and 2008), most likely because of persecution there, which often occurs prior to hatching (Etheridge *et al.*, 1997; Stott, 1998; Green and Etheridge, 1999). Hatching success was lower than that recorded in Spain and France (García and Arroyo, 2001; Millon *et al.*, 2002). Hatching success varied across study areas, with eggs in Kerry and West Clare 62% more likely to hatch than eggs in the Ballyhouras and Slieve Aughties. Hatching success in the Ballyhouras and Slieve Aughties was relatively poor, with 61.9% of clutches in the Aughties hatching and only 48.1% of eggs in the Ballyhouras hatching. The fact that the Ballyhouras had the highest mean clutch size, but lowest brood size reflects this study area having the lowest hatching rate. Even discarding nests which were lost at egg stage, less than half (43.3%) of the eggs counted in the Ballyhouras produced nestlings. Hatching success can be influenced by foraging habitat quality (Amar *et al.*, 2008), predation (Green and Etheridge, 1999), disturbance, stage of season and/or persecution rates (Schipper, 1978; Etheridge *et al.*, 1997). The incidence of polygyny can increase the number of eggs which fail to hatch (Balfour, 1957; Balfour and Cadbury, 1979; Simmons, 2000; Amar *et al*., 2003a). The Ballyhouras was one of the earliest study areas in terms of breeding activity, polygyny was not common there, and no clutches were predated or persecuted. Therefore, it is most probable that food limitation is limiting the egg hatching rate there (Newton, 1979 and 1998; Koenig, 1982; Arroyo, 1998; Amar *et al*., 2003a; Simmons, 2000) and evidence for this was recorded through prey delivery rates (Chapter 3, Diet). At least two entire clutches in the Ballyhouras were shown to be unviable or addled, while one nest in the Slieve Aughties was deserted at egg stage. The most likely explanation for these occurrences is poor food conditions or nutritional state of the females (Newton, 1979). In contrast, almost 80% of all eggs in Kerry and West Clare hatched.

5.4.4 Nestling Stage

While international studies provide a wealth of clutch size data, just one was found to provide brood size data (while young were still in the nest). Millon *et al.* (2002) recorded a mean brood size of 3.64 chicks in France. Following from clutch size, it appears that brood size of Hen Harriers in Ireland ($\bar{x} = 3.13$ chicks) may also be lower than elsewhere.

Overall sex ratio was biased in favour of female chicks (1.32 females : 1 male). Other studies pertaining to brood sex ratios showed the Netherlands to have a sex ratio of 1.20:1 (Schipper, 1978), Orkney to have a sex ratio of 1.15:1 (Picozzi, 1980a) and Scotland to have a sex ratio of 0.92:1 (Etheridge *et al*., 1997). Whitfield and Fielding (2009) found a sex ratio in Welsh Hen Harriers of 0.99:1. The bias towards producing more females was particularly pronounced in Kerry and West Clare, but less so in the Ballyhouras. The Slieve Aughties was the only area that had more male chicks than female chicks. Harriers are able to manipulate the number of males and females they produce in response to several potential factors, such as population characteristics, food abundance or other influences on the probability of offspring recruitment (Simmons, 2000). Field studies by Witkowski (1989) and MacWhirter (1994) found no significant difference between the investment and energy afforded to male and female harrier chicks (in terms of food deliveries) and concluded that the reproductive value of either sex was equal. However Riedstra *et al.* (1998), using a more accurate assessment of energy intake (radioactively labelled isotope of water), found that male harrier chicks used 20% less energy as nestlings than females and concluded that males were cheaper to rear than females. This is probably because male chicks mostly fledge lighter and younger than their sisters (Watson, 1977; Picozzi, 1980a; Scharf, 1992; MacWhirter, 1994; Simmons, 2000; Hardey *et al*., 2006). Areas producing predominantly male chicks may indicate a constraint in terms of food supply, as males would be cheaper to produce than females. Conversely, areas where many more female chicks are produced may represent breeding grounds which are relatively rich in terms of food supply (MacWhirter, 1994; Arroyo, 2002). Both of these hypotheses corroborate with the general breeding success trends found in the four study areas and their respective prey delivery rates (Chapter 3, Diet).

5.4.5 Fledging

The average time it took both male (33 days) and female (35 days) chicks to fledge was greater in this study than that stated by Hardey *et al.* (2006) for 'well-fed' chicks (28 and 32 days for males and females respectively). However, the pattern observed is generally in line with what Scharf and Balfour (1971) and Watson (1977) reported. The youngest fledged male (28 days) was a lone chick, regularly provisioned by both parents, and therefore at an advantage food-wise. Conversely, the two oldest fledged males (39 and 40 days) were reared by just one parent (the female). It appears then, that better fed individuals grew faster and fledged earlier than poorer fed chicks. The observation of the 'adopted' fledgling in West Clare is interesting, as a similar occurrence was observed during the same season in Bowland, England (S. Murphy, pers. comm.). This may be a ploy by the juveniles to extend the period of provisioning by adults through locating an active territory after their own has terminated. While such 'visiting' by newly fledged chicks was also previously noted by Balfour (1962b), Simmons *et al.* (1987) reported Northern Harrier parents in America to discriminate between their own fledglings and intruding fledglings.

5.4.6 Dispersal Dates

The fact that breeding attempts lasted on-site up to late August, 42 days after fledging, is an important guide to timing human activity/work in Hen Harrier territories to avoid disturbance to breeding attempts. In other years, breeding attempts may finish earlier or later, while some breeding sites may also be non-breeding roost sites (Chapter 6, Non-breeding Ecology). Therefore it is imperative that site-specific monitoring is undertaken ahead of any potentially disturbing works. Adult females typically remained committed to the young for longer than the males, although the investment by the male throughout the season in provisioning the female and young probably outweighs or at least balances his earlier departure.

5.4.7 Breeding Success and Productivity

The overall breeding success rate of 65.4% almost mirrors that found by Hamerstrom (1969) for her study population of Northern Harriers in Wisconsin (64.7%), but is less than that presented by Norriss *et al.* (2002), who estimated an Irish breeding success rate of 78%. However in that study, a successful nest was defined as one which was still active on 1 July. It is now apparent that this assumption could have overestimated the breeding success rate, because in the present study, the fate of 74 nests was not confirmed until 1 July or after, and 19% of these nests failed. If 19% of nests referred to by Norriss *et al.* (2002) failed after 1 July, a success rate of no more than 63.5% would have been recorded (albeit the failure rate of nests in that study may have been lower or higher than 19%). Overall, 77.3% of attempts in which young hatched went on to fledge young. This figure compares closely with Hamerstrom (1969) and Amar *et al.* (2008) who recorded rates of 78.0% and 80% respectively. However, the proportion of nestlings which went on to fledge (59.2%), was less than that reported by Redpath *et al.* (2002c), who found this figure on the Scottish mainland to vary between 67.2% and 76.0%.

Breeding success was found to be most highly influenced by region. The underlying causal mechanism determining the reason why certain areas had higher breeding success than others is difficult to evaluate in the absence of critical information on habitat availability within the territories of the respective pairs. If a breeding attempt did prove to be successful, the number of young which were reared was largely determined by prey delivery in the early stages of the breeding season. This same finding has also been established in previous studies and has been related to habitat quality (e.g. Simmons, 2000; Amar and Redpath, 2002; Amar *et al*., 2005 and 2008). Food availability (related to food provisioning) influences territory occupation and breeding productivity of raptors (Barth, 1964; Hamerstrom, 1969; Schipper, 1978; Newton, 1979; Martin, 1987; Grant *et al*., 1991; Butet and Leroux, 1993; Ontiveros and Pleguezuelos, 2000; Redpath *et al*., 2002a; Amar *et al*., 2003a, 2005 and 2008; Katzner *et al*., 2005; Arroyo *et al*., 2007; Klaassen *et al*., 2008). Comparatively low successful brood sizes in Ireland may be related to a relatively low assemblage of mammalian prey species (Hayden and Harrington, 2000), as originally hypothesised by O'Flynn (1983). The same suite of prey (including all small mammals) existed in all four study areas but the abundance and availability of prey in these study areas may have differed, as suggested by the different prey delivery rates (Chapter 3, Diet). This also corroborates with different hatching successes associated with food supply (Section 5.4.3).

The fact that harriers nesting in glens reared significantly less young than those nesting elsewhere is important to note, as harriers in this study apparently selected to nest in glens (Chapter 4, Nest Sites). This may be an ecological trap, borne out of necessity. Glens may have presented the most attractive, or only undisturbed location within a territory for nesting. However, such areas are also attractive for other fauna, including predators of Hen Harriers.

A further (unmeasured) variable dictating the number of young reared may be that of foraging distances. Hen Harriers in Ireland may need to travel long distances to access useful foraging grounds which are often fragmented and isolated from nesting areas by intensive grassland, mature forest, wind farms or degraded moorland (pers. obs.). Not only might this increase energy demands on the males, but it might increase the intervals between prey delivery rates. Habitat fragmentation may also cause higher nest predation rates and increased competition with other predators for their primary prey items (Andren, 1992; Slater and Rock, 2005).

5.4.8 Breeding Failure

Just over a third of all nests failed in each study year. Study areas differed in terms of their failure rates. In Kerry, 19.4% of nests failed; in West Clare this value was 22.7%; in the Ballyhouras 40%, and in the Slieve Aughties 66.7%. The failure rate for the Slieve Aughties is one of the highest known for any Hen Harrier population in published literature. If it is considered that as many as 49% of all territories confirmed in the Aughties are thought not to have progressed to even clutch stage, then an even more drastic situation exists, with up to 83% of confirmed territories not rearing any chicks.

A number of nest failure events could not be attributed to a specific cause. This is a common disadvantage of 'opportunistic' observational studies (MacDonald and Bolton, 2008; Nicoll and Norriss, 2010). However, as 83.3% of failures were attributed to a specific cause, a good understanding of breeding failure has been achieved. The main cause of breeding failure was identified as nest predation, accounting for over half (55%) of all failures. Norriss *et al.* (2002) may have underestimated the role which predation plays in Hen Harrier breeding failure in Ireland when asserting it was *"not significant"*. An overall predation rate of (at least) 19.2% is relatively high when compared to studies of other harrier populations (Table 5.9). An important caveat with predation rates however (pertaining to all studies listed in Table 5.9) is that it may not always be clear whether predation is additive or compensatory (Newton, 1979; Quinn *et al.*, 2008).

Table 5.9. Predation rates of international harrier populations, ranked in order of magnitude.

Publication	Species	Country	Predation Rate (%)
Simmons (2000)	*C. ranivorus*	South Africa	52
Simmons *et al.* (1986b)	*C. hudsonius*	Canada	21
Butet and Leroux (1993)	*C. pygargus*	France	21
This Study	***C. cyaneus***	**Ireland**	**≥19.2**
Picozzi (1984a)	*C. cyaneus*	Scotland	18
Underhill-Day (1984)	*C. aeruginosus*	England	11
Witkowski (1989)	*C. aeruginosus*	Poland	13
Baker-Gabb (1982)[†]	*C. assimilis*	Australia	13
Hamerstrom (1969)	*C. hudsonius*	U.S.A.	12.5
Natural England (2008)*	*C. cyaneus*	England	8
Arroyo (1996)	*C. cyaneus*	Spain	3.7
Arroyo (1996)	*C. pygargus*	Spain	1.8

[†]Tree nesting, *predation rate may be reduced by predator control

Given Ireland has a relatively limited predator fauna compared to other study populations, a relatively high predation rate may signal that harriers in Ireland are nesting in areas with high densities of predators and/or that a proportion of females are spending longer away from their nests, possibly in order to supplement a low food provisioning rate. Predation appears to be a particular issue in the Ballyhouras and Slieve Aughties, which suffered predation rates of at least 24.0% and 23.8% respectively. The fact that nests closer to tracks and watercourses were more prone to failure may have been related to easier access or discovery of nests by predators from tracks, while American Mink (*Mustela vison*) typically occupy watercourses (Deane and O'Gorman, 1969; Roy *et al*., 2009). Indeed, two nests during the course of this study are known (from scats) to have been visited by mink, both within 5m of a watercourse. It was found in Chapter 4 (Nest Sites) that Hen Harriers were choosing to nest further from tracks than might have been expected, so lessening the chance of nest predation may be the reason for this.

Hooded Crows (*Corvus corone cornix*) were often seen attempting to raid harrier nests (involving 20 crows in one instance at a forest nest). Not only have they the potential to take eggs, but crows were also suspected to take at least one well-feathered chick (a likelihood supported by observations from Amar and Burthe (2001) in Orkney). Targeted and well planned predator control has the capacity to reduce significantly the amount of breeding attempt failures by ground nesting birds (Fletcher *et al.*, 2010). Within 1km of a Hen Harrier nest in Kerry, Hooded Crows (*Corvus corone cornix*), Fox (*Vulpes vulpes*) and American Mink (*Mustela vison*) were virtually eradicated and six Hen Harrier chicks subsequently fledged from that nest.

The majority of confirmed nest failures occurred during the chick stage, contrary to Hamerstrom (1969) and MacWhirter and Bildstein (1996), where failure was weighted towards pre-hatching. Failure during brood stage rather than chick stage could be related to a number of events, but as egg stage and brood stage are broadly similar in duration, food supply (a stress more pronounced during brood stage) may be a driving factor in many cases. Picozzi (1980a); Simmons *et al.* (1986a); Sutherland (1987) and Kantrud and Higgins (1992) all found starvation was the main cause of harrier nestling mortality. Taking the Ballyhouras as the most extreme example, 70% of failures occurred during chick stage, with 86% of these failures unexplained. As the Ballyhouras has an exceptionally low food provisioning rate (Chapter 3, Diet), undernourishment of broods (which is not readily identifiable and in some cases masked by nest scavenger after starvation) may have contributed in a large way towards this 86% of unexplained failures. Nest desertion, often related to poor food supply (Bildstein, 1979b; Newton, 1979; Simmons *et al.*, 1986a), was also recorded in the Ballyhouras.

Failure of breeding attempts in consecutive years can be seen as of greater consequence than failure in one year offset by success the preceding or following year. With repeated failures, the viability of a territory is undermined. Four territories experienced failure in both study years, one of which was in the Ballyhouras and three of which were in the Slieve Aughties, representing a quarter of all territories that were occupied in both years in these areas.

Higher failure rates were observed in nests which were visited during the egg stage, although the fact that the final model did not select the ‘egg visit’ variable as significantly influencing breeding success suggests confounding factors may have been at play. Nevertheless, it is important to be conscious of this, given negative effects have previously been linked to research during egg laying and incubation (Simmons, 1983; Thompson-Hanson, 1984; Simmons and Smith, 1985; Simmons *et al*., 1986a; MacWhirter and Bildstein, 1996). Hamerstrom (1969); Follen (1986); Millon *et al.* (2002) and Scott (2008) avoided visit nests during laying or incubation in order to minimise disturbance to nests at this sensitive stage and Hardey *et al.* (2006) recommend not visiting during egg laying. Nests are thought to be less prone to desertion after hatching, given a strong bond with the offspring (Simmons, 1983; Simmons *et al*., 1986a; MacWhirter and Bildstein, 1996).

While it was found to be the most popular nesting habitat, restock forest was the poorest in terms of breeding success, with 41% of nests in this habitat failing. Concurrent research (Wilson *et al*., in review) on the same study populations found that the amount of restock forest within Hen Harrier territories exerts negative influence on breeding success and productivity. The distribution of nests in the Ballyhouras, biased towards the edge of the afforested area, may reflect the influences exerted by mass afforestation and corroborates with Wilson *et al.* (2006a) who purported that Hen Harriers avoided breeding in areas with less than 30% potentially suitable foraging habitat within 1km. Nesting in habitats other than those traditionally used by harriers has previously been shown to be maladaptive (Thompson-Hanson, 1984; Arroyo *et al*., 2002; Scott and Clarke, 2007). Higher failure rates may be caused by increased predator concentrations in forested landscapes (Chadwick *et al*., 1997; Smedshaug *et al*., 2002; Carey *et al*., 2007) and it has been shown that predation can increase in fragmented forest landscapes (Andren, 1992; Manolis *et al.*, 2002; Rodriguez *et al.*, 2001). Both Bibby and Etheridge (1993) and Etheridge *et al.* (1997) found productivity in conifer forests to be lower than on (unkeepered) moorland.

5.4.9 Breeding Performance of Irish Hen Harriers in Comparison to International Populations

While at first glance Ireland has a comparatively favourable overall fledging rate with respect to the nearest populations in Britain (Table 5.10), this favourable comparison is due largely to persecution in Britain (Etheridge *et al*., 1997; Potts, 1998; Whitfield *et al*., 2008), which diminishes hatching success and breeding success there. When only successful (non-persecuted) nests are compared between populations (Table 5.10), Ireland has the lowest breeding productivity of all. In fact, when Irish breeding attempts are successful, they are likely to fledge at least 0.5 chicks less than in Britain. The breeding performance of Irish Hen Harriers is also poor compared to figures for Continental Europe. In France, Millon *et al.* (2002) reported 3.41 chicks fledged per successful attempt. In Spain, García and Arroyo (2001) reported 1.88-3.00 chicks produced per all attempts. In Holland, where the population is in decline (P. de Boer, pers. comm.), a more recent (2004-2008) productivity of 1.39 per all attempts has been recorded (Klaassen *et al*., 2008), whereas Schipper (1978) had previously recorded a mean of 2.52 chicks fledged per attempt. In Norway, an overall productivity of 2.06 chicks per attempt was reported by Barth (1964), proving that Hen Harriers at the extreme of their distribution can realise a high breeding productivity. In North America, Hamerstrom (1969) reported 2.14 chicks fledged per all occupied sites, while Simmons *et al.* (1986a) found a mean productivity per successful pair of 3.38. Northern Ireland was the only other study population which fledged less than a mean of 3.00 chicks per successful attempt. Ireland as a whole (combining this current study with that of Scott and Clarke, 2007 and Ruddock *et al*., 2008) can be said to have a productivity of just 2.57 chicks per successful attempt (1.62 chicks per attempt overall). Lower fecundity in Ireland may reflect the fact that Ireland lies at the edge of the Hen Harrier's range of distribution. The edge of a species range is often the least suitable and least productive part of the species' range (Brown, 1984; Jump and Woodward, 2003; Zaidan *et al*., 2003). However, the obviously lower productivity of Irish Hen Harriers compared to nearby populations in Britain, re-enforces the assertion that the Irish landscape is suboptimal. Hen Harrier habitat loss and degradation has been regularly referred to in literature on Irish Hen Harriers (Jones, 1981; O'Flynn, 1983; Scott, 2000; O'Donoghue, 2004) and poor fecundity may well be a manifestation of this. Such impacts have greatest effect at the edge of a species range (Brown, 1984; Jump and Woodward, 2003; Zaidan *et al*., 2003).

Britain was found by Anderson *et al.* (2009) to be among the least climatically suitable for Hen Harrier across its European range, so it is likely that Ireland, at the Atlantic edge of the species distribution is also less than suitable in this respect. However, commentators should be dissuaded from attributing poor breeding performance to relatively poor weather during the two study years (Met Éireann, 2007c and 2008c). The early parts of the summers were dry, sunny and warm (Met Éireann, 2007a,b and 2008a,b), yet clutch size (a major determinant of breeding productivity) was still poor compared to international populations. Weather was unlikely to have been very different between and indeed within ranges which are all located in the south of Ireland, yet breeding success and productivity varied substantially, with a national record of six fledglings produced at one nest. O'Flynn (1979) reported Hen Harrier numbers to increase in the 1960s, despite some very cold and wet months of April and May, while the most recent breeding season of 2010 showed poor breeding fecundity across Ireland despite favourable weather conditions (B. Dunlop; P. Troake; S. Jones; F. McMahon; M. Ruddock and R. Wilson-Parr, pers. comm.; pers. obs.).

Table 5.10. Most recent breeding success (%) and productivity figures (fledglings per attempt and fledglings per successful attempt) in Britain and Ireland.

Country	**Success Rate (%)**	**Fledglings per attempt**	**Fledglings per successful attempt**
England[1]	56.7	1.57	**3.23**
Wales[2]	44.0	1.42	**3.21**
Scotland[3]	53.3	1.49	**3.00**
Northern Ireland[4]	61.4	1.63	**2.65**
Republic of Ireland[5]	65.4	1.62	**2.47**

[1]Natural England (2008); [2]Whitfield *et al.* (2008); [3]Fielding *et al.* (2009); [4]combined raw data of Scott and Clarke (2007) and Ruddock *et al.* (2008); [5]This study.

5.5 SUMMARY

The breeding ecology of Hen Harriers in Kerry, West Clare, Ballyhouras and Slieve Aughties was examined, by means of observing 104 nests to their completion, in the breeding seasons of 2007 and 2008. Laying, hatching and fledging dates were investigated, as were hatching and fledging success. Causes of failure were investigated, and for the first time the impact of predation on Irish Hen Harriers was determined, and found to be of importance. The breeding success and productivities of individual nests and breeding areas were compared and contrasted. Kerry and West Clare had good reproductive rates, while the Ballyhouras produced a relatively low number of fledglings per successful attempt and the Slieve Aughties had a particularly low success rate. Breeding success was most highly influenced by breeding area, distance to nearest track and distance to nearest stream. Breeding productivity was most highly influenced by early season prey delivery rate and whether or not the nest was in a glen. Overall, Ireland was found to have one of the lowest breeding productivities in Europe (based on fledged brood size), though the absence of sustained persecution and failures relating to crop harvesting (as is the case elsewhere in Europe) mean that nest success rate is relatively good.

Chapter Six

Non-breeding Ecology

Although the problems of studying breeding raptors are great, the problems of studying wintering raptors are even greater.

Keith Bildstein. 1987.

This chapter documents aspects of Hen Harrier ecology throughout the non-breeding season, which accounts for the majority of the Hen Harrier's year and is crucial in terms of survival, yet has received relatively little attention in terms of research or conservation. In particular, this study aims to establish where Hen Harriers in Ireland spend the non-breeding season, the types of roosts they use, the number of birds frequenting these roosts, duration of stay at roosts and any potential threats to Hen Harriers or their habitats during this important period.

6.1 INTRODUCTION

Given that the Hen Harrier (*Circus cyaneus*) breeding season in Ireland mainly concerns the five months from April to August, the non-breeding season accounts for the majority of the year. The non-breeding ecology of harrier species has received attention in a wide range of studies (e.g. Watson and Dickson, 1972; Schipper *et al*., 1975; Watson, 1977; Bildstein, 1979a and 1987; Marquiss, 1980; Picozzi and Cuthbert, 1982; Arroyo *et al*., 1995; McCurdy *et al*., 1995; Cormier and Baillon, 1991; Clarke and Watson, 1990 and 1997; Clarke and Prakash, 1997; Clarke *et al*., 1993, 1997 and 1998; Ganesh and Kanniah, 2000; Dobson *et al*., 2009). Such studies have identified the non-breeding season as being of integral importance to the population dynamics of the species and have provided insight into behaviour otherwise not seen during the breeding season. The Hen Harrier Winter Roost Survey in Britain (coordinated by The Hawk and Owl Trust and British Trust for Ornithology) for example, is a long-term (1983-present) non-breeding survey that has documented trends in numbers, has added greatly to the knowledge of non-breeding behaviour, and was integral in devising non-breeding Special Protection Areas for Hen Harriers in Britain (Dobson, 2009). However, the non-breeding aspect of the Hen Harrier's ecology has received relatively little attention in Ireland, where research and conservation efforts have been focussed almost exclusively on the breeding season (but see Clarke and Watson, 1990; Scott and McHaffie, 2001; O'Donoghue, 2004). Research or conservation efforts fall short of providing a comprehensive understanding or safeguarding, if elements outside of the breeding season are not studied, or winter sites are not protected. Establishing a knowledge-base on the non-breeding season is essential to creating a complete and cohesive picture of Hen Harrier population dynamics in Ireland. The current study investigates the distribution of Hen Harriers in Ireland during the non-breeding season, their roosting sites, habitats, roost attendance patterns, composition of roosts in terms of ringtails and grey males, and non-breeding behaviour. Identifying roost sites is the first step in direct conservation of the species during the non-breeding season, while addressing various other aspects of non-breeding ecology will facilitate a more thorough understanding of the full ecology of Hen Harriers in Ireland.

6.2 METHODS

This study was undertaken throughout the Republic of Ireland between 2005 and 2008 and comprises the first three seasons of the Irish Hen Harrier Winter Survey, which is ongoing. Within Ireland, three separate and distinct regions were identified (Figure 6.1), based on climatic, geographical and geophysical criteria, using values from Collins and Cummins (1986), Environmental Protection Agency (1996) and Met Éireann (2010). The Western Seaboard is shaped by the Atlantic Ocean and is typified by rugged terrain, extensive pastoral/livestock agriculture, blanket bog and high rainfall. The Shannon/Midlands region is shaped by the longest river in Ireland; The Shannon. Its floodplains and associated wetlands provide ample foraging and roosting habitat for Hen Harriers. The South and East region has the most clement climate, with above average temperatures and below average rainfall. This, coupled with free draining soils, means this region has the majority of tillage land in Ireland (Lafferty *et al*., 1999).

Two separate but complementary approaches were used as part of this study; (1) dedicated and detailed roost surveys (Section 6.2.1) and (2) collection of roving records/casual sightings (Section 6.2.2).

6.2.1 Dedicated Roost Surveys

As part of an extensive study, a total of 475 dedicated watches were conducted by a team of volunteer surveyors at 143 (occupied and unoccupied) sites over three winters from 2005/6 to 2007/8. In the interests of co-ordination, standardisation and repeatability, surveys were undertaken on the first day of each of the six months from October to March, or as close as possible to these dates. At a subset of 15 roost sites, surveys were also undertaken during July, August, September and April, to gain more information on roost attendance at the earliest and latest stages of the non-breeding season. At the outset of each winter's survey, observers were provided with site-specific sunrise and sunset times (Morrissey, 2005). Roost watches began at least thirty minutes before sunrise or sunset. Evening watches continued until it was too dark to observe harrier activity, while morning watches were conducted until at least thirty minutes after sunrise. The average roost watch lasted 1.02 ± 0.1hrs. Observations were carried out only in weather conditions that facilitated uncompromised views. Data from observations were recorded on standardised sheets, logging information such as the number of birds at roost, time of arrival, intra-specific and inter-specific interactions (Appendix IV).

Sixteen of the roosts observed were already identified by O'Donoghue (2004). Local knowledge or interpretation of up-to-date colour ortho-photographs was used to identify new sites. Habitats which were previously recorded to host roosting harriers (e.g. heather/bog, reedbeds and bracken) and habitats which were not previously recorded to host roosting harriers (e.g. rank grassland, forests and tillage) were targeted in such investigations. Nine regular communal roosts were observed every month for the full duration of the three seasons, from October 2005 to March 2008. As these roosts provided complete datasets, they are considered to have been intensively studied, and to provide the most comparable datasets in terms of attendance at non-breeding roosts across months, years and regions.

A standardised sheet (Appendix V), completed by the roost observer or survey co-ordinator, was used to record roost details, including location, habitat and apparent threats, as well as other details of use for future surveys or investigations (including access details, vantage points and surrounding habitats). Flora within 100m of where harriers settled was recorded to provide more detail as regards the vegetative features within the roost used by harriers. The size of the 'habitat complex', as a measurement of the extent of habitat similar and contiguous to the area used for roosting, was measured using ortho-photographs in ArcView GIS 3.2 (Environmental Systems Research Institute, 2004).

6.2.2 Casual Sightings

Casual sightings (roving records) can be used to census bird populations, including Hen Harriers (Hamerstrom, 1969; British Trust for Ornithology, 2010). For the winter of 2007/8, a public awareness campaign for the Irish Hen Harrier Winter Survey was mounted locally and nationally through various media, including press, radio, internet and public presentations. All sightings of Hen Harriers were sought and details including harrier type (grey/brown), date of sighting and location were recorded on a standardised sheet (Appendix VI). Further information such as time and direction of travel were also recorded and proved useful in determining the possibility of roosting in a given area (e.g. a harrier seen as darkness fell would indicate roosting nearby). Upon receiving a report, follow-up contact was made to thank the observer and to validate the sightings. Validation was primarily based on bird identification, eliminating possible confusion with other birds and defining other details of the sighting. Casual sightings were chance sightings (not actively pursued by the observer) and thus gave a relatively unbiased view of the distribution of Hen Harriers throughout Ireland.

6.2.3 Distinguishing Age and Sex of Birds

Hen Harriers were distinguished as either 'grey males' (2nd winter male and older) or 'ringtails' (females or juveniles of either sex), as complete accuracy in distinguishing juveniles from females cannot be guaranteed by all observers, particularly at times of fading light during roost watches (Watson, 1977; Picozzi and Cuthbert, 1982; Clarke and Watson, 1997; Clarke *et al.*, 1997).

6.2.4 Data Grouping and Analysis

All roost locations were recorded, plotted on a map and assigned to one of the three regions identified on Figure 6.1. Habitat details were categorised according to habitat and vegetation types. Threats were classified according to type. Minimum, maximum and mean values were calculated for roost details such as elevation (m ASL), distance to water bodies (km) and area (ha). Composition and patterns of attendance at roosts were examined primarily for the nine intensive study sites. Casual sightings were grouped and analysed by month, location, elevation and harrier type. A distribution map of Hen Harriers in Ireland during the non-breeding season was generated from casual sightings recorded on a 40km^2 basis. The ratio of adult males and ringtails in each of the three regions was compared to identify any geographical patterns in distribution. Both analysis of variance (ANOVA) and non-parametric Mann-Whitney U-tests and Kruskal-Wallis tests were used where appropriate, using Minitab 15 (Minitab Inc., 2007).

6.3 RESULTS

6.3.1 Description of Non-breeding Roosts

6.3.1.1 Distribution of Non-breeding Roosts

Of the 143 sites surveyed, 52 (36.4%) were found to host roosting Hen Harriers (Figure 6.1). The majority of these (*n*=30) were found along the Western Seaboard, which accounted for 58% of all roosts, while the South and East region held 27% (*n*=14) and the Shannon/Midlands region held 15% of roosts (*n*=8).

6.3.1.2 Roost Types

Six different types of Hen Harrier non-breeding roost were recorded (Table 6.1). Regular communal roosts held more than one Hen Harrier (on the same night) on more than 50% of watches (where at least four watches were carried out). Irregular communal roosts held more than one Hen Harrier (on the same night) on less than 50% of watches or in some years only. Regular solitary roosts were single-bird roosts, in which the bird was present on more than 50% of watches. Irregular solitary roosts were solitary roosts where harriers roosted on less than 50% of occasions or in some years only. Once-off roosts were roosts at which roosting was observed just once out of multiple watches. Disused roosts were those found to hold roosting harriers in the winter of 2005/6 but not thereafter.

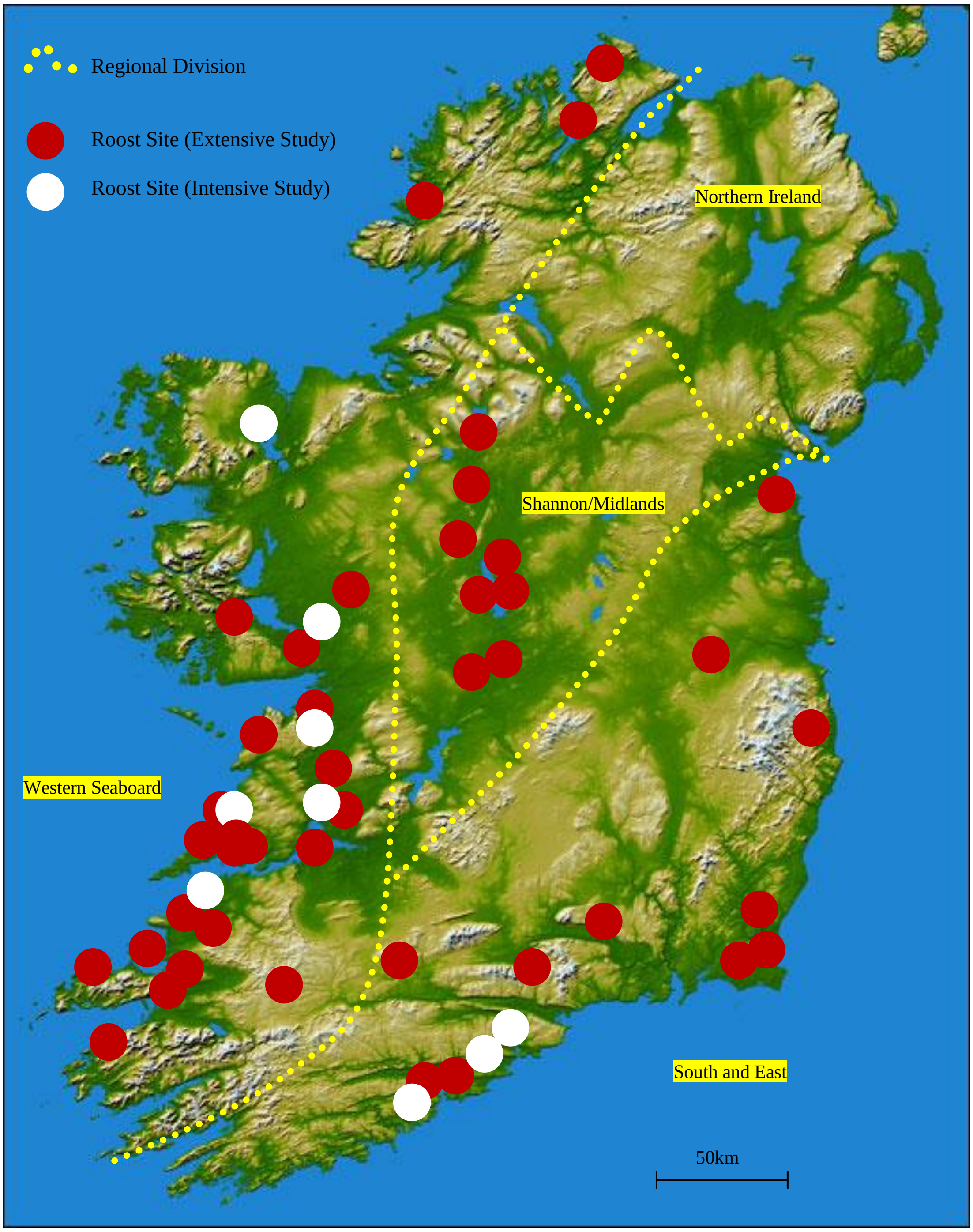

Figure 6.1. Distribution of Hen Harrier non-breeding roost sites in Republic of Ireland with regional divisions (Northern Ireland not surveyed for roosts).

6.3.1.3 Roost Site Characteristics

Roosts were found in reedbed (mainly *Phragmites australis*), heather/bog (mainly *Erica* spp. or *Calluna* spp. with *Molinia caerulea, Juncus* sp. and scrub such as *Salix* spp.), rank grassland (mainly overgrown Poaceae grasses and *Juncus* sp.), fen, Bracken (*Pteridium* spp.), Gorse (*Ulex* spp.) and salt marsh (Figure 6.2). Such sites were generally remnants of habitat, which had not been altered by man and could be classed as undisturbed. The type of habitat used differed across the three regions (Kruskal-Wallis H=6.74, *df*=2, *P*=0.03), with heather/bog being the primary roosting habitat along the Western Seaboard, and reedbeds being the most popular roost type in the Shannon/Midlands and South and East regions. Figure 6.3 summarises in more detail, the habitat composition within 100m radius of roost positions. Most roosts were situated in lowland areas (<100m ASL), with 53.8% occurring in the first 30m ASL. However, six winter roosts were found at elevations over 100m ASL; the highest occurring at 238m ASL. Four of these roost sites were also confirmed summer breeding sites. A further non-breeding roost was found at a lowland breeding site (<100m ASL). Roosts were commonly associated with water bodies such as lakes and coastal locations, but proximity to such landscape features was not a pre-requisite for roost sites (Table 6.2).

6.3.1.4 Threats and Protection Status

A total of 31 of the 52 roosts are part of a protected or proposed protected area, whether Natural Heritage Area, Special Area of Conservation, Special Protection Area, wildlife sanctuary or similar. However, 48% of all winter roosts enjoy no statutory protection and over 96% of roosts have no specific conservation measures for Hen Harriers. Virtually none of the hinterland surrounding roosts, which the harriers would rely on for foraging, is protected. Every roost was identified to have at least one of the following associated threats and many sites faced multiple threats:

- Disturbance through human activity (*n*=38);
- Persecution (*n*=25);
- Commercial development of roosting grounds (*n*=32);
- Afforestation (*n*=16);
- Drainage (*n*=16);
- Flooding (*n*=29);

- Pollution/dumping (*n*=25);
- Reed-cutting (*n*=18);
- Burning (*n*=33);
- Intensification/expansion of certain existing activities (*n*=33);
- Increase in predator populations (*n*=44);
- Increase in corvid populations (*n*=44);
- Invasion of alien species/excessive growth of scrub (*n*=35);
- Changes in the hinterland negatively affecting prey availability (*n*=22).

6.3.2 Attendance of Hen Harriers at Non-breeding Roosts

6.3.2.1 Composition of Roosts in terms of Harrier Type and Patterns of Attendance

Taking the maximum number of birds counted at each of the 52 roosts watched between 2005/6 and 2007/8, a total of 165 Hen Harriers were counted at Irish roosts, with a mean of 3.17 ± 0.36 birds per roost. Of these harriers, 38.2% were grey males (there were significantly more ringtails; χ^2=4.21, *df*=1, *P*=0.040). However, the ratio of ringtails to grey males varied across geographical regions. Grey males were found to constitute almost half (46.2%) of birds at roosts along the Western Seaboard, while ringtails dominated roosts in the South and East of the country (85.0%). The proportion of grey males in the Western Seaboard was significantly higher than in the South and East (Mann-Whitney W=762.5, *P*=0.024), while the ratio of grey males to ringtails in Shannon/Midlands roosts (comprising 38.1% adult males) did not differ from either the Western Seaboard (Mann-Whitney W=131.0, *P*=0.371) or South and East (Mann-Whitney W=103, *P*=0.466).

The number of harriers attending roosts did not differ significantly between years ($F_{2,17}$=1.95, *P*=0.176). Across all years, Hen Harriers occupied roosts from October to March (Figures 6.4 and 6.5). Numbers peaked in November and February, while the intervening months of December and January saw reduced numbers and by March most birds had left their roosts. Nevertheless, the maximum count of Hen Harriers at any one roost was in December, when ten birds were counted at a site in North Kerry. Significantly less harriers were counted at roosts in March than in November (Mann-Whitney W=909.5, *P*=0.003) and February (Mann-Whitney W=920.5, *P*=0.002). When grouped into bimonthly stages (Figure 6.6) there was a gradual decline in roosting numbers, particularly of ringtails, while the number of grey males remained relatively stable. There was no significant difference in the number of grey males or ringtails between the bimonthly periods of early (Oct-Nov), mid (Dec-Jan) and late (Feb-Mar) winter. The ratio of ringtails to grey males across all roosts (Figure 6.7) varied between 2 and 4.3 and was closest in December and February. Watches conducted at non-breeding roosts outside of the October-March period showed that Hen Harriers were present at roosts from July to April in 33.3% of cases (*n*=5). As five of the roost sites were also breeding sites, these held Hen Harriers throughout the entire year.

6.3.2.2 Behaviour at Non-breeding Roosts

Hen Harriers were seen to interact with each other at roosts, but also with nine types of other birds; details of which are provided in Tables 6.3 and 6.4 respectively. A total of 18 species of wader, ten bird of prey species, ten duck species, six species of geese, six corvid species, three swan species and multiple species of passerine were recorded at various winter roosts over the three years of the study. Birds of prey observed either hunting or roosting at the sites included Marsh Harrier (*Circus aeruginosus*), Short-eared Owl (*Asio flammeus*), Long-eared Owl (*Asio otus*), Barn Owl (*Tyto alba*), Common Buzzard (*Buteo buteo*), Sparrowhawk (*Accipiter nisus*), Kestrel (*Falco tinnunculus*), Peregrine Falcon (*Falco peregrinus*), Merlin (*Falco columbarius*) and White-tailed Eagle (*Haliaeetus albicilla*).

Table 6.1. Types of non-breeding roost recorded between 2005/6 and 2007/8.

	Regular Communal	**Irregular Communal**	**Regular Solitary**	**Irregular Solitary**	**Once-off**	**Disused**
Number	31	13	1	1	4	2
%	59.6	25.0	1.9	1.9	7.7	3.8

Table 6.2. Distance to water bodies (km), elevation (m ASL) and size (ha) of Irish Hen Harrier non-breeding roosts. Size refers to the area of habitat similar and contiguous to that used by harriers and does not reflect the size of the actual area used for roosting (as harriers may have used different parts of the entire area on different nights).

	Min	**Max**	**Mean (± s.e.)**
Elevation (m asl)	0	238	44.3 (± 8.3)
Distance from Coast (km)	0	81	17.4 (± 3.4)
Distance from Water Body*	0	26	3.4 (± 0.89)
Size of 'Habitat Complex' (ha)	1	2000	399.8 (± 76.3)

* of area >1ha

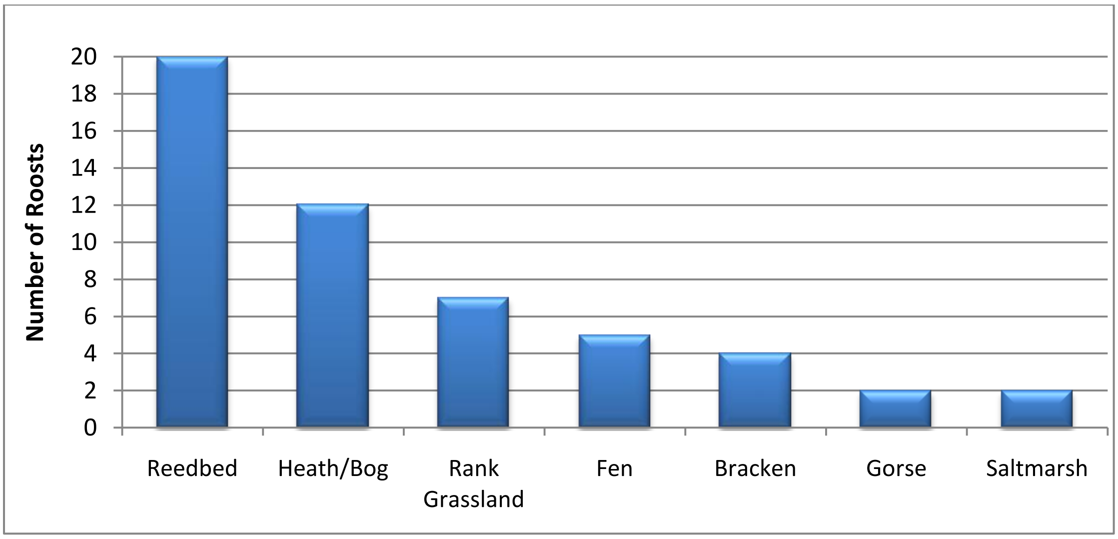

Figure 6.2. Primary habitat types of Irish Hen Harrier non-breeding roosts (*n*=52).

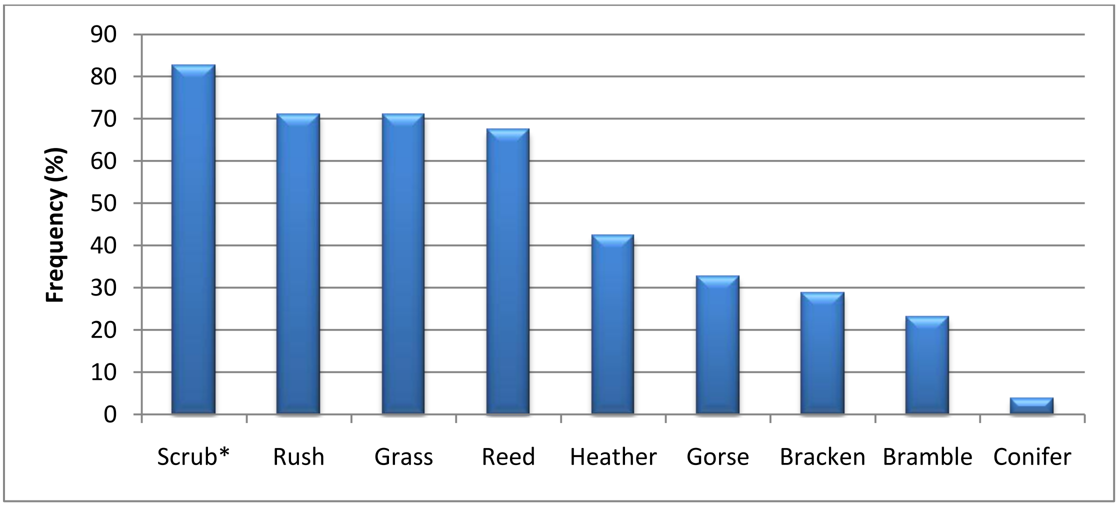

Figure 6.3. Vegetative composition of 52 Irish Hen Harrier non-breeding roosts (in terms of frequency of occurrence of different vegetation types within 100m of where harriers roosted). *Scrub includes Willow (*Salix* spp.), Alder (*Alnus* spp.) and Birch (*Betula* spp.)

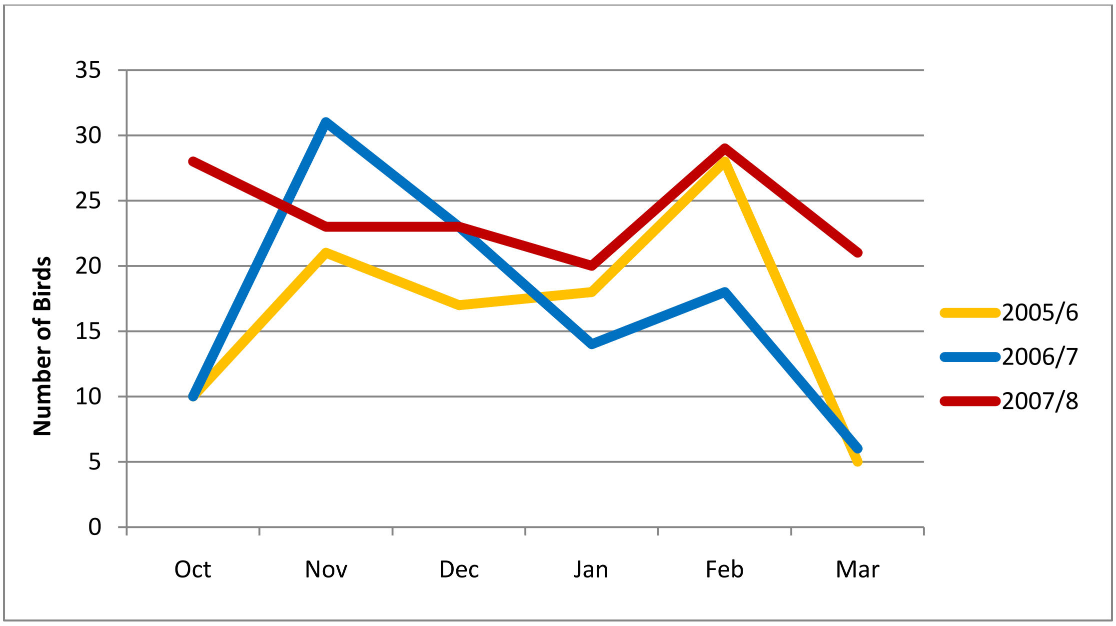

Figure 6.4. Trend of attendance at nine intensively monitored non-breeding roosts (2005/6 - 2007/8).

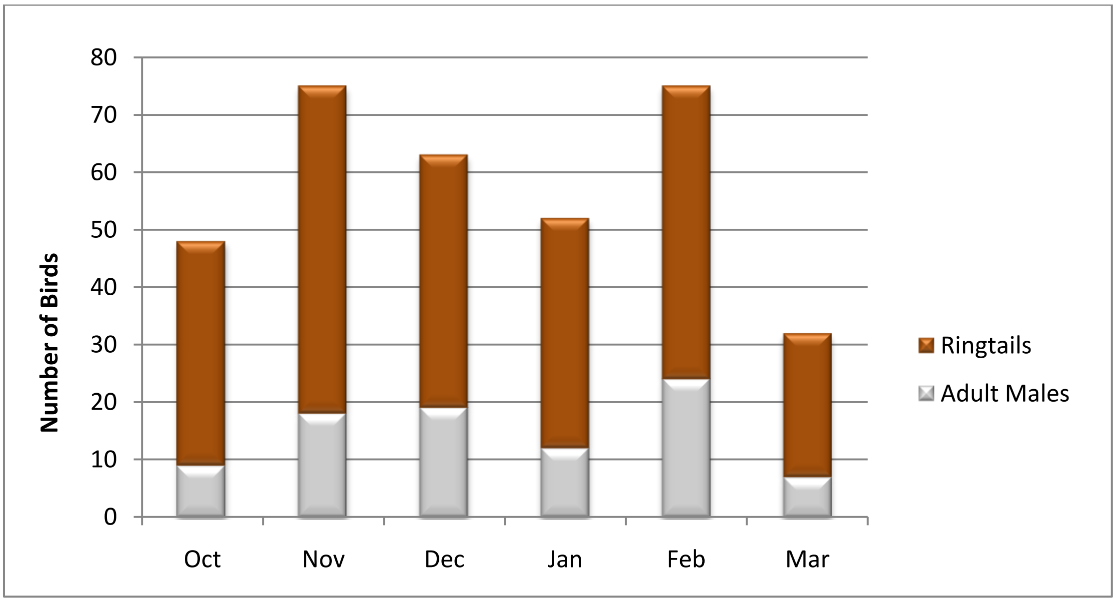

Figure 6.5. Monthly attendance and constitution of harriers at nine intensively monitored non-breeding roosts (2005/6 - 2007/8).

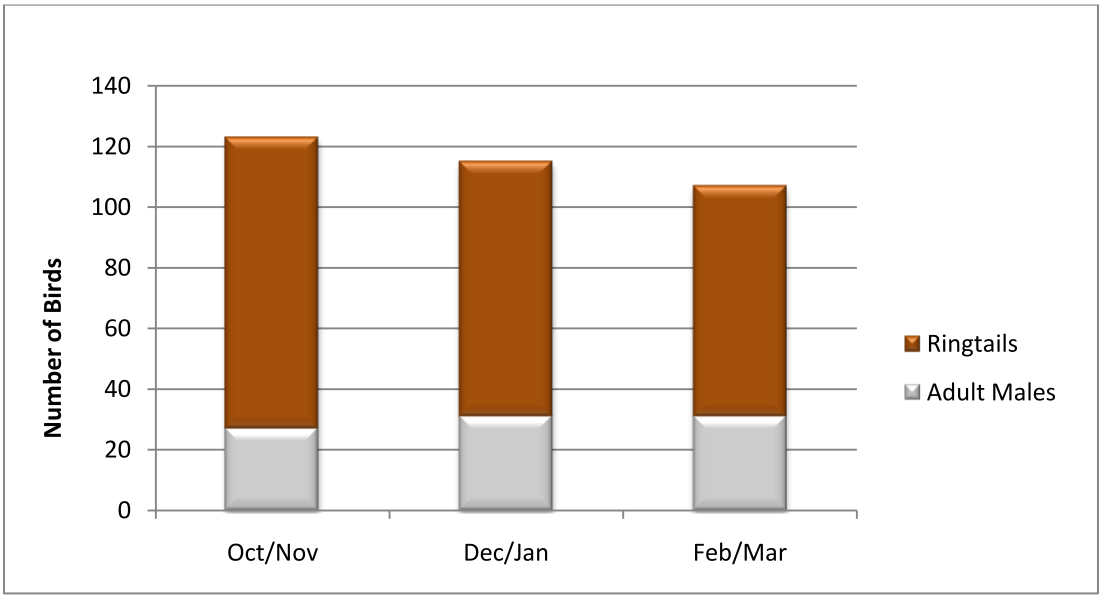

Figure 6.6. Bimonthly attendance of Hen Harriers at nine intensively monitored non-breeding roosts (2005/6 - 2007/8).

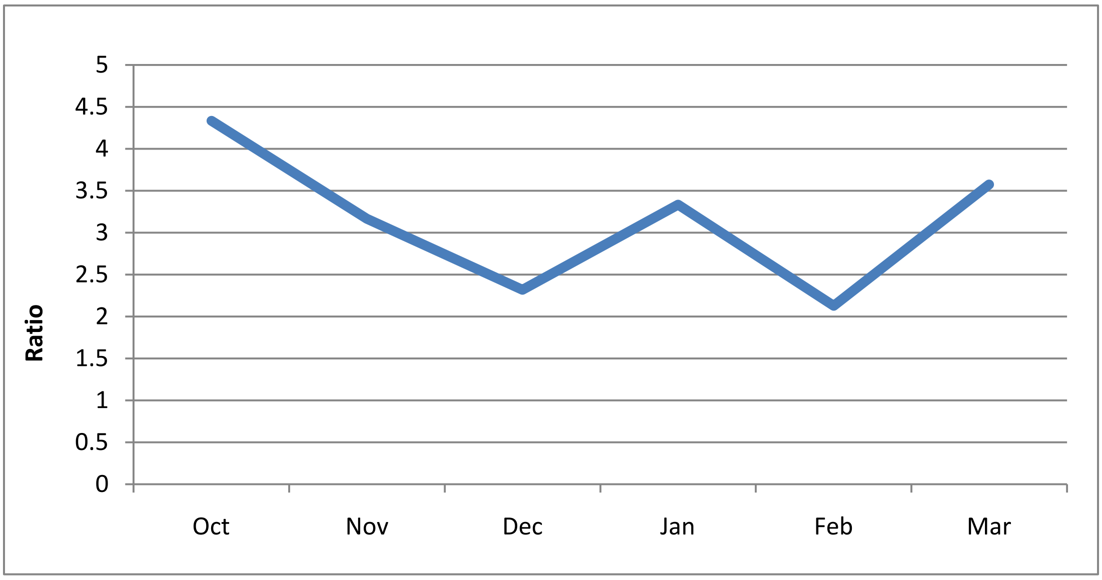

Figure 6.7. Ratio of ringtails to adult males at nine intensively monitored non-breeding roosts (2005/6 - 2007/8).

Table 6.3. Interactions between Hen Harriers at non-breeding roosts 2005/6 – 2007/8.

	Disturbing	**Chasing**	**Rising Together**	**Roosting within 1m**	**Arriving Together**	**Departing Together**	**Other***
Number of interactions	32	2	18	20	23	26	3
Percentage of all interactions	25.8	1.6	14.5	16.1	18.6	21.0	2.4

*included sky dancing, collective defence and fighting.

Table 6.4. Inter-specific interactions noted at Hen Harrier non-breeding roosts between 2005/6-2007/8.

	Co-roosting	**Mobbed *C. cyaneus***	**Mobbed by *C. cyaneus***	**Hunted by *C. cyaneus***	**Collaborative hunting**
Corvidae	-	31	1	-	-
Falconidae	15	5	4	-	4
Accipitridae	4	3	4	-	1
Strigidae	7	-	-	-	-
Phasianidae	16	-	-	1	-
Ardeidae	-	-	1	-	-
Laridae	24	-	-	-	-
Anatidae	27	-	-	3	-
Passeriformes	155	34	-	41	-

6.3.2.3 Affinity to Roost Positions and Arrival/Departures

Hen Harriers were noted to normally use a core part of a given habitat complex, but were also noted to switch on occasion to locations which were removed from the core area. Numerous roosting platforms were found at all roosts examined (when birds had vacated the roosts). Multiple pellets were collected from single roost forms (max 15), indicating that the harriers used the same resting points within the roost on different nights. Times of arrival and departure to and from roosts are summarised in Figure 6.8. Hen Harriers were found roosting from as early as 90 minutes before sunset and on at least three occasions, individual birds were observed in roost locations in the middle of the day. The peak time for harriers returning to roost occurred three to four minutes before sunset, but continued until as late as 40 minutes after sunset, in virtual darkness. In the morning, harriers generally rose and departed prior to sunrise, from as early as 44 minutes before sunrise. Some did not depart their roost until as late as seven minutes before sunrise. Indeed others may not have left in the morning at all (cf. casual sightings at roosts during daytime).

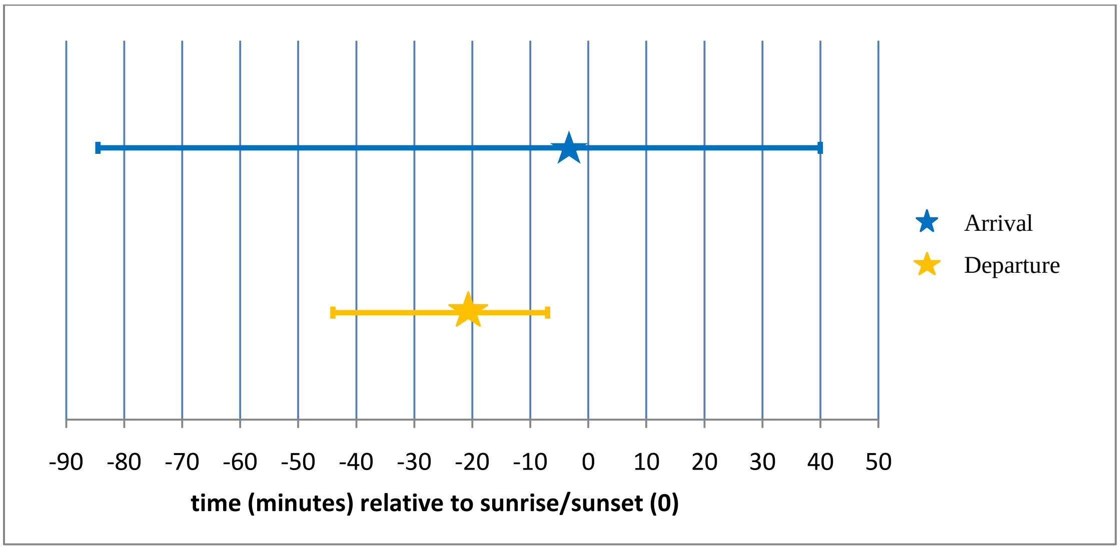

Figure 6.8. Times of arrival (blue) to and departure (yellow) from non-breeding roosts. Stars denote mean arrival/departure times; bars denote range of arrival/departure times (from earliest to latest).

6.3.3 Casual Sightings

Between 01 September 2007 and 31 March 2008, a total of 444 casual sightings were reported by 156 observers (Table 6.5). Out of the 213 days of this time period, Hen Harriers were seen on 195 days (91.5%). The largest number of Hen Harriers sighted on one day over the recording period was eight, in an upland area in March, as Hen Harriers began to regroup for the impending breeding season. A mean of 2.08 (±0.12) sightings of Hen Harriers were recorded each day during the period 01 September 2007 to 31 March 2008. A significant difference was noted in the number of sightings between months (Kruskal-Wallis $H=35.62$, $df=6$, $P<0.001$), with *post-hoc* Mann-Whitney tests showing the significance to lie with January which had the lowest number of sightings ($P<0.001$). November was the peak month in terms of casual sightings (Figure 6.9). When casual sightings were corrected to account for a slight difference in daylight hours between the months, the pattern in hourly sightings rate did not noticeably differ from the daily sightings rate.

6.3.3.1 Ratio of Ringtails to Grey Males in Casual Sightings

Ringtails (including adult females and all juveniles of either sex) accounted for 61.9% of casual sightings, giving an overall ratio of 1.63 ringtails to 1 grey male. This ratio ranged between its highest at the beginning of the non-breeding season (4.5 ringtails : 1 grey male in September) and its lowest towards the end of the season, when ringtails were outnumbered by grey males (0.82:1). By the end of the winter (March), almost as many ringtails as grey males were recorded, with a ratio of 0.97:1. Figure 6.10 summarises this pattern and how it varied as the winter progressed. When divided into three different geographical regions (Western Seaboard, Shannon/Midlands and the South and East), a significant contrast in the proportion of sightings contributed by grey males was observed. Along the Western Seaboard and in the Shannon/Midlands regions, grey males contributed almost half of the casual sightings (45.0% and 44.8% respectively), whereas in the South and East, where there was an abundance of juvenile harriers, grey males accounted for just 12.7% of casual sightings. Significantly more ringtails were seen in the South and East than in the Western Seaboard (Mann-Whitney $W=14869.5$, $P<0.001$) and the Shannon/Midlands (Mann-Whitney $W=7848.0$, $P<0.001$).

6.3.3.2 Elevation Data for Casual Sightings

Almost 72% of all casual sightings were in lowland locations, which was significantly higher than might have been expected by chance (χ^2=42.67, *df*=1, *P*<0.001). However, birds were still recorded in the uplands, with up to 28.4% of sightings at altitudes greater than 100m ASL (Table 6.5; Figure 6.11).

Casual sightings showed a marked separation of harrier type (ringtail/grey male) in relation to elevation. Grey males accounted for 69.0% of all upland sightings, but just 25.8% of lowland sightings. In fact, over half (51.5%) of all grey male casual sightings during the non-breeding season were in upland locations. On the other hand, ringtails dominated lowland elevations, accounting for 74.2% of casual sightings below 100m ASL. Ringtails did not favour wintering on the uplands, with just 14.2% of all ringtail sightings during this period occurring in such locations. Figure 6.12 summarises the ratio of upland to lowland sightings for both males and ringtails. The ratio for males rose considerably in the month of March as they began to establish upland territories prior to the impending breeding season. At this point there were 2.3 times more grey males as ringtails reported on the uplands.

6.3.3.3 Paired Sightings

There were a number of occasions throughout the winter when ‘paired sightings’ were noted, i.e. two or more harriers in proximity or interacting with each other (away from roosts). Such incidents were recorded on 31 occasions between 01 September 2007 and 31 March 2008. Table 6.6 details these sightings. Of 27 casual sightings after 17 March, six were of paired harriers.

6.3.3.4 Relationship between Casual Sightings and Numbers at Roosts

November was a peak month for both casual sightings and numbers at roosts (Figure 6.13), while lower numbers were recorded during mid-winter (December and January). Both casual sightings and attendance at roosts increased during February. An increased ringtail to grey male ratio at (primarily lowland) roosts was recorded in March, linked with a sharp increase in the occurrence of males on the uplands in March (Figure 6.12).

Table 6.5. Details of non-breeding casual sightings recorded between 01 September 2007 and 31 March 2008.

Total Casual Sightings	444
Ringtail Sightings	275
Grey Male Sightings	169
Ratio Ringtails : Grey Males	1.63
Lowland Sightings (<100m ASL)	318
Upland Sightings (>100m ASL)	126
Ratio Lowland : Upland Sightings	2.52
Lowland Ringtail Sightings	236
Upland Ringtail Sightings	39
Lowland Grey Male Sightings	82
Upland Grey Male Sightings	87

Table 6.6. 'Paired' casual sightings records during the non-breeding season 2007/8.

Combination	**Number of Incidents**
1 Ringtail and 1 Ringtail	11
3 Ringtails	1
1 Ringtail and 1 Adult Male	12
1 Adult Male and 1 Adult Male	4
2 Adult Males and 1 Ringtail	2
2 Adult Males and 2 Ringtails	1
Overall 'paired' sightings	31

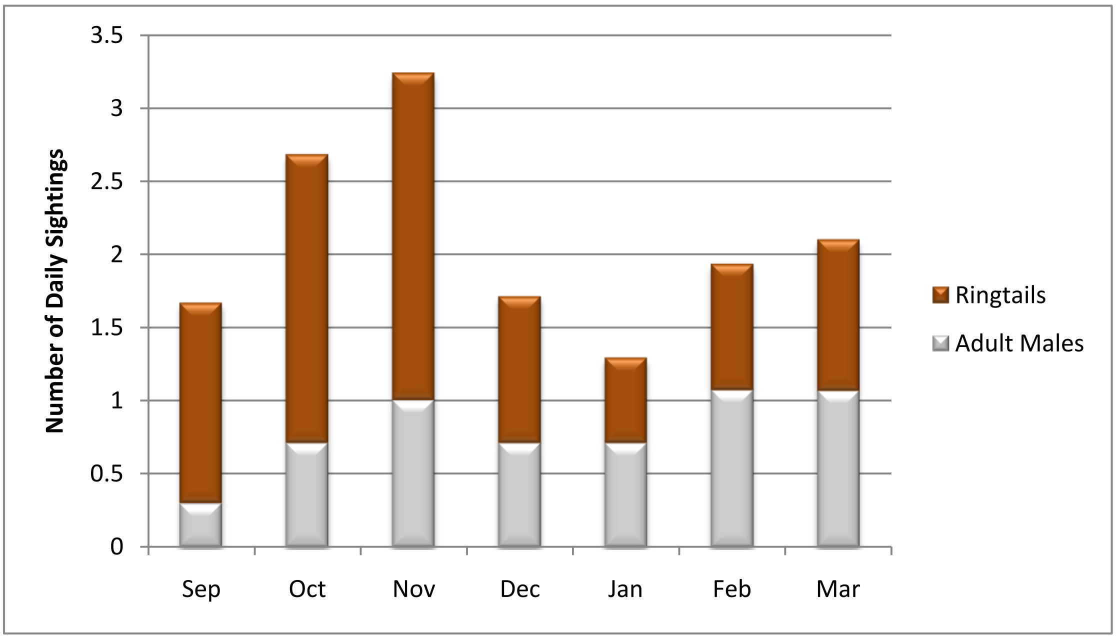

Figure 6.9. Pattern of casual sightings recorded throughout the winter of 2007/8.

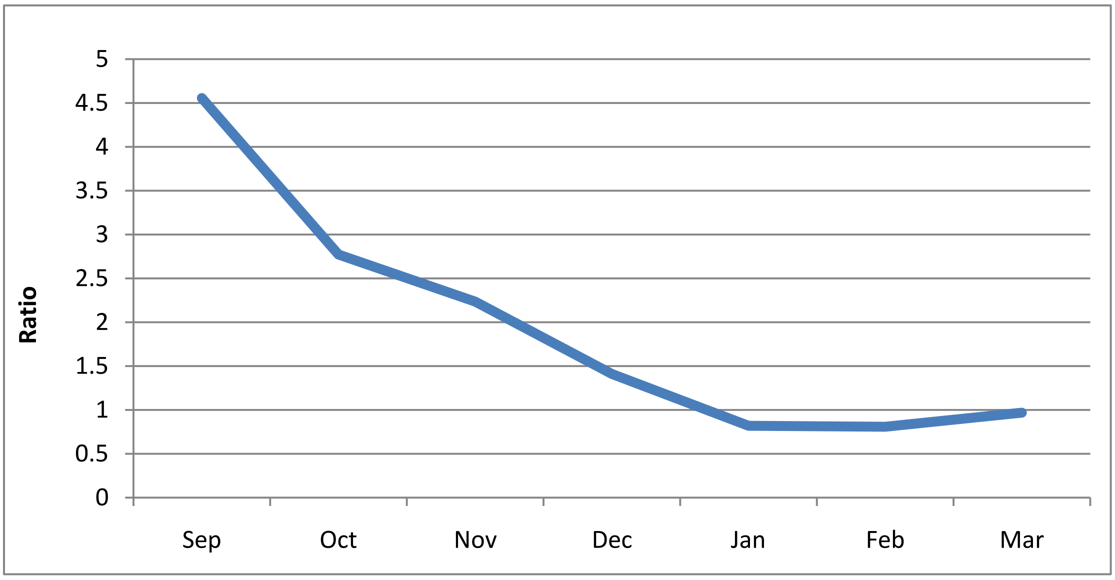

Figure 6.10. Monthly ratio of ringtail to grey male casual sightings during the winter of 2007/8

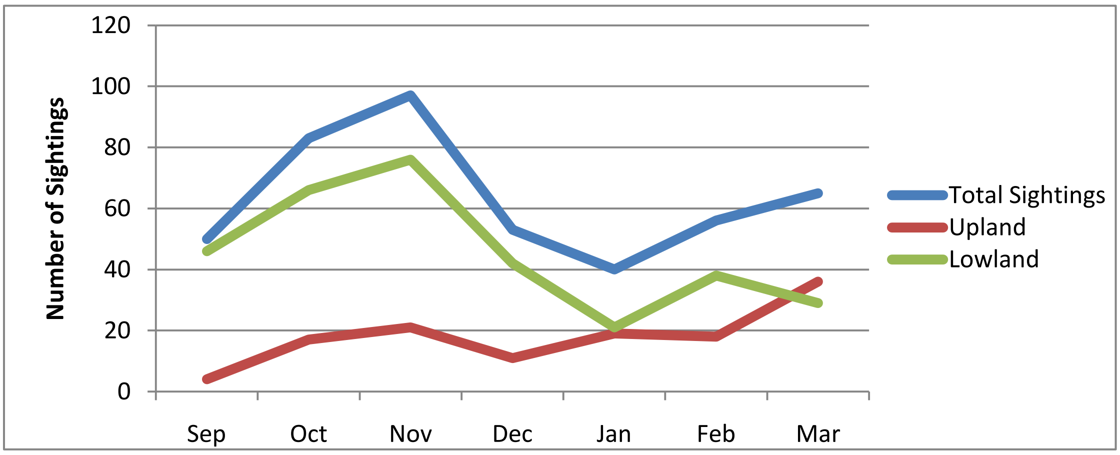

Figure 6.11. Monthly casual sightings of Hen Harriers recorded over the 2007/8 winter, according to upland and lowland elevations.

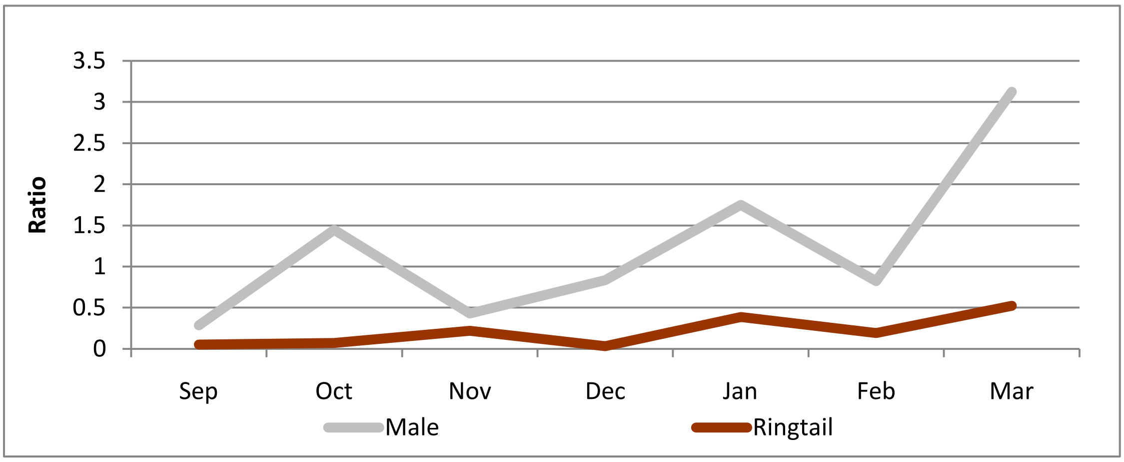

Figure 6.12. Ratio of upland to lowland ringtail and adult male sightings according to month.

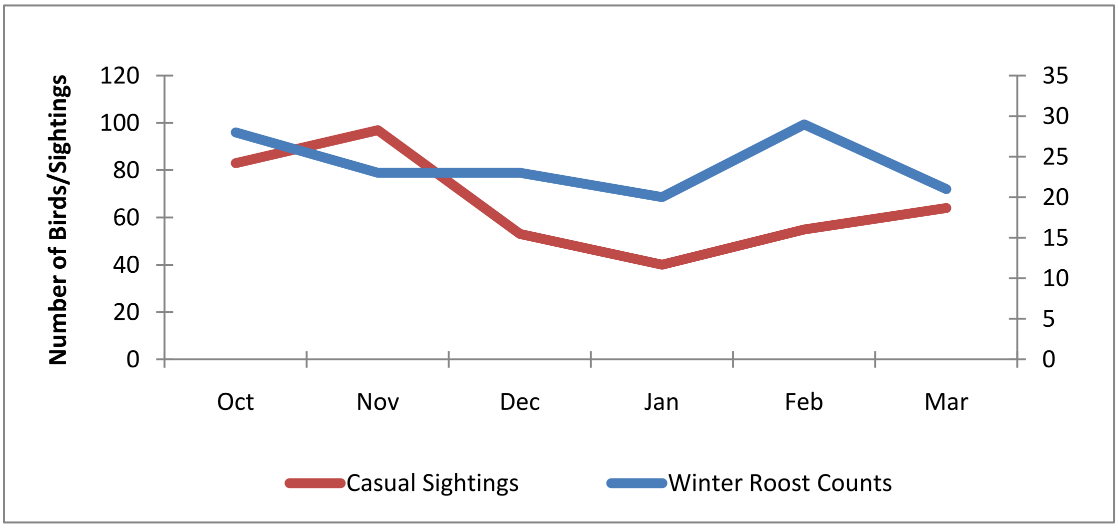

Figure 6.13. Casual sightings (left axis) compared with occupation at winter roosts (right axis).

6.3.4 Hen Harrier Non-breeding Distribution in Ireland

The distribution and frequency of casual sightings of Hen Harriers in Ireland was not uniform across all areas, with sightings regularly recorded in some areas and rarely in others. The distribution map of Hen Harriers in Ireland during the non-breeding season (Figure 6.14) depicts the frequency with which harriers were seen, ranging from rarely (<4 records per $40km^2$) to regularly (>10 records per $40km^2$). Areas where Hen Harriers were recorded with greatest frequency included Kerry, the mid-west, mid-River Shannon, south-east, and an area extending from Mayo to Inishowen in the north-west. Certain parts of Leinster in the east held few Hen Harriers during the non-breeding period. Hen Harriers were reported in 23 of the 26 counties in the Republic of Ireland. While this survey did not specifically involve Northern Ireland, sightings of Hen Harriers were received from four of the six counties there (Table 6.7).

Table 6.7. Provinces and Counties with Hen Harriers recorded during the non-breeding season between 2005/6 and 2007/8.

Munster (6 counties)	**Connaught (5 counties)**	**Leinster (12 counties)**	**Ulster (9 counties)**
Clare	Galway	Dublin	Antrim
Cork	Leitrim	Kildare	Derry
Kerry	Mayo	Kilkenny	Donegal
Limerick	Roscommon	Longford	Down
Tipperary	Sligo	Louth	Fermanagh
Waterford		Laois	Monaghan
		Offaly	
		Wexford	
		Wicklow	
		Westmeath	

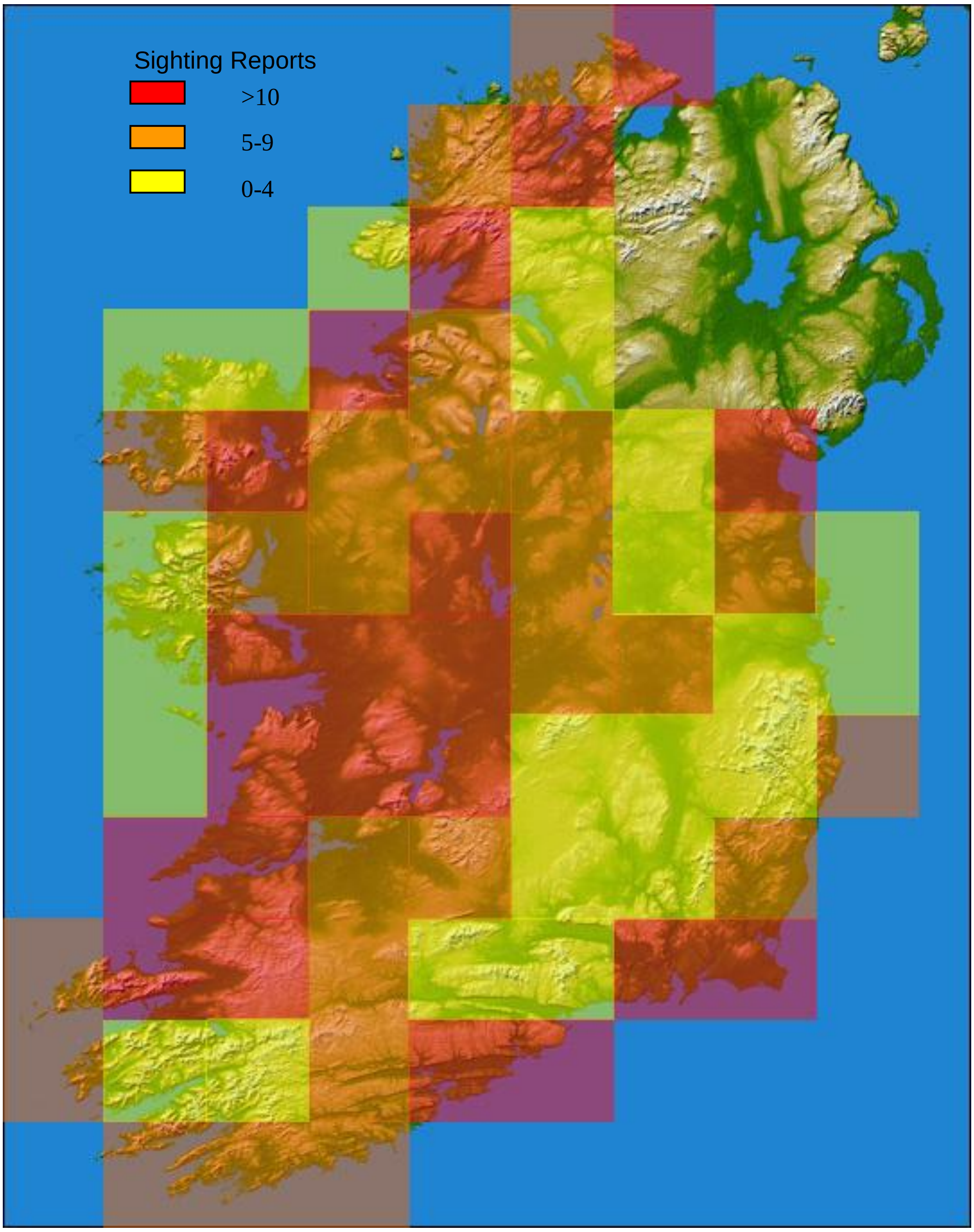

Figure 6.14. Distribution map of Hen Harriers in Ireland during the non-breeding season according to reported sightings per 40km^2 cell.

6.4 DISCUSSION

6.4.1 Non-breeding Roosts in Ireland

This study accounted for 52 roosts, and a maximum of 165 individual Hen Harriers at these roosts. The first brief study of Hen Harrier winter roosts in Ireland (Clarke and Watson, 1990) reported a total of twelve roost sites, with small numbers of harriers attending.

The majority of non-breeding roosts were found along the Western Seaboard, with a concentration in the south-west and mid-west. This was in line with the breeding distribution of the Hen Harrier in Ireland, with strongholds in Counties Kerry, Clare and South Galway (Barton *et al.*, 2006). However, there were many roosts found outside of the breeding range, so the non-breeding season accounts for a more widespread distribution. The Shannon/Midlands region may be seen as a commuting corridor for harriers moving north or south through Ireland, given the amount of casual sightings in this primarily non-breeding region, coupled with recorded movements of tagged birds from the breeding strongholds (Chapter 7, Movements and Survival). The River Shannon and associated reedbeds and bogs of the midlands offer migrating harriers opportunities for roosting and foraging in this region. Similarly, while the South and East region holds few pairs of breeding Hen Harriers, it is one of the most important areas for Hen Harriers during the non-breeding season. The drier, milder climate and abundance of productive tillage ground are likely to attract non-breeding harriers to this region. Arable land is a widely used foraging habitat during winter for Hen Harriers (Clarke, 1986; Clarke *et al.*, 1997; Ottens, 1999). Where tillage is retained as stubble over winter, it is one of the best sources of prey species (Schipper *et al.*, 1975; Wilson *et al.*, 1996; Moorcroft *et al.*, 2002; McMahon *et al.*, 2003). Indeed, much of the prey found in the diet of Hen Harriers in the South and East region was found to be associated with such habitats (Chapter 3, Diet).

6.4.1.1 Characteristics of Roost Sites

As per Clarke and Watson (1990), the single most popular roosting habitat type was reedbed (composed mainly of *Phragmites australis*). However, habitats around roosts were often mixed mosaics and it was not uncommon to have a combination of heather/bog, rank grassland and Bracken (*Pteridium* spp.) grouped together. While the prevalence of habitat types differed across regions, the general pattern observed was that Hen Harriers were using undisturbed sites with tall and dense ground vegetation, presumably for shelter and protection. This was much in line with roosts in Britain and Poland (Picozzi, 1980b; Picozzi and Cuthbert, 1982; Clarke and Watson, 1990; Kitowski and Wojtak, 1998). It also follows the choice of tall and dense vegetation for nesting in during the breeding season (Chapter 4, Nest Sites). Bracken (*Pteridium* spp.) and Gorse (*Ulex* spp.) are two habitats found to be used in Ireland, which were not reported by Clarke and Watson (1990). While Clarke and Watson (1990) found a small number of roosts in dunes and cereal crops, these habitats were not present in any roosts discovered in this study (though they were adjacent to a number of roosts). Despite a number of searches, no roosts were found in coniferous plantations. Even in areas where conifer plantations existed adjacent to roosts, harriers always chose an 'open' habitat. A similar observation was made by Clarke and Watson (1990), though the same authors report on some possible rare occasions of forest roosting. Scott (1994) had previously found the tree nesting Hen Harriers of Northern Ireland to apparently take to roosting in trees, as did Kropp and Münch (1979) in Germany.

The mean elevation of roosts in Ireland was 44.3 ± 8.3m ASL, which is lower than the mean breeding elevation of 209m ASL (Chapter 4, Nest Sites). The discovery of upland non-breeding roosts is significant, as upland roosting during this time of year is an aspect that has been largely overlooked or not even considered in Ireland. Upland winter roosts have also been found in Britain, with Clarke and Watson (1990) reporting one roost at 427m ASL (though the majority were 0-15m ASL). In addition to the four upland roosts found during the present study, a fifth roost was found at a breeding site at a lowland location. Therefore, certain sites can hold Hen Harriers throughout the entire year; an important consideration for potentially intrusive human operations in Hen Harrier areas.

6.4.1.2 Roost Occupation

Hen Harriers were regularly present at winter roosts from October to March (as per Clarke and Watson, 1990) and at a number of sites from July to April, or even throughout the entire year in the case of roosts which were also breeding sites. High counts of Hen Harriers attending communal roosts in Ireland in November and February broadly matched what Leonard (2004) found on the Isle of Man. November

marks a deepening of winter, so lower temperatures may force more harriers from the colder uplands to roosts in lowland areas. From November on, ringtail numbers at roosts declined and this may have been linked to higher mortality (or overseas migration) of first winter harriers as the winter progressed (Chapter 7, Movements and Survival). An influx of adult males to the roosts in February was the main reason for resurgence in numbers at that point. Counts at roosts were lowest in March as harriers returned to their breeding territories.

The highest count of ten birds at one roost is just short of the previous highest attendance of twelve birds reported by O'Donoghue (2004). As per Picozzi and Cuthbert (1982); Clarke and Watson (1990) and Clarke and Watson (1997), most roosts were occupied by less than five individuals on a single night. The mean maximum number of birds recorded during this study was 3.2, slightly less than the 3.8 recorded by Clarke and Watson (1997).

6.4.1.3 Behaviour at Non-breeding Roosts

Passeriformes, many of which roosted in tandem with Hen Harriers, were the most commonly interacted with at roosts. Though Hen Harriers were noted to simply roost rather than hunt at roost sites in most cases, there were 41 recorded instances of hunting of passerines, the chief dietary group of Hen Harriers in Ireland (O'Donoghue, 2004 and Chapter 3, Diet). In contrast to being the most hunted group by Hen Harriers, passerines were also the group that most commonly mobbed Hen Harriers; a defence tactic on behalf of the smaller birds. Corvids (mostly Hooded Crow *Corvus corone cornix*) closely followed in terms of recorded instances of mobbing of Hen Harriers (n=31) and are considered a particular threat, with harriers occasionally expelled from roosts by the crows.

Interactions with other birds of prey varied from confrontational behaviour in the form of mobbing to co-operative behaviour in the form of collaborative hunting. This relationship, previously noted by Watson (1977); Cudworth and Massingham (1986); Lawton Roberts (1986) and somewhat differently by Redpath (1990), was recorded with Sparrowhawk (once) and Merlin (four times). On such occasions, the smaller hawk or falcon would follow the harrier as it quartered over the roost, flushing prey on its course, which the pursuer would opportunistically chase. The fact that Merlin, Short-eared Owl and Marsh Harrier were the birds of prey most commonly recorded to share roost sites with Hen Harriers reflects the similar habitat associations of these sympatric species and has been noted across their respective ranges (Schipper *et al*., 1975; Watson, 1977; Walk, 1998; Kitowski and Wojtak, 1998; Kitowski *et al*., 2003).

In terms of interactions between Hen Harriers at communal roosts, aggressive interactions (mobbing/fighting) were rare when the number of birds and observations are considered. However, it was relatively common to see one harrier disturbing another from its roosting platform. This peculiar activity was also described by Watson and Dickson (1972). Kitowski (2007) noted that juvenile Marsh Harriers never got to settle in central parts of their roost and were often expelled to the perimeter, which might be classed as being a higher risk location in terms of predation. This may be part of the trade-off that young birds must settle for in communal roosts in return for information on safe roost sites and quality winter foraging grounds (Weatherhead, 1983; Beauchamp, 1999). While this is a credible hypothesis, it was noted during roost watches as part of this work that juvenile Hen Harriers roosted in central parts of the roost, and even displaced adults on occasions. As per Watson (1977), the most common interaction witnessed during the current study was females displacing males from roosting platforms. This may have arisen from a desire to assert authority or may have been linked to the attractiveness of that position for certain attributes which it possessed (e.g. shelter, dryness or security). Assertion of dominance by females over males has been commented on by Watson (1977); Picozzi (1980b) and Temeles (1986). As males were also witnessed to disturb females, it is of course possible that displacing harriers from roost positions may also be a feature of individual personality, as much as age or sex.

6.4.1.4 The Function of Communal Hen Harrier Roosts

Picozzi (1980b) suggested communal roosting among Hen Harriers may serve a protection or security role. The relatively inaccessible nature of sites and tall, dense vegetation used for roosting in Ireland certainly point to a protection role. However, the fact that multiple individuals avail of this protection may be a cause of communal roosting; rather than protection arising from multiple individuals roosting together. However, if a predator were to enter a site, roosting in numbers would almost certainly offer the advantage of alerting occupants to the presence of that predator (Picozzi, 1980b). Gurr (1968) suggested that pair formation is an important function of

Australasian Harriers (*Circus approximans*) roosting communally. This may also be the case for Hen Harriers. The influx of males to roosts just prior to the breeding season supports such a theory. Courtship displays have been noted at Hen Harrier winter roosts in Ireland (O'Donoghue, 2004; P. McDaid, pers. comm.). 'Paired' behaviour has been noted on a number of occasions in the past and during this present study. A considerable amount of sightings of Hen Harriers arriving to or departing from roost together may support the theory of information exchange (Ward and Zahavi, 1973). Such exchange could be particularly important to first winter harriers requiring knowledge of useful roosting sites and quality foraging grounds. Furthermore, at least some roosts are likely to function as staging points along a migratory route (Beske, 1982; S. Murphy, pers. comm.). Whatever the purpose(s) of communal roosting, it is clear that roosts serve as bases for the harriers to radiate out and forage the local landscape.

6.4.1.5 Non-breeding Roosts: A Threatened Refuge?

There is no doubting the importance of non-breeding roosts to the national population of this threatened species, given these sites play host to the majority of the harrier's year. While almost 52% of roosts have some form of statutory protection, just 3.8% of sites are protected for the Hen Harrier. The fact that over 48% of known roosts enjoy no protection at all, and over 96% of roosts have no specific conservation measures for Hen Harriers, is of concern. Loss and degradation of wetlands is listed by Tucker and Heath (1994) as one of the main factors affecting the Hen Harrier in Europe. Destruction of roosts and disturbance and loss of Hen Harriers from an entire area has occurred on a number of occasions in Ireland and abroad (e.g. Clarke and Watson, 1990; Kitowski *et al.*, 2003; pers. obs.). The majority (84.6%) of roosts were found to be communally shared by harriers, which is more common than that reported by Clarke and Watson (1990). Since O'Donoghue (2004), at least two roosts have been lost (due to afforestation of one roost and land-use change in the hinterland of another).

The list of threats to all roost sites in Ireland is extensive and consideration should be given to protecting roost sites and winter hunting grounds under the EU Bird's Directive, as a number of other EU countries have already done. It is imperative to understand that a roost, as with a nest site, is a reflection of the surrounding landscape in its ability to support a group of harriers. If the habitats to which the harriers rely on for sustenance were to become unsuitable, it is likely that this would render the roost site itself obsolete.

6.4.2 Casual Sightings

6.4.2.1 Ratio of Ringtails to Adult Males

More ringtails than adult males were recorded during the non-breeding season. The proportion of males in the winter population was not dissimilar to what Clarke and Watson (1997) found for Hen Harriers in Britain, although work by Howells (1986) and Castle and Clarke (1995) showed that this ratio in Britain can differ from region to region. A difference in sex ratio across regions was also noted in the present study, with the Western Seaboard holding higher proportions of grey males than the South and East. The ratio of ringtails to grey males during this present study, both with casual sightings and at roosts was highest at the beginning of the winter, when there would have been a high representation of young ringtails born during the summer. By the end of the winter, similar numbers of browns and greys were to be seen in the general landscape, probably as a result of many juveniles dying in their first winter (Watson, 1977; Newton, 1979; Picozzi, 1984a). However, at non-breeding roosts, more ringtails were seen in March, as the males had begun to return to breeding territories ahead of the females.

The ratio of ringtails to adult males in both casual sightings and dedicated roost watches may be used to indicate future demographics in the population. For example, a significant and consistent increase or decrease in incidences of casual sightings relative to the number of observers may indicate an increasing or decreasing population. As another example, should the proportion of grey males increase significantly, this may indicate the population is getting older or the number of juveniles is decreasing due to a poor breeding season and/or recruitment rate.

6.4.2.2 Elevation of Casual Sightings

The fact that most casual sightings (and roost sites) occurred in lowland areas, supports (to a point) the traditionally held view that Hen Harriers are a lowland bird outside of the breeding season (Watson, 1977; Clarke and Watson, 1990 and 1997). However, it is important to realise that not all harriers leave the upland breeding areas, as almost 30% of all sightings occurred in upland locations. This is of particular importance in informing conservation measures, which have not previously taken account of this fact. The partitioning of males and ringtails in terms of elevation (Table 6.5 and Figure 6.12) is most interesting. Males showed a tendency to remain in the uplands, while ringtails were more common in the lowlands. This contradicts the findings of Marquiss (1980) and Etheridge (2002) whereby females remained on the uplands in Scotland, while the males migrated to lower and milder locations. Marquiss (1980) attributed his findings to the ability of the larger females to catch the larger prey such as lagomorphs which remained on the uplands, while the smaller and more agile males which were adapted to catching small birds had to follow their prey to the lowlands. Such a difference between Scottish and Irish Hen Harriers may be due to a milder winter climate in Ireland (Met Éireann, 2009; Met Office, 2009). Given enough prey to sustain themselves, Irish male Hen Harriers are afforded the opportunity of remaining on breeding grounds throughout the winter, as with Merlin (*Falco columbarius*) (McElheron, 2005), Peregrine Falcon (*Falco peregrinus*) (Ratcliffe, 1980) and Golden Eagle (*Aquila chrysaetos*) (Watson, 1997). The reason why a lesser proportion of ringtails share the uplands during the winter months may be related to the propensity of young birds to travel (Chapter 7, Movements and Survival). Males that would have frequented lowland roosts apparently returned to upland breeding haunts ahead of ringtails, as found by Hamerstrom (1969); Haugh (1972) and Bildstein and Hamerstrom (1980) for Northern Harriers (*Circus hudsonius*) in America.

6.4.3 Non-breeding Distribution

The non-breeding season has been found to represent a more widespread Hen Harrier distribution throughout Ireland than the restricted range during the breeding season (cf. Barton *et al*., 2006). The non-breeding season distribution map (Figure 6.14) is not thought to be greatly biased by observer effort, given this was a national survey with a widespread network of observers. Parts of Ireland with the highest human population (and thereby potential observers) (e.g. in the east) returned the lowest number of roving records, while some of the least populated areas returned the highest number of roving records.

It was apparent that the South and East region was a wintering region for ringtails, while the Western Seaboard held a relatively high percentage of adult males. The Shannon/Midlands region was intermediate in terms of this divide. From the maximum count at roosts in the Western Seaboard (the region with the largest number of breeding territories), 46% of birds were adult males, while 45% of casual sightings there were of adult males. This is further linked to casual sightings showing many males to remain on upland breeding territory throughout the winter. Etheridge and Summers (2006) found adult males were the cohort least likely to make long distance movements. In contrast, the South and East region (which holds the smallest breeding population), had just 15% adult males at winter roosts and 13% adult males in casual sightings. Wing tag movements (Chapter 7, Movements and Survival) show up to a quarter of juveniles move from breeding grounds to winter in the South and East. Interestingly the topography in the Western Seaboard region is the most rugged and diverse in Ireland, so the findings of Schipper *et al.* (1975) which showed males to be restricted mainly to flat agricultural landscapes do not necessarily apply.

6.5 SUMMARY

The current study explored on a national scale, where Hen Harriers spend the non-breeding season in Ireland. The composition of non-breeding roosts, in terms of habitat and harriers, as well as the dynamics and behavioural ecology of Hen Harriers in non-breeding mode were investigated. A total of 52 winter roosts were found across the country. Most roosts were in lowland locations, but some were found in upland breeding areas. Hen Harriers selected roost sites that were undisturbed, with tall and dense vegetation, probably for shelter and protection. Peak numbers at regular communal roosts occurred in November and February. Ringtails outnumbered grey males at roosts and in the general landscape. The Hen Harrier was found to have a more widespread distribution during the non-breeding season than in the breeding season. Trends showed grey males were more likely to be found in upland locations during the non-breeding season than ringtails, and were also more likely to be found in the West and Shannon/Midlands regions than in the South and East.

Plate 6.1. Winter (top) and summer (bottom) at a Hen Harrier breeding site.

Chapter Seven

Movements and Survival

It is in my heart, and in my mind, and in my soul! It burns like a fire! It drives me like a tireless wind! I am going. Farewell!

The Children of Lir.

This study sets out on the final frontier of Hen Harrier research in Ireland; to determine the movements and survival of individual birds. In doing so, this study will facilitate increased understanding of the links between the breeding and non-breeding seasons, as well as providing population specific survival data that can be applied in population viability analyses.

The following hypotheses (and popular beliefs) are addressed:

- Hen Harriers from the same breeding site disperse in the same direction;
- If Hen Harriers are going to travel, they will generally travel south;
- Hen Harriers seen during the non-breeding season have come from the nearest breeding area;
- Hen Harriers remain in or return to their natal ranges to breed;
- Hen Harriers in Ireland are unlikely to migrate outside of Ireland.

7.1 INTRODUCTION

Knowledge of dispersal, survival and philopatry can inform population ecology and management (Greenwood, 1980; Walters, 2000; Clobert *et al.*, 2001; Garant *et al.*, 2005) and is thus a topic of substantial interest to animal ecologists and has been the subject of a wide range of studies (e.g. Greenwood and Harvey, 1982; Riley-McClelland *et al.*, 1994; Forero *et al.*, 2002; Fiuczynski *et al.*, 2009; Griffin *et al.*, 2009; Loe, 2009; Monzón-Argüello *et al.*, 2009). A number of such studies have been focussed on Hen Harriers (*Circus cyaneus*) (e.g. Picozzi, 1984a; Balfour and Cadbury, 1979; Klaassen *et al.*, 2006 and 2008). Apart from a ringing scheme operated by the British Trust for Ornithology (e.g. Spencer and Hudson, 1973), Etheridge and Summers (2006) undertook the largest single study of Hen Harrier movements in the north-western part of the species range to date. This work identified a number of British birds travelling to Ireland, as earlier reported by Thomson (1958) and Mead (1973). Etheridge (2002) however, highlighted that not enough work was being carried out in Ireland to further develop knowledge of the movements of Hen Harriers here. Without such research, it is impossible to know what happens to individuals after leaving the nest, and what links may exist between breeding and non-breeding areas or indeed between Irish Hen Harriers and those elsewhere. Thus, the motivation for the present study. For the first time in Ireland, the movements of young Hen Harriers that have fledged are tracked. By association, the origins of Hen Harriers seen during the breeding or non-breeding seasons are determined. Natal philopatry and site fidelity are investigated. In addition, survival rates of Hen Harriers in Ireland are calculated, facilitating specific viability modelling for the Irish population. Wing-tagging also identifies links between different breeding areas and examines whether harriers excluded from one area can establish themselves on another.

7.2 METHODS

7.2.1 Appraisal of Tracking Methodologies

Methods used for studying the movements and survival of Hen Harriers (and Northern Harriers, *Circus hudsonius*) have included following birds by banding/ringing (e.g. Thomson, 1958; Mead, 1973), coloured jesses/leg rings (Hamerstrom, 1969; Balfour and Cadbury, 1979; Klaassen *et al*., 2006 and 2008), feather imping (Hamerstrom, 1969), wing-tagging (Picozzi, 1984a; Etheridge and Summers, 2006), radio tracking (Martin, 1987; Arroyo *et al*., 2005) and most recently, satellite tracking (Natural England, unpubl. data; Irish Raptor Study Group, unpubl. data). Currently in Europe, Hen Harriers are being tracked, by various methods, in Ireland, Scotland, England, Wales, Isle of Man, France, Spain, The Netherlands, Germany and Finland (B. Etheridge; D. Sowter; B. van Hecke; A. Pinnila; P. de Boer; J. Dierschke and J. Haapala, pers. comm.). Before embarking on a tracking scheme, a review of current methodologies was carried out and this is summarised in Table 7.1.

Time and financial constraints excluded the possibility of tracking Hen Harriers by radio, satellite, Passive Integrated Transponder (PIT) and genetic methods, while Global Positioning System (GPS) is inappropriate for dispersal and survival studies. Colour-ringing was deemed limited in its ability to identify individuals (vital for survival estimates). Patagial wing-tagging has been judged by Whitfield and Fielding (2009) as the 'best' method to trace Hen Harriers. It was also deemed to be the most appropriate to a study of this type, for the advantages outlined in Table 7.1 and the disadvantages of other methods mentioned above. Wing-tagging began as a pilot study in Kerry in 2006, before expanding in 2007 to include the three other distinct breeding areas of West Clare, Ballyhouras and Slieve Aughties. Choosing four areas increased the amount of nestlings available for tagging and allowed for comparisons and investigations of movements, philopatry and interactions between different breeding areas as well as non-breeding areas. Using these four areas also enables reference to other research conducted in the same study areas as part of this thesis.

7.2.2 Marking Techniques and Retrieval of Information

7.2.2.1 Fitting of Wing Tags to Nestlings

Wing-tagging for identification of birds was first pioneered in the 1950s (Koskimies and Routamo, 1953) and has been modified through the years by the works of Anderson (1963); Hester (1963); Knowlton *et al.* (1964); Kochert (1973); Nesbitt (1976 and 1979); Bartlelt and Rusch (1980) and Kochert *et al.* (1983). It was first trialled with Hen Harriers by Picozzi (1971). As part of the present study, a total of 60 nests were visited during the four breeding seasons of 2006–2009 (inclusive), for the purposes of individually marking nestlings. Of 152 nestling Hen Harriers encountered during these visits, all were measured for biometrics, including weight (g), wing length (mm), tarsus length (mm) and tarsus width (mm) using a 600g Pesola spring balance, wing ruler and digital callipers. A total of 151 were fitted with a metal British Trust for Ornithology (BTO) ring carrying a unique identification number, and 137 (between the ages of 22 and 35 days) were wing-tagged. Using a methodology similar to Etheridge and Summers (2006), wing-tagging involved fitting a colour PVC-coated nylon tag (75x35mm) to each wing, so that it sat on the dorsal side of the wing and would later be visible as the bird flew or was perched. Tags were attached and held in place by piercing the patagium of the wing with a 1.5mm diameter nylon pin which had a nylon washer placed between the tag and a heat formed bauble at either end of the pin on either side of the wing. Wing tags fitted in this way are expected to last on the bird for five to six years (B. Etheridge, pers. comm.).

Table 7.1. Review of tracking methodologies for Hen Harrier dispersal studies.

Tracking Method	**Advantages**	**Disadvantages**
Metal Ringing	Long Life. Recognised administrative/ringing authorities.	Low percentage returns. Recovered birds usually dead. Human population density may bias re-sightings.
Colour Ringing	Long Life. More obvious than metal rings. Re-sightings of live birds.	Difficult to identify individuals. Not as obvious as wing tags. Larger on leg(s) than metal ring. Human population density may bias re-sightings.
Patagial Wing-tagging	Inexpensive. Obvious to observers. Re-sightings of live birds. Limited case histories of birds possible, including links between areas.	Individuals not always identified. Limited colour combinations. Routes of travel not known. Dependent on surveying and public reporting. Human population density may bias re-sightings. Possibly draws attention from irresponsible shooters or other birds.
Radio	Long life if harness-mounted. Accurate tracking of individuals locations.	Relatively low set up cost. Limited life if tail-mounted. Time and labour-consuming. Involves travel (can be expensive).
Satellite	Long life. Close to full case histories of birds possible. Routes of travel and time travelling known. Not restricted by location or dependent on surveying/re-sighting. No ambiguity regarding identification of individual. Of educational use (e.g. on internet/in schools). Eliminates need for observer to travel.	Expensive. Number of individuals can be tracked is limited (by cost). Dependent on good satellite reception.
Global Positioning System (GPS)	High accuracy. Frequent and intensive information.	Expensive. Very short life span (<1wk for Hen Harrier).
PIT (Passive Integrated Transponder)	Identity of individuals known. Case history of territory occupation/partners/natal philopatry in a territory possible.	Expensive. Requires visits to nest/favoured perch to identify individual.
Genetic	Case history of territory occupation/partners/natal philopatry in a territory possible. Easy and fast to collect. Non-intrusive. Of use in wildlife crime investigations.	Expensive to analyse. Of limited use until a significant databank has been built up.

7.2.2.2 Indentifying Age and Provenance, Identifying Individuals and Collection of Sightings Data

Each breeding area had its own individual colour tag which was placed on the right wing of the bird, so that when later seen, the origin of the bird could be identified. The tag colour of the left wing was consistent across areas, but varied by year so that the age of the bird could be identified. Each bird had its own individual letter, number or symbol marked on its two tags. Such markings were selected to avoid confusion at a distance (e.g. if '8' was used on a tag, this rendered 'B' unusable, and if 'P' was used on a tag, this rendered 'p' 'G', 'g' 'b', 'Q', 'q', '6' and '9' unusable. These markings were made using black or white PVC ink to contrast on the background colour of the tag. The combinations of tag colours (Table 7.2) were chosen in conjunction with Hen Harrier wing-tagging schemes in Britain, so as to avoid conflict with combinations used by our nearest neighbours. Unfortunately however, given a limited amount of colours and permutations, there was a combination clash with a Hen Harrier wing-tagging scheme in France, although the French do not use individual markings (B. van Hecke, pers. comm.).

In the event of a marked bird being found dead or injured; contact details were written on the underside of each tag. Each set of tags also had a unique registration number on their underside, detailing year and place so that even if just one tag was recovered, the individual could be identified. Nests were monitored after tagging to ascertain how many of the tagged chicks fledged. This was important to support accurate assessments of survival and re-sightings of tagged chicks that had fledged.

A publicity campaign was launched nationally through various media so that the public would be aware of the tagging scheme and report any sightings to the co-ordinator. Media outlets included television, radio, newspapers, magazines, websites and internet forums, public presentations, posters (Appendix VII) and pamphlets, which were sent to all 5,628 landowners in the Hen Harrier Special Protection Areas. Notification was also given to harrier researchers and national ringing authorities across Europe, and posted on the website http://www.cr-birding.be, which lists various bird marking projects. National Hen Harrier surveys ran concurrently to the wing-tagging programme and participants of both the annual Irish Hen Harrier Winter Survey and the 2010 Republic of Ireland Breeding Hen Harrier Survey were asked to record any wing-tagged individuals. This meant that close to full coverage of known wintering and breeding Hen Harrier sites was achieved.

7.2.2.3 Verification of Sightings Data

On receiving a report of a wing-tagged Hen Harrier, a verification process followed to ensure that (a) the observer had in fact seen a Hen Harrier and (b) the tag combination was correctly identified. Information including date and time of sighting, habitat, activity, direction of travel and sex of the bird were all recorded. Photographs of tagged individuals were received in a number of cases. In cases where tag combination or tag ID was not positively identified, the co-ordinator either searched for the bird or informed survey volunteers of the location of the bird and any potential roosting sites, with a view to positive identification.

7.2.2.4 Data Grouping and Analysis

Only re-sightings of birds more than six weeks after fledging or greater than 5km from the nest during that period are used in analyses so as to avoid excessive autocorrelation with the nest site prior to dispersal (see Chapter 5, Breeding Ecology). Sightings are generally grouped according to provenance and year, though individual cases are also referred to. The ‘ruler’ tool in Google Earth (Google, 2009), cross referenced with the ‘measure’ tool in ArcView GIS 3.2 (Environmental Systems Research Institute, 2004), was used in analysing the movements of Hen Harriers. The furthest point that an individual was known to have travelled from its natal site was used to determine the straight line (Euclidian) dispersal distance of that individual. An eight-point compass direction was also attributed to this movement.

7.2.3 Wing Tag Trials

Field trials were carried out to ascertain the efficacy of wing tags, in terms of identifying colour and tag character (individual number/letter). Two observers, equipped with 8x30 Swarovski binoculars, watched a model ringtail (brown) Hen Harrier with 48 different wing tag combinations (replicates) using 32 different tag characters (not known to the observers prior to trials), from a distance of 100m, while the model was carried at a height of 1.5m for a period of 10 seconds. This represented a typical encounter with a tagged Hen Harrier according to the sightings that were reported. In addition to the tag colours used in the course of this study (blue, red, green, yellow and black), the possibility of the bird having lost a tag was also accounted for by flying the model missing one tag. The trials were carried out on two occasions: at midday in good sunshine, and in lower light levels at sunset, when harriers are typically seen to arrive at roosts (Chapter 6, Non-breeding Ecology). In addition, tags were placed on brown and grey backgrounds to determine if there was any difference in detection rate of tags on ringtails and males.

7.2.4 Estimation of Survival Rates

The formula used by Batten (1973) to calculate the apparent survival rate of juvenile birds through to their first summer was adapted for wing-tagged Hen Harriers:

$$\text{Juvenile survival} = \frac{(\text{percentage juveniles known to have made it to } 1^{st} \text{ summer x adult survival})}{\text{percentage adults recovered}}$$

Annual adult survival rate was taken as 0.744 after Whitfield and Fielding (2009) and Fielding *et al.* (2009) for the nearest breeding populations in Wales and Scotland, because the dataset generated from the current study spans four years (primarily three years) and Hen Harriers have been recorded to live for over 17 years (Staav and Fransson, 2008). The ‘percentage adults recovered’ was taken as 0.375. This was the proportion of tagged harriers which were known to have made it to their first summer and were re-sighted in subsequent summers.

Table 7.2. Wing tag colour combinations and number of fledged individuals with tags per area and year (2006-2009).

Year Left	**Area Right**	**Kerry**	**W. Clare**	**Ballyhouras**	**Aughties**	**All**
2006		3	0	0	0	3
2007		14	8	9	2	33
2008		21	17	11	10	59
2009		5	5	8	7	25
All Years		43	30	28	19	120

Plate 7.1. Tag combination for Hen Harriers fledged in 2009 (yellow left with black character) from Kerry (red right with white character).

7.3 RESULTS

7.3.1 Wing Tag Trials

During midday trials, observers correctly identified the tag colour on all occasions almost immediately. However, black tags appeared least obvious, and green and blue tags were thought to be less obvious than yellow and red. At sunset, the apparent 'dullness' of the black tags was exacerbated and one of the eight black tags used was not seen by one of the observers. All other colours were recognised correctly in all cases. The overlooking of one black tag did not create a significant difference between the possibility of identifying tags however (χ^2=4.10, *df*=4, *P*=0.392). The white character on the black background provided one of the highest rates of individual identification (75%). Yellow tags (with black characters) shared this high rate of character recognition, while red tags (with white characters) had a 62.5% identification rate, and blue tags and green tags (with white characters) had a 50% identification rate. The difference between colours in terms of reading tag ID was not significant however (χ^2=1.52, *df*=1, *P*=0.676). Without binoculars, tag characters could not be read until observers were within 35m (measured using Bushnell range finder accurate to 1m). There was no difference in detection rates of tags (correctly identified in all cases) on either brown (ringtail) or grey (male) backgrounds.

7.3.2 Re-sightings of Wing-Tagged Harriers

Of 137 harriers that were wing-tagged, 120 fledged and from these, 182 re-sightings involving at least 43 individual birds were recorded between August 2006 and August 2010. An additional seven reports were discarded; once because the observer thought the faded upper-wing coverts of an individual were yellow tags, twice because tagged Common Buzzards (*Buteo buteo*) in a Merseyside town park with the same colour combination as Kerry 2008 were reported, and four times because the observers could not fully determine the tag colour or placement combination (i.e. confusion over right and left wing). In addition, the possibility of a bird tagged in the Ballyhouras in 2007 being recorded in Burgundy, France (1,120km from the Ballyhouras) could not be confirmed, as French Hen Harriers carried the same combination (albeit they were also tagged at distance from the re-sighting location). Conversely, what was originally reported to be a Hen Harrier at three different locations in Ireland (Dublin, Offaly and Wexford) was identified as a Montagu's Harrier (*Circus pygargus*) tagged in France.

Individual Hen Harriers were reported on between 1 and 26 occasions, with 23 of the 43 re-sighted individuals reported on more than one day. The number of re-sightings of wing-tagged harriers is presented in Table 7.3. Of all individuals identified through re-sightings, 85% were female Hen Harriers, meaning females were re-sighted significantly more than males (χ^2=9.50, *df*=1, *P*=0.002). Movements and sightings locations of individual harriers are summarised in Figures 7.1 and 7.2, while Figure 7.3 and Tables 7.4 and 7.5 summarise data on distances and directions of those movements.

Tagged harriers were re-sighted a mean distance of 112.1 ± 16km from their natal sites. The single furthest re-sighting of an individual from its natal site was that of a 2nd calendar year (cy) male from Kerry, who was seen in Bowland, England - a distance of 520km. The closest re-sighting of an individual to their natal site more than six weeks after fledging was that of a female in Kerry, who returned in her 3rd calendar year to breed just 1km from the site in which she was born, and flew directly over her own natal site. There was no significant difference in the distances travelled by wing-tagged birds from the four study areas (Kruskal-Wallis H=1.80, *df*=3, *P*=0.614). Males were observed to travel further ($\bar{x}$=272 ± 57km) than females ($\bar{x}$=98 ± 17km), though this difference was short of being significant (Mann-Whitney W=374, *P*=0.079).

Table 7.3. Re-sightings of wing-tagged Hen Harriers which were reported and verified between August 2006 and August 2010.

	Tagged and Fledged	**Reports**	**Individuals Identified**	**Minimum Re-sightings Rate**
Kerry	43	41	15	34.9%
West Clare	30	56	10	33.3%
Ballyhouras	28	53	12	42.9%
Aughties	19	31	6	31.5%
All	120	178	43	35.8%

Table 7.4. Distances (km) moved from natal sites by individually identified wing-tagged Hen Harriers in Ireland according to place of origin.

	Arithmetic Mean	**Geometric Mean**	**95% C.L.**	**Min**	**Max**
Kerry	108.8	46.0	43 -174	1	520
West Clare	158.0	75.6	78-238	1	315
Ballyhouras	84.6	66.7	58-111	10	136
Aughties	99.2	48.2	36-162	1	175
All	112.1	58.8	81-143	1	520

Table 7.5. Directions of movements of individually identified wing-tagged Hen Harriers in Ireland according to place of origin (presented as percentage in each 45° arc of the compass).

	N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Kerry	30.8	23.1	15.4	15.4	7.7	0.0	7.7	0.0
West Clare	10.0	30.0	30.0	20.7	10.0	0.0	0.0	0.0
Ballyhouras	8.3	16.7	16.7	8.3	8.3	8.3	8.3	25.0
Aughties	0.0	0.0	40.0	0.0	20.0	0.0	20.0	20.0
All	15.0	20.0	22.5	12.5	10.0	2.5	7.5	10.0

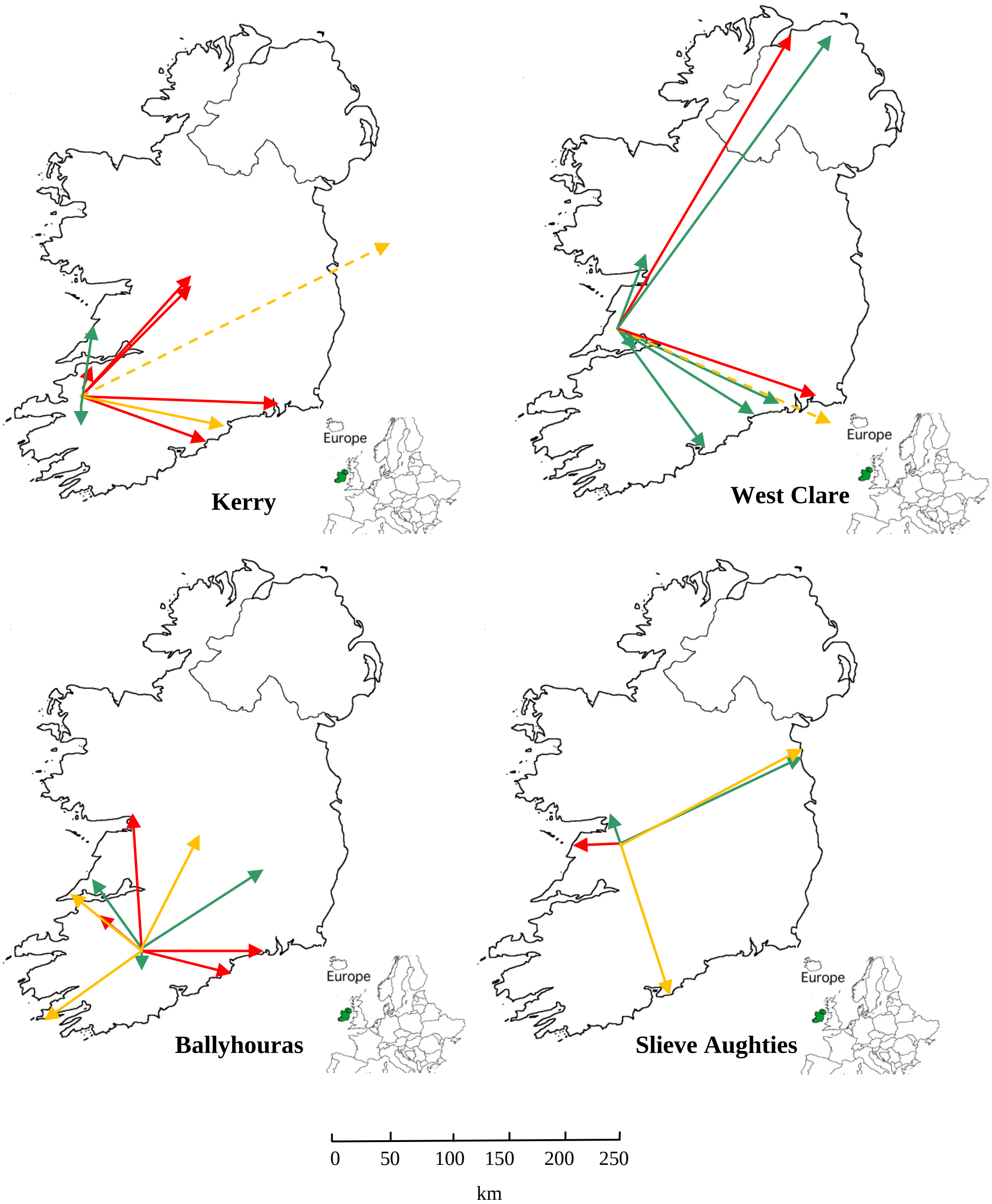

Figure 7.1. First-winter movements of wing-tagged Hen Harriers. Red (2007), Green (2008) and Yellow (2009) arrows show directions from natal site to furthest sighted destination.

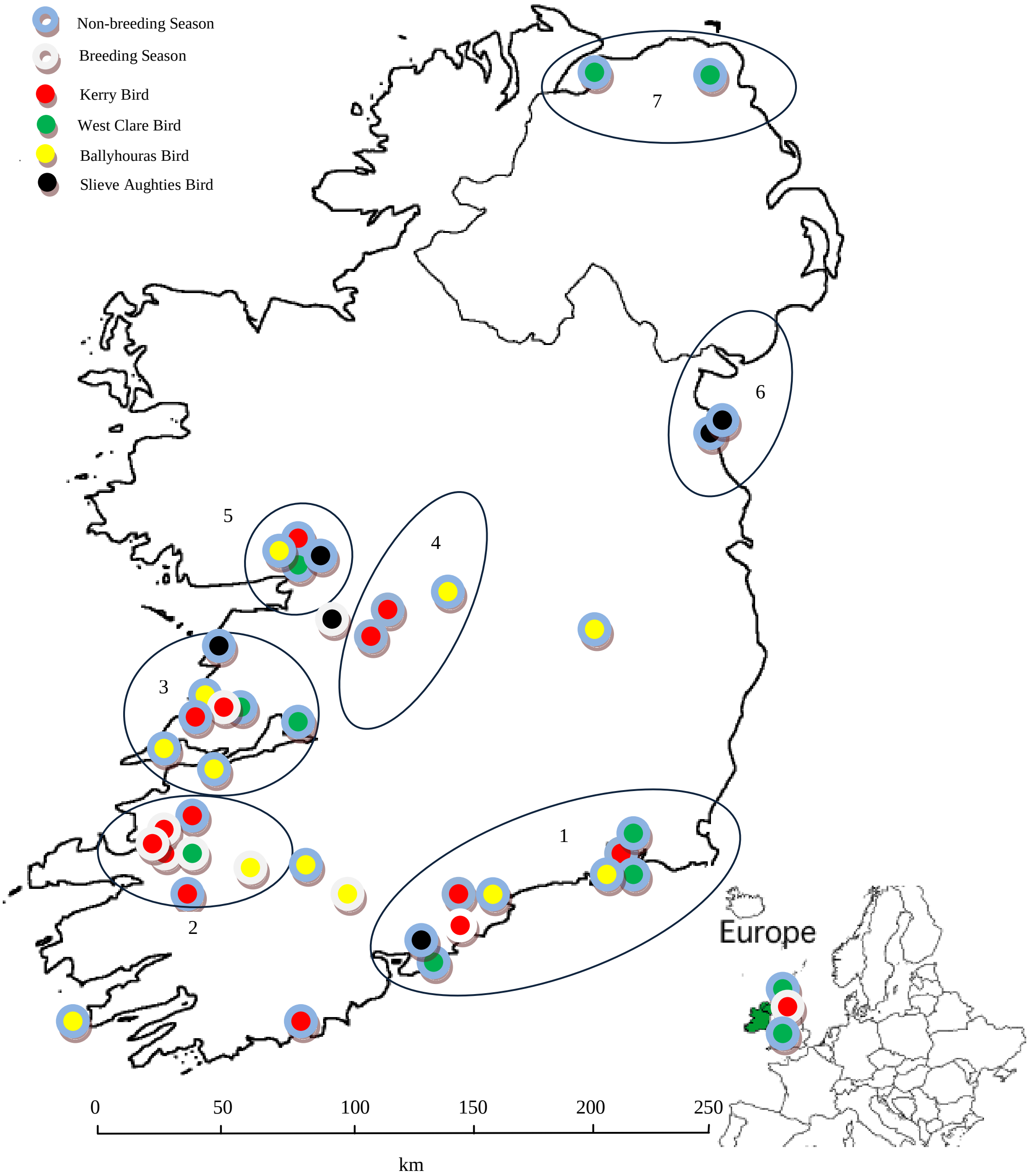

Figure 7.2. Furthest re-sighted points (from natal site) of wing-tagged individuals of all ages.

While Figure 7.2 displays 44 re-sighting incidents, no more than 43 re-sightings can be confirmed as definite individuals, as there was an element of uncertainty regarding an individual from West Clare in Scotland, which may have earlier been re-sighted in Derry and Donegal.

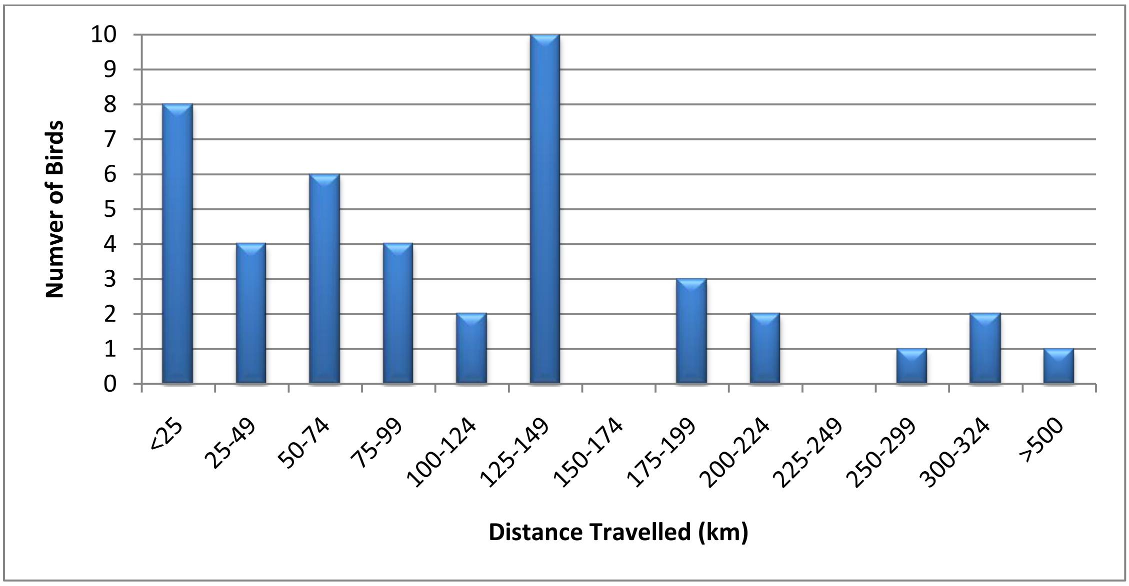

Figure 7.3. Furthest re-sighted distances (from natal site) of wing-tagged Hen Harriers.

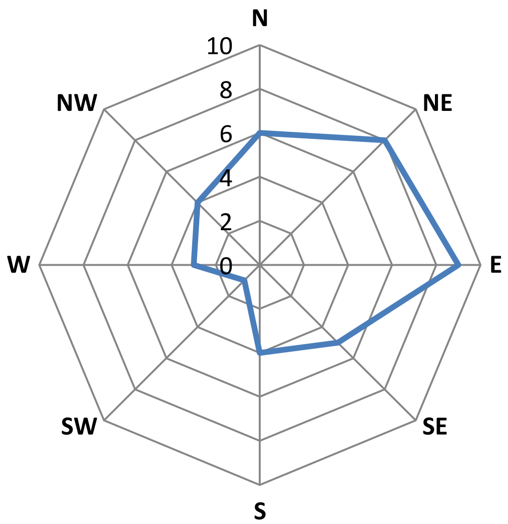

Figure 7.4. Direction of wing-tagged Hen Harrier movements in Ireland (extent of blue line represents the number of movements in a particular direction).

7.3.3 Main Destinations of Tagged Harriers within Ireland

Seven distinct areas within Ireland were identified as the general destinations of multiple numbers of wing-tagged Hen Harriers during the non-breeding or breeding season (see Figure 7.2). These are now discussed in detail.

Area No. 1. South-east Coast

A minimum of nine wing-tagged individuals from all four study areas were re-sighted in the south-east of the country. An Irish harrier re-sighted in Pembrokeshire, Wales was also likely to have travelled via the south-east coast. Therefore, the south-east accounted for almost a quarter of individuals re-sighted. All individuals sighted in this area were reported during the non-breeding season in their first autumn/winter. A number of individuals in this area were found to have returned to the region in consecutive winters, while one individual remained and bred there.

Area No. 2. Stack's to Mullaghareirk Mountains

At least seven individually wing-tagged birds were re-sighted on this mountain range, which is the most populous Hen Harrier breeding area in Ireland (Barton *et al*., 2006). Most of the re-sightings were during the breeding period and comprised individuals from three of the four study areas.

Area No. 3. West Clare

This region, which is an important Hen Harrier stronghold both during breeding and non-breeding seasons, was found to have hosted at least nine independent individuals, representing all four study areas.

Area No. 4. Shannon/Midlands

Three individually wing-tagged Hen Harriers (from further south in Kerry and the Ballyhouras) were found close to the middle River Shannon, which holds ample roosting and foraging potential.

Area No. 5. Galway

A non-breeding roost in Galway was the only specific site known to have held individuals from all four study areas.

Area No. 6. North-east Coast

Two wing-tagged individuals from neighbouring natal territories in the Slieve Aughties were among those sighted in the north-east during this study, one of whom returned to the area in consecutive winters.

Area No. 7. North Coast

At least two individuals from as far as West Clare were re-sighted on the north coast of Ireland.

7.3.4 Movements Outside of Ireland

At least two and probably three wing-tagged individuals departed the island of Ireland, and were re-sighted in Britain. The first ever confirmed record of an Irish born Hen Harrier outside of Ireland came on 02 October 2009, when a female harrier named Lissycasey 7/Skomer Saith was sighted on Ramsey Island off the Pembrokeshire Coast of Wales, 277km from where she fledged 12 weeks earlier. The most direct route to Ramsey from West Clare includes a crossing of 76.5km over St. George’s Channel. Upon leaving her natal site, this young female did not take a direct south-easterly route, but was first re-sighted 33km north-east of her nest on 25 July 2009, 15 days after fledging.

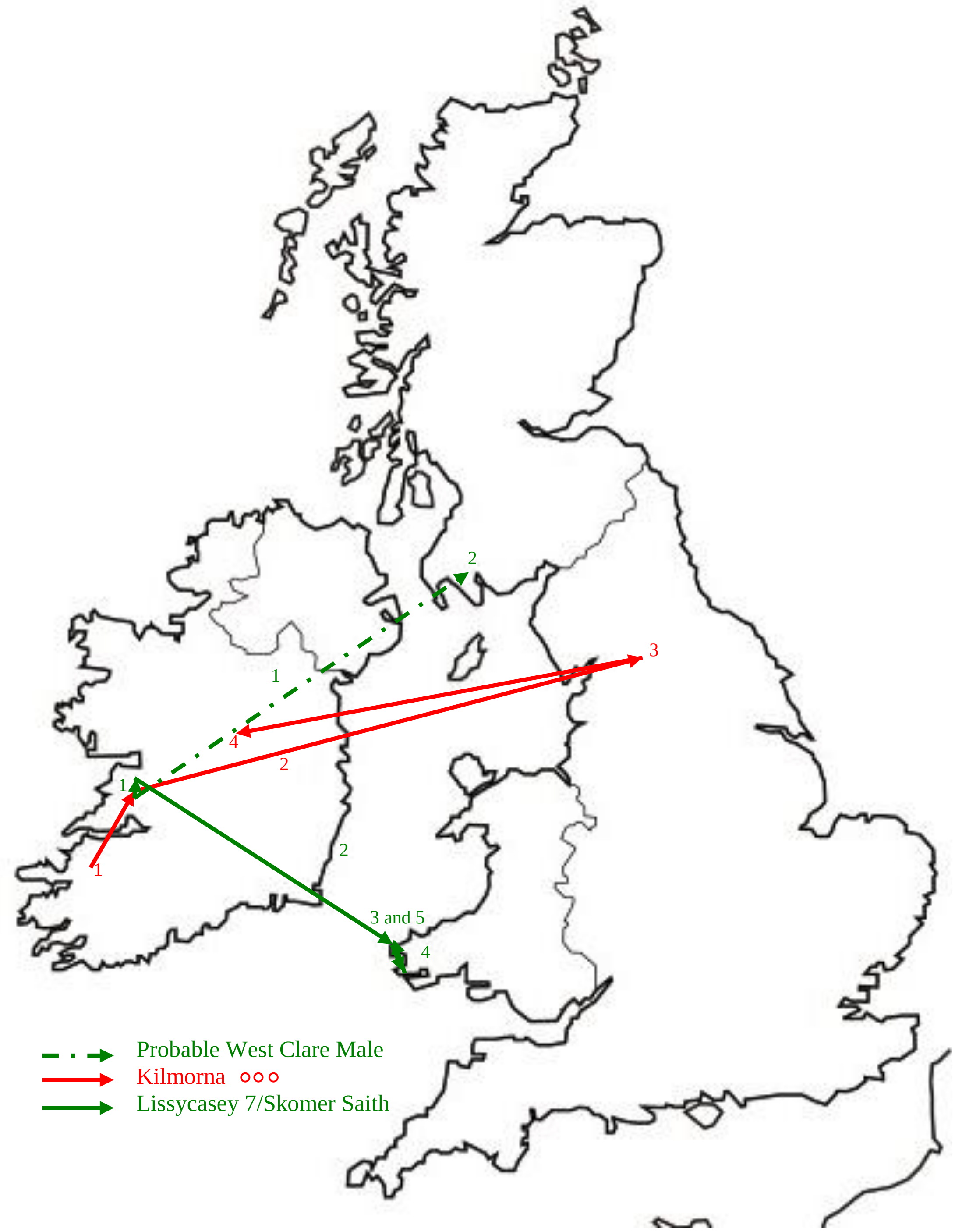

Figure 7.5. Overseas movements of Hen Harriers wing-tagged in Ireland (numbers represent sequence of sighting points for each individual, see Table 7.6).

Table 7.6. Recorded movements of Hen Harriers that travelled outside of Ireland.

	Probable West Clare Male	**Kilmorna** ○ ○ ○	**Lissycasey 7 / Skomer Saith**
Provenance	West Clare	Kerry	West Clare
Overseas Destination	Wigtownshire, SW Scotland	Lancashire, England	Pembrokeshire, Scotland
Born	2007	2009	2009
Sex	Male	Male	Female
Last seen at natal area (1)	-	12 July 09	14 July 09
Number of re-sightings	1	3	26
1st re-sighting (2)	23 August 08	17 October 09	25 July 09
2nd re-sighting (3)	-	19 March 10	02 October 09
3rd re-sighting (4)	-	23 March 10	11 October 09
4th re-sighting (5)	-	-	01 April 10
Furthest sighted from natal area	380km	520km	295km
Minimum distance accounted for	380km	864km	313km
Bearing	NE	NE	SE
Notes	First probable record of an Irish-born Hen Harrier outside of Ireland. An unpublicised Scottish tagging scheme in Ayrshire used the same colour combination in 2004. The reported bird was identified as mainly grey with brown on the wings, fitting the description of a 2nd Winter Male, not a 5th calendar year male from 2004.	First re-sighted on a West Clare breeding territory in Autumn 2009, and the following spring in Bowland, the core of the English Hen Harrier breeding population, where he was seen sky dancing before getting in a fight with a resident adult male. Next and most recent re-sighting was back in Ireland 4 days later, apparently homeward bound.	First confirmed record of an Irish born Hen Harrier outside of Ireland. Travelled NE before heading SW. Established winter territory in Pembrokeshire, Wales. Suspected to have succumbed to unfavourable conditions while attempting to return to Ireland, crossing St. George's Channel in late March 2010. Found dead on the tide line close to where she was first seen in Wales.

7.3.5 Apparent Survival

The majority of re-sightings of tagged harriers were of young birds in their first autumn or winter (as per Etheridge, 2002). Four of the 43 individuals accounted for were recovered dead, all in their first winters, 6, 20, 32, and 38 weeks after they had respectively fledged their nests. Two of these were from the same territory (in consecutive years). The apparent survival rate for Hen Harriers to their first summer was calculated as 0.275 (27.5%). Survivorship of females and males was found to differ, whereby 34.4% of females were estimated to have made it to their first summer, but only 9.0% of males were calculated to have survived to breeding age (which from personal observations in Ireland can occur at 1 year old).

7.3.6 Natal Philopatry and Site Fidelity

Of the 120 birds that fledged bearing wing-tags, at least eleven individuals were re-sighted in breeding areas during the breeding season, with a median natal dispersal of 27.5km. Two of these were females from the same brood and both bred as two-year-olds (Appendix VIII). Three of the six wing-tagged birds from Kerry found in the breeding season were re-sighted in Kerry, while the other three were re-sighted in Bowland (England), Waterford and West Clare. A tagged bird from West Clare was found during the breeding season in Kerry. One tagged bird from the Slieve Aughties was confirmed breeding in the Slieve Aughties. The three tagged birds from the Ballyhouras seen during the breeding season were all found in breeding areas other than the Ballyhouras; namely the Mullaghareirk's, Nagles and Kilworth Mountains.

Of the 43 individuals identified, the roosting or breeding grounds of 23 (53.5%) were accounted for. Of 23 individuals that were re-sighted on more than one occasion in the same area, the average period from first to last re-sighting in that area (in a single season) lasted 73.7 ± 13.0 days (range 2 – 182 days). At least four individuals returned to same site in consecutive years, either to the same non-breeding roost (n=3) or the same breeding site (n=1), at distances up to 200km from their natal sites. Two females were recorded at the same non-breeding roost for their first three winters. Sightings showed these birds were remarkably faithful to the areas which they hunted. At least five individuals were accounted for in both the non-breeding and breeding seasons, with winter and summer stations separated by up to 120km. One individual was observed in the same winter to switch between two roosts that were 10km apart.

A number of wing-tagged individuals shared a common non-breeding roost. A female from Kerry (2007) and a female from West Clare (2008) were observed interacting with one another in the winter of 2008/9 at a roost in East Cork, 111km and 130km south-east of their respective natal sites. The same 2008 West Clare female was also re-sighted using another winter roost 10km away, where a Slieve Aughties (2009) female also spent her first winter, 132km south of her natal site. A sibling to this 2009 Slieve Aughties female travelled 175km north-east, to spend her first winter in the very same place (in County Louth) as a Slieve Aughties female born in 2008. A non-breeding roost in Galway was shown to host tagged harriers representing all of the four study areas.

7.3.7 Age at First Breeding

The earliest age at which a wing-tagged harrier was confirmed to breed was two years of age. However, five wing-tagged individuals were re-sighted on breeding grounds in their first year, including a female that nested as a two-year-old in the same bog as she was seen in as a one-year-old, and a male that was seen sky dancing in Bowland.

7.3.8 Individual Case Studies

Investigating individual cases can give added value to patterns of movements assessed at the population level. Movements by individuals which were either siblings, or from the same natal territory are presented in Appendix VIII and show that related birds can follow very different paths, once independent of their parents.

7.4 DISCUSSION

7.4.1 Re-sightings, Distances and Directions of Travel

The proportion of wing-tagged birds that fledged and were later re-sighted was relatively consistent across the four study areas, ranging from 31.5% of Slieve Aughties birds, to 42.9% of Ballyhouras birds (Table 7.3). The fact that most of the public do not carry binoculars is one of the main reasons why tag ID was identified less often in reality than in trials. The vast majority of re-sightings were of first winter birds. Overall, 79.1% of birds were re-sighted at locations less than 150km from their natal site (the most frequent distance was between 125km and 149km). This probably reflects the fact that Ireland is an island, and the possibility of long-range movement within Ireland will be limited by distance to the coast. The fact that almost 80% of all first winter birds with wing tags were re-sighted near the coast suggests that many young birds after leaving their natal areas continued to travel until they reached the Atlantic Ocean, Celtic Sea or Irish Sea. Plotting the locations of confirmed individuals, wing tag re-sightings accounted for a very minimum of 5,895km of Hen Harrier movement.

The main direction travelled by harriers differed according to which breeding area they were from, resulting in a widespread distribution of tagged harriers across the island. Most harriers from Kerry travelled north; most harriers from West Clare travelled north-east or east; most harriers from the Ballyhouras travelled north-west, and most harriers from the Slieve Aughties travelled east. Overall, the most popular directions of movement were east or north-east. Given the populations studied were rather south-westerly lying on the island of Ireland, it was perhaps probable that most movements of tagged harriers would be in a generally northerly or easterly direction. A similar explanation was offered by Whitfield and Fielding (2009) when most Welsh tagged harriers moved in a north-easterly direction. There was however scope for movements even further south and west (in both Ireland and Wales), and in the current study this was realised in 23.3% and 20.6% of cases respectively. There may then be alternate reasons for movement in a generally easterly or north-easterly direction for harriers from each of the four breeding areas, which would bring them towards the south-east or east coasts of Ireland:

1. Prevailing westerly or south-westerly winds in Ireland. Beske (1982) noted juvenile dispersal movements were primarily downwind. However this has not been realised with Scottish Hen Harriers, which despite prevailing south-westerlies, display mostly southerly movements (Etheridge and Summers, 2006).

2. The east and south-east coasts provide a more Hen Harrier ‘friendly’ winter than the breeding areas of the west and south-west, which are more highly exposed in terms of wind and rainfall (Met Éireann, 2010).

3. Movement towards the eastern coasts (east of Malin Head to Mizen Head) is essentially the only way to safely leave the island of Ireland, if emigration is a driving force.

A potential bias associated with wing-tagging (as per Table 7.1) is that instilled by the location of observers and in particular, location of observers with an interest, curiosity or understanding that their sighting of a bird bearing wing tags should be reported. However, it would be speculation to suggest that the data collected by the current research would be different if every person who had seen a wing-tagged harrier had reported it.

Kerlinger (1989) noted that natural features can act as migration corridors for many raptors and Etheridge (2002) touched on this possibility for Hen Harriers. Of the 43 individuals identified during the present study, 11 (25.6%) appear to have moved along a river channel/valley/plain from natal area to re-sighting area, while 18 (41.8%) were re-sighted on a mountain range adjoining their natal area. This equates to 67.4% (n=29) of individuals apparently having used topographical features such as rivers or mountains on their travels. Satellite tracking would provide more a conclusive picture of routes travelled.

What happens in the non-breeding season can have carry-over effects on the dynamics of populations during the breeding season (Bearhop *et al.*, 2004; Norris and Taylor, 2006). Therefore, establishing links between breeding and non-breeding areas is an important outcome of the current research.

7.4.2 Movements Outside of Ireland

Etheridge (2002) believed that Irish Hen Harriers were largely resident and did not leave the country in the majority of cases. The findings of the current study generally concur with this assertion, as most harriers were re-sighted in Ireland, sometimes over successive winters. However some (6.9% of all re-sighted) were shown to have migrated to Britain. The proportion of harriers making or attempting to make this journey to Britain (and/or mainland Europe) may be greater than currently known, as the Irish tagging scheme was not widely publicised overseas (though research colleagues abroad were informed). Given that emigration of Irish Hen Harriers to Britain has now been shown, there is no reason to suggest emigration further to the continent (e.g. France, Iberia, Holland) is not possible or undertaken. Time may yet show Irish Hen Harriers to be found in such locations (cf. possible Irish record in France). Welsh birds have been known to reach Portugal (Etheridge, 2002), and Scottish birds have been known to reach the Pyrénées, Netherlands, Germany and Denmark (Mead, 1973).

A total of 14 records of (untagged) Hen Harriers flying over the sea or ocean, have been submitted to the Irish Hen Harrier Winter Survey since its inception in 2005. Key migration points in Ireland are likely to exist on prominent headlands along the coast, namely Cape Clear, the Old Head of Kinsale, Hook Head, Carnsore Point, Clogher Head, Ards Peninsula and Malin Head. These landmarks can act as recognisable departure or arrival points for harriers travelling to or from Britain or the continent, in the same way as points along the south-west coast of England are for harriers emigrating from Britain to the continent (Etheridge, 2002). In addition to what has been shown through this tagging research and studies by Thomson (1958), Mead (1973) and Etheridge and Summers (2006), there have been some historical eye-witness accounts of harriers using headlands on migration (Anonymous, 1961 and 1973, Durman, 1976).

Of the 15 specific sites in Ireland where Scottish wing-tagged harriers were found during the mid 1990s (Etheridge and Summers, unpubl. data), six were found to host Irish harriers that were tagged as part of the current study, and eight of these sites are known through the Irish Hen Harrier Winter Survey to be communal roosts. Thus, there is likely to be a mixing of Irish and Scottish harriers across the island of Ireland during the non-breeding season. The hypothesis of communal winter roosts acting as social centres with the possibility of mate finding (Chapter 6, Non-breeding Ecology) then becomes all the more interesting, given the possibility of Irish harriers pairing with overseas harriers. Of course it is not just Scottish harriers that may be visiting Ireland, as shown by a record of an English bird in Wexford in 2007 (K. Mullarney, pers. comm.). Birds from Wales, the Isle of Man and even the Continent or Scandinavia may also visit Irish shores.

As British Hen Harriers have been shown to migrate to Ireland and Irish harriers to Britain, there is every likelihood that Hen Harriers in Britain and Ireland may be part of the one metapopulation. ‘Cross-over’ breeding between Britain and Ireland is yet to be confirmed, but observations of the Kerry male sky dancing in Bowland, England shows that this is clearly possible. The non-breeding roost on the Isle of Man, centrally located to all British and Irish populations and one of the biggest in Europe (Leonard, 2004), may also act as a gathering point for Hen Harriers of various natal origins.

7.4.3 Survival

The fact that the majority of re-sightings of wing-tagged harriers were of first winter birds reflects the high attrition rate that Hen Harriers and other birds of prey are known to experience during early stages of their independent lives (Watson, 1977, Newton, 1979; Picozzi, 1984a). The apparent survival rate for Hen Harriers to their first summer was calculated as 27.5%, effectively meaning over 72% of Hen Harriers fledged in Ireland each summer do not survive their first winter. This is higher than the 64% mortality rate estimated for Scotland (Etheridge *et al*., 1997) and Wales (Whitfield and Fielding, 2009). It is important to place the caveat that estimated survival rates for Irish harriers may increase if more individuals are re-sighted in the future. This study spanned four years, whereas that in Scotland and Wales spanned seven years (Etheridge and Summers, 2006). However, it is also possible that estimated survival rates may drop further in future years. Given the current study spanned no more than four years, it would be injudicious to estimate adult mortality from the re-sightings of adults made in this time. Previous estimates by Newton (1979) and Clarke and Watson (1990) placed adult Hen Harrier mortality at 30% and 25% respectively, while more modern appraisals in light of substantial wing-tagging schemes in Britain estimate adult mortality to be approximately 22-23% (Etheridge *et al*., 1997 and Whitfield and Fielding, 2009). Higher mortality rates in Ireland may be related to the fact that Ireland is the most westerly frontier for Hen Harriers. The edge of a species range is often the least suitable (Brown, 1984; Jump and Woodward, 2003; Zaidan *et al*., 2003). It may also be the case that the landscape itself is not productive in terms of prey availability, particularly when it is considered that fewer young are reared per successful breeding attempt in Ireland than elsewhere (Chapter 5, Breeding Ecology).

The strikingly low apparent survival rate of males in their first year (just 9% surviving to breeding age) was also observed by Picozzi (1984a) who estimated only 14% survived their first year in Orkney and Whitfield and Fielding (2009) for Hen Harriers in Wales, where only 7% of male harriers apparently made it to breeding age. To date no adult male Hen Harriers have been sighted in Ireland with wing tags. Whitfield and Fielding (2009) considered males were reported with tags less often because the tags may have been harder to see on their grey/white plumage, yet trials during the current study showed tag colour to be distinguished as effectively on a grey background as on a brown background. In addition, during this study it was found that even males with brown juvenile plumage were sighted less often. One explanation for a lower survival rate in males is that a higher proportion of juvenile males, like adult males in Ireland, are remaining on the uplands throughout the winter months rather than travelling to the lowlands. This may result in higher than average mortality rates, given generally harsher conditions in the uplands during winter. It is possible that males may be more vulnerable in times of food shortages or cold weather, particularly in winter when daylight hours are limited. It is also possible that young males are more likely to continue travelling rather than committing to a non-breeding site that provides quality foraging and safe roosting, thereby being at greater risk during this vulnerable period. A further possibility is that male harriers are more likely to remove the tags than females. In addition, it is possible that males, being smaller, are more commonly predated or fatally injured than their female counterparts. Increased attention from predators may be brought by conspicuous wing tags, thus exacerbating the disparity. During the course of this research, more sightings of wing-tagged harriers being harassed by Peregrine Falcon (*Falco peregrinus*) and Raven (*Corvus corax*) were received than was the case with non-tagged birds, even though wing-tagged birds were in the minority. Wing-tagged Hen Harriers and Montagu's Harriers have been documented in Peregrine nests (Zuberogoitia *et al*., in prep.), and wing-tagged Pallid Harriers (*Circus macrourus*) have been predated by Imperial Eagles (B. Arroyo, pers. comm.). As passerines were found to contribute a significant proportion of winter diet in Ireland (Chapter 3, Diet) it is unlikely that males (which are more adept at catching avifauna) need to travel abroad in search of prey and thus leaving themselves at more risk on such migrations.

7.4.4 Age at First Breeding

While the earliest proven breeding by wing-tagged birds was at two years of age, a number of personal observations have confirmed untagged males and females with juvenile plumage or eye colour to breed as one-year-olds. Various other studies have confirmed breeding by one-year-olds, though most males probably don't get a good chance to breed until their second year (Picozzi, 1984b; Hamerstrom *et al*., 1985; Etheridge *et al*., 1997; Millon *et al*., 2002; Whitfield and Fielding, 2009).

7.4.5 Natal Philopatry

Hamerstrom (1969) and Beske (1982) found very few, if any Northern Harriers returned to breed in the area they came from. Studies in Europe suggest Hen Harriers are more faithful to the sites where they were born (Balfour, 1962a; Picozzi, 1984b; Picozzi and Cuthbert 1982; Klaassen *et al.*, 2008). Etheridge *et al.* (1997) found a median natal dispersal of 10.5km to 150km depending on sex and land management class in which the harriers fledged. During the current study, the median natal dispersal was found to be 27.5km. Of eleven wing-tagged harriers accounted for as confirmed or potential breeders, no more than four were re-sighted back on their natal range. This proportion (along with a higher median natal dispersal distance) may reflect a limited availability of territories in the ranges from which the individuals came, and/or an availability of suitable territories elsewhere (Mougeot *et al.*, 2003; López-Sepulcre and Kokko, 2005). In any case, there is evidence to suggest Hen Harriers in Ireland may establish themselves as part of the breeding population in areas other than their natal area (as proven by the Kerry bird which bred in West Clare). Dispersal can elevate local abundances and reduce extinction risk for populations in temporarily variable 'sink' habitats (Pulliam, 1988), and permit sites to be recolonised after extinction or disturbance (Guo *et al*., 2005). Such movements may also serve to avoid inbreeding (cf. Dale, 2010). To what extent areas can facilitate immigrants must be closely related to resources. Those areas in greatest need of recruitment, given lower fecundity rates, may not be attractive to or suitable for potential recruits.

A number of siblings or birds from the same territory in different years, travelled in opposite directions, to end up as far away as 260km from each other (Appendix VIII). Two female siblings bred in different breeding areas. On the other hand, individuals from different breeding areas happened to roost in the very same non-breeding roost, or were found in the same breeding area during the breeding season. Again, such movements may serve to avoid inbreeding (cf. Dale, 2010).

It was interesting to note that the four wing-tagged harriers which were known to make nests, all did so in habitat which closely reflected the habitat from which they were reared. In three cases the habitat was heather/bog, while in the fourth case the habitat was scrub. Etheridge *et al.* (1997) had previously shown that 90% of harriers born and reared in heather moorland bred as adults in heather moorland, whereas 20%

of harriers born in conifer forests returned to breed in conifer forests, the majority instead choosing to nest in heather moorland.

7.4.6 Site Fidelity

At least one Hen Harrier was proven to switch between winter roosts (10km apart) in a single season and it is possible that individuals will use a number of different roosts throughout the non-breeding period, particularly those travelling long distances to their ultimate destinations. Overall however, harriers tagged during this study showed a high degree of site fidelity, both within and across seasons. Coupled with the findings of other studies which showed individuals to use the same sites each year for breeding (e.g. Etheridge *et al*., 1997; Whitfield and Fielding, 2009), it appears that Hen Harriers in Britain and Ireland are generally faithful to their chosen sites.

7.4.7 Differences between Male and Female Dispersal and Survival

Male harriers were re-sighted less often, had lower apparent survival rates, and travelled further than females. Similar observations had previously been made by Picozzi (1978 and 1984a); Newton (1979); Etheridge and Summers (2006) and Whitfield and Fielding (2009). Efforts towards understanding the driving mechanisms behind these apparent differences between the sexes may be best progressed using the modern technology of satellite tracking, given thousands of wing-tagged birds thus far have posed, rather than answered questions on this matter.

7.5 SUMMARY

Between 2006 and 2009, a total of 151 Hen Harriers were ringed as nestlings; 137 of which were fitted with colour wing tags; 120 of which fledged successfully. Sightings of these Hen Harriers were sought from the public, landowners and those involved in national Hen Harrier surveys. A total of 182 such encounters were recorded and verified, involving at least 43 individual birds; a re-sightings rate of at least 35.8%. Re-sightings data were classified and analysed according to age, natal area, distance travelled, fidelity to natal area, sex and individual birds where possible. Movement of individuals was generally in an easterly or north-easterly direction. Over 83% of re-sighted birds were recorded away from their natal breeding area. The furthest confirmed movement was of a young male re-sighted 520km from his natal site. A juvenile survival rate of 27.5% was calculated using re-sightings of wing-tagged harriers. Eleven harriers were re-sighted during the breeding season; four of which were re-sighted in their natal breeding area and seven of which were re-sighted on other breeding areas. Of all individuals identified, 85% were female and 83% of birds known to have survived their first winter were female. Young males which were re-sighted apparently travelled further than their female counterparts, but had a lower survivorship (9.0%) than females (34.4%). Considerable fidelity to winter and summer territories was shown by those re-sighted in multiple seasons. The possibility of transfers between Irish Hen Harrier breeding areas has been realised, as have links between breeding and non-breeding areas. This study also proves for the first time that Irish born Hen Harriers can and do travel outside of Ireland. A hypothesis for a British/Irish metapopulation has been proposed.

Plate 7.3a. Gort E. Remaining at non-breeding roost in County Galway, 19 April 2009. Photo credit (Plate 7.3a): Tom Cuffe.

Plate 7.3b. Gort E. Passing food to one of her two female fledglings 10km from where she was born herself, 20 August 2010. Within 14 days she was back at her non-breeding roost in County Galway.

Plate 7.4a. Listowel L, as a nestling with missing talon, tag day, 03 July 2007.

Plate 7.4b. Listowel L returning to her own nest just 1km from where she fledged two breeding seasons previously, 18 April 2009.

Photo credit (Plate 7.4b): Ciarán Cronin

Plate 7.5. Listowel N ‘pirating’ an adult male in West Clare, 01 June 2009.

Plate 7.6a. Lissycasey 7/Skomer Saith at her natal site, tag day 06 July 2009.
Photo credit: Paul Troake.

Plate 7.6b. Lissycasey 7/Skomer Saith hunting on Skomer Island, Wales, 19 October 2009. This female was originally taken to be a bird tagged in England in 2002 until the Irish co-ordinator saw a photo of her and correctly identified her as a juvenile female tagged in Ireland. This later photo clearly shows the juvenile plumage of the bird, as well as a lack of 'cross-over' strips between the left and right tags used on British birds. Photo credit: Dave Boyle.

Chapter Eight

Synthesis

The disturbance caused...and the subsequent radical transformation of the terrain rendered it more or less unsuitable for the possibility of return.

Gordon D'Arcy. Ireland's Lost Birds. 1999.

The findings of the preceding chapters are now synthesised with the aim of drawing conclusions from this research; to make recommendations for the conservation of Hen Harriers in Ireland and to identify areas in need of further research.

8.1 Overview

This research has been structured, undertaken and completed with the conservation of one of Ireland's rarest and most threatened birds of prey as its core objective. A holistic approach was adopted, by researching the major elements of Hen Harrier (*Circus cyaneus*) ecology; from non-breeding to breeding season studies, dietary investigations throughout the year, and tracking of movements and survival. A review of the history of the species in Ireland was undertaken and an assessment made of its current status. Data are provided to plan for the future conservation of Hen Harriers in Ireland. This body of research has been pioneering and original in an Irish context, yet also facilitates an increased understanding of the Hen Harrier in the context of Ireland as a neighbour to Britain, as a member of the European Union and as a western-most outpost on the Hen Harrier's global range.

8.2 Diet

Understanding of Hen Harrier diet in Ireland has been advanced by identifying and ranking in terms of frequency occurrence, the species and categories of prey taken by Hen Harriers throughout the entire year (Chapter 3, Diet). A wide range of taxa, including small mammals, lagomorphs, waders, amphibians and reptiles were taken, but small birds were the most commonly consumed category. Meadow Pipit (*Anthus pratensis*) was found to be the single most numerous prey item. Knowledge of the Hen Harrier's diet can now be used to inform conservation measures through habitat management i.e., by protecting, restoring, improving and creating habitats which will provide the most prey. Knowledge of diet can also enhance investigations of breeding productivity and population trends, by relating such features to the abundance and availability of prey, particularly at crucial periods of the breeding season such as the pre-egg laying period. Linked to this, the provisioning rates of Hen Harriers have been established and shown to vary between areas (Chapter 3, Diet) and to influence breeding productivity (Chapter 5, Breeding Ecology). If provisioning rates in Ireland

are lower than in Britain (Chapter 3, Diet), this is likely to be an important reason why successful nests in Ireland produce less fledglings (Chapter 5, Breeding Ecology).

8.3 Nest Sites

Just three habitat categories were found to be used by Hen Harriers for nesting: restock forest (46.7%), heather/bog (29.9%), and scrub (23.4%). A recurring theme throughout the nests documented during this research (Chapter 4, Nest Sites) was that of tall and dense vegetation, linked with requirements for shelter from the elements and protection from predators (given predation was found to be an important issue in Chapter 5, Breeding Ecology). Habitat structure then, was likely to be as critical a feature in nest sites as habitat composition or type. For example, the ground vegetation of scrub and restock forest nests were often the same; dominated by Bramble (*Rubus* spp.), which offered both shelter and protection.

While Hen Harriers were found to exist in proximity to human habitation and activity, they nested further from such activity, tracks and roads than was the case with random control nests. They also nested more often in glens and further up hills than would have been expected at random, probably because such areas have not been as significantly impacted upon by man, particularly in terms of agricultural intensification and afforestation. Further sustained habitat loss and degradation may prove intolerable at local, regional and indeed national scales.

With harriers, food availability cannot be separated from a discussion of nesting habitat (Simmons and Smith, 1985). Food resources are thought to be a more limiting factor than nesting resources (Dobson, 2009). The presence and availability of prey on the landscape will ultimately dictate population size and distribution (Newton, 1979). The fact that Hen Harriers are choosing to nest on the upper reaches of the rolling landscape which they occupy may not only reflect loss of nesting habitat at lower elevations, but also loss of foraging habitat. Heather/bog and scrub are probably the two most obvious examples. Both have been shown to rank as two of the most important foraging habitats on the landscape for Hen Harriers (O'Donoghue, 2004) and provide good numbers of prey (Chapter 3, Diet). However, they have been lost at a higher rate at lower elevations closer to farmland than at higher elevations, including elevations above 300m where forests were not usually planted (Feehan, 2003).

8.4 Breeding Ecology

Breeding ecology was assessed in terms of chronology, nest sites, breeding success and productivity of a representative sample of territories across four of the main breeding areas of the Hen Harrier in Ireland (Chapter 5, Breeding Ecology). The findings of this study present a baseline from which to evaluate future breeding performance, and help inform reasons underlying positive or negative fluctuations in population.

Irish Hen Harriers experienced relatively good breeding success in comparison to neighbouring populations in Britain. However, given failure rates in Britain are exacerbated by human persecution (Etheridge *et al.*, 1997; Potts, 1998; Natural England, 2008; Whitfield *et al*., 2008), comparing British and Irish breeding success is not comparing like with like. Were it not for persecution in neighbouring Britain, the Irish population would likely display the lowest overall breeding productivity in Western Europe (Section 5.4.9). The Irish population exhibited low clutch size, hatching success and fledged brood size; all classic symptoms of a population in decline (Kalejta-Summers, 1995; Meek *et al.*, 1998; Amar *et al*., 2003a). This may be related to the fact that conditions for a species are least favourable at the limits of its distribution (Brown, 1984; Jump and Woodward, 2003; Zaidan *et al*., 2003). However, Scotland, Spain and Norway are also at the limits of the species' distribution, but have higher breeding fecundities (Barth, 1964; García and Arroyo, 2001; Fielding *et al*., 2009). Therefore, poor breeding performance in Ireland may more likely reflect a sub-optimal landscape for Hen Harriers.

Breeding success and productivity were most highly influenced by breeding area, prey delivery in the early breeding season, distance to the nearest track, distance to nearest stream and whether or not the nest was in a glen. As with any raptor species (Newton, 1979), the outcome of Hen Harrier breeding attempts in Ireland are then, essentially reliant on nest security and food availability.

8.5 Non-breeding Ecology

Non-breeding ecology was researched on a national scale; investigating the general distribution of Hen Harriers and their roosts, as well as habitats used, and documenting threats and conservation concerns (Chapter 6, Non-breeding Ecology). In addition, detailed surveys of specific roosting sites were undertaken to record numbers, constitution of roosts in terms of grey males and ringtails, and behaviour of Hen Harriers attending these roosts over a three year period.

Advancing the understanding of the Hen Harrier's non-breeding ecology is vitally important. Not only does this account for the majority of the Hen Harrier's year; but it also represents a more widespread distribution of the species across Ireland than the breeding season. The non-breeding season accounts for the most critical period of a young harrier's independent life and arguably acts as one of the most important influences on the entire Hen Harrier population, in dictating how many harriers will be available for the following breeding season. Fifty-two roosts were located and the Hen Harrier's non-breeding distribution has been mapped. Harriers were found to occupy both upland and lowland locations during the non-breeding season. A divide was noticed between adult males and ringtails in terms of elevation, whereby grey males were more likely to be found in upland locations than ringtails. In addition, most harriers in the west of the country were grey males, while most harriers in the south and east were ringtails. It was interesting to learn that harriers which frequent non-breeding roosts year after year may be the same individuals, as indicated by wing-tagging as part of this research (Chapter 7, Movements and Survival). It was also discovered that individual harriers may use more than one roost over the course of a season. With such information, particularly on roost locations and general distribution, a more in-depth understanding of the Hen Harrier's non-breeding season has been achieved and conservation measures can now be devised for the entire year. A platform for further research and monitoring through the Irish Hen Harrier Winter Survey has been firmly established.

Using data from Chapter 5 (Breeding Ecology) and Chapter 7 (Movements and Survival), a mid-winter population estimate (MWPE) for Hen Harriers in Ireland can now be calculated using the following equation:

$$MWPE = (j.(1 - \tfrac{1}{2} M_j)) + (a.(1 - \tfrac{1}{2} M_a)) + m$$

Where

j = number of juveniles at end of breeding season (calculated by multiplying a confirmed breeding population of 132 pairs (Barton *et al.*, 2006) by overall productivity of 1.62 (Chapter 5, Breeding Ecology).

M_j = annual juvenile mortality (calculated as 0.725 in Chapter 7, Movements and Survival). This mortality is halved to derive an estimate for the number of juveniles existing in mid-winter (December/January, six months from the end of the breeding season in July/August).

a = number of adults (>1yr olds) at the end of breeding season (calculated by multiplying a confirmed breeding population of 132 pairs (Barton *et al.*, 2006) by 2 (assuming monogamy) and adding 42 other individuals that were not confirmed breeding during the most recent breeding survey (Barton *et al.*, 2006)

M_a = annual adult mortality (taken to be 0.226 after Whitfield and Fielding, 2009 and Fielding *et al.*, 2009). This mortality was halved to derive an estimate for the number of adults existing in mid-winter (December/January, six months from the end of the breeding season in July/August).

m = migration. This may be a positive or negative figure, depending on whether there is net emigration or immigration. If an estimated 6.9% of all harriers born in the Republic of Ireland each year migrate out of Ireland (Chapter 7, Movements and Survival), this equates to an outward movement of 15 harriers. The West Highlands in Scotland is the principal area from which immigration to Ireland occurs (Etheridge and Summers, 2006). Applying productivity values from Redpath *et al.* (2002c) to population figures for the West Highlands in Sim *et al.* (2007), and assuming that 2.8% of harriers from the West Highlands will travel to Ireland each winter (as per Etheridge and Summers, 2006), an influx of approximately 15 harriers from that region might be expected to move to Ireland. Thus, migration effects may balance each other in terms of the number of harriers arriving to and departing from Ireland each winter. Links with other areas are also possible or likely, and it is assumed that migration effects balance in these circumstances also.

The mid-winter population of Hen Harriers in the Republic of Ireland during the study period of 2005/6 – 2007/8 is thereby estimated to have been 410 harriers. Clarke (1986) speculated a non-breeding population of less than 150 birds in Ireland, though at the time the Irish breeding population was estimated to be approximately 70 pairs (Watson, 1983). The magnitude by which the Hen Harrier non-breeding population estimate has grown since the 1980s (~ x 2.75) is then relatively similar to the magnitude of growth in breeding population during this time period. Given 165 Hen Harriers were counted during dedicated roost watches (Chapter 6, Non-breeding

Ecology), approximately 40% of the non-breeding population was accounted for during the first three seasons of the Irish Hen Harrier Winter Survey.

8.6 Movements and Survival

The movement of Hen Harriers is one of the least understood aspects of their biology, yet one of the most important, as it links the breeding and non-breeding seasons and is central in population genetics (Simmons, 2000). Until this study (Chapter 7, Movements and Survival), the movements of Hen Harriers in Ireland were subject to speculation. A better understanding of the Hen Harrier's movements in Ireland presents a more complete picture of the Hen Harrier's year and ecology as a whole. This research also adds to knowledge of Hen Harriers across Britain and Ireland collectively, complementing previous and on-going research in Britain (e.g. Etheridge and Summers, 2006).

The general trend of movement by young harriers was towards the east of the country, perhaps in search of a more 'harrier-friendly' winter with better food and climatic conditions, or even in order to migrate off the island. Nevertheless, harriers were recorded to move in all directions, as ultimately represented in the widespread distribution recorded in the non-breeding survey (Chapter 5, Non-breeding Ecology).

The possibility of a British-Irish metapopulation of Hen Harriers is both promising and exciting. From ringing and wing-tagging schemes operated in Britain and now Ireland, it has become increasingly apparent that Hen Harriers can and do migrate between the breeding areas found in this north-western part of the species' global distribution. O'Flynn (1983) suggested that any increase in the Irish population would have to be generated from within the Irish breeding population. While the viability of the Irish Hen Harrier breeding population is fundamentally reliant upon the breeding performance and survivorship of harriers within Ireland, it is possible that birds from Britain could supplement the Irish population and add to its genetic diversity. This would be welcome from a conservation perspective (Pulliam, 1988; Guo *et al*., 2005). However, the possibility of any increase will ultimately be limited by the quality and quantity of suitable breeding habitat, and it is unlikely that birds from elsewhere will be attracted to breed in Ireland if habitat quality is poor, or if there is limited space for extra territories. At a more local scale, the fact that harriers in Ireland have established breeding territories in areas away from their natal areas shows that it is possible that scarcely occupied or completely unoccupied areas may become recolonised should habitat or other circumstances which have prevented harriers from nesting there improve.

Survival rates of juveniles were estimated at 27.5%, but differed between males (9.0%) and females (34.4%). While hypotheses can be offered, the reason for lower male survival, which has also been reported elsewhere (Etheridge *et al*., 1997; Whitfield and Fielding, 2009), is as yet indefinite. The fact that Irish Hen Harriers have been found to have a lower juvenile survival rate than that calculated for the nearest populations in Scotland and Wales (Etheridge *et al*., 1997; Whitfield and Fielding, 2009) adds to a pattern of Irish Hen Harriers being ecologically less well off on a number of issues (including fecundity and recruitment).

8.7 Conservation and Population Modelling

If a population is at favourable conservation status it should be capable of maintaining itself, or expanding, without a requirement for recruitment from other populations. At its simplest this is achieved when reproduction and survival are greater than the combined effects of mortality and dispersal to other populations. This is ultimately linked to habitat availability and quality (Newton, 1979).

The concept of favourable conservation status as addressed by Watson and Whitfield (2002) requires the following parameters to be met:

1. Population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats;
2. The natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future;
3. There is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

Whether any of these criteria are met for the Hen Harrier in Ireland is questionable, given current breeding performance of at least some areas, coupled with a system as changeable as commercial forestry. Fielding *et al.* (2009) set national and regional favourable condition targets for Scottish Hen Harriers of a minimum of 1.2 young fledged per breeding attempt, at least 50% of the apparently suitable habitat occupied and a density (number of pairs per 100 km^2) threshold of 2.12 pairs per 100 km^2 . Each of the four regions studied in Ireland exceeds the breeding density threshold.

Given the large-scale degradation and loss of quality habitats such as heather moorland and scrub, it is also likely that a large proportion of what suitable habitat remains in Ireland is occupied. However, the threshold of 1.2 young fledged per breeding attempt is based entirely on Scottish breeding and survival data and is not necessarily applicable to Ireland.

As various parameters (including breeding performance, sex ratio, and survival) have been evaluated as part of this research, for the first time an assessment of the viability of Irish Hen Harrier populations is possible. To determine based on fecundity and survival/mortality rates whether a population is likely to increase or decrease, the following equation is commonly used in wildlife population modelling:

$$\lambda = S_{ad} + (R \, . \, S_{juv})$$

where λ = population trend; S_{ad} = adult survival; R = number of females fledged per breeding female and S_{juv} = juvenile survival.

A juvenile survival rate of 0.275 (from fledging to first summer) was calculated for Irish Hen Harriers (Chapter 7, Movements and Survival). Adult survival rate was taken as 0.774 using calculations for the nearest breeding population in Wales (Whitfield and Fielding, 2009). This value for adult survival closely matches that for Scotland (Etheridge *et al*., 1997; Fielding *et al*., 2009) and so is the best estimate available in the absence of a longer period of wing-tagging in Ireland. Given a ratio of 1.32 female chicks to 1 male chick and a fecundity rate of 1.62, R was calculated as 0.921. Therefore, λ was calculated as 1.02, meaning should the survival and fecundity rates remain the same, the population should increase by 2% per annum until a carrying capacity is reached. Current data show Kerry and West Clare command population growth rates of 1.12 and 1.14 respectively, meaning that at current productivity, a fledgling surplus of 12% and 14%, respectively, will be produced annually. Kerry and West Clare may thus act as sources for population regeneration in other parts of the country, provided the habitat there is accommodating to such an infiltration. So far, the only exchange has occurred between these two areas themselves (Chapter 7, Movements and Survival). On the other hand, the Ballyhouras has a λ value of 0.93, equating to calculated population decline of 7% per annum, and the Slieve Aughties has a λ value of 0.87, meaning the population is expected to decline by 13% per annum if the currently low breeding productivity continues. Given the survival rate of juveniles and the known sex ratio, an overall productivity threshold for favourable conservation status of the four populations studied is set at 1.45 fledglings per breeding attempt. This productivity threshold calculated for the Irish population has been met and exceeded by Kerry and West Clare, but has not been reached by the Ballyhouras and Slieve Aughties. The threshold is higher than that set for the Scottish population (Fielding *et al.*, 2009), but follows the outlook for the Dutch population where a threshold of more than 1.3 is required (Klaassen *et al.*, 2008), as despite reaching a productivity of 1.3, the population there is in decline (Bijlsma, 2009). It is important to remember that thresholds and calculations of population viability are based on current circumstances and may not necessarily be the case in the future (particularly in a landscape as dynamic as that occupied by Irish Hen Harriers), but it is equally important to consider these for what they are; a view to the future if things stay as they are.

More detailed population viability analysis (PVA) was carried out using Vortex 9.99, a stochastic simulation program (Lacy *et al.*, 2009), which considers parameters such as population size, percentage adults breeding, breeding success and productivity, dispersal, survival rates of first year birds and birds greater than 1 year old, and the carrying capacity of the landscape. The population size of the four study areas was taken as the maximum number of breeding territories identified. While it is reasonable to assume the majority of breeding territories were identified during the course of the two-year study, the possibility of the landscape supporting an extra 20% in Hen Harrier population was considered. This gave an indicative carrying capacity in the four study areas of 101 pairs. The figure of 20% is based on the increase in breeding numbers found by Barton *et al.* (2006) compared to Norriss *et al.* (2002), given the national breeding population between those surveys either increased by 20%; or an extra 20% of birds were found in the second survey that were overlooked in the original survey. While necessarily arbitrary, this is intended to act as a guide to the trend of population growth, up to a defined carrying capacity (which is as yet unknown). The survival rate of juveniles was taken as 0.275 and that of adults as 0.774 (after Whitfield and Fielding, 2009 and Fielding *et al.*, 2009). The maximum age of reproduction was taken as 10 years (after Balfour and Cadbury, 1975; Picozzi, 1984b). The sex ratio for each individual area was known from nest visits in those areas. Simulation was run for 100 years, with 100 iterations. The output of the simulation agreed with what was found by the population growth equation with populations in West Clare and Kerry remaining viable and the Ballyhouras and Slieve Aughties populations predicted to decline. It is interesting to note that both the Ballyhouras and Slieve Aughties were previously documented by O'Flynn (1983) to have become extinct, but had recently recovered somewhat with harvesting of mature forest (Norriss *et al*., 2002; Barton *et al*., 2006), so their existence appears to be influenced by the dynamics of forest growth. Wilson *et al.* (2006a) reported that within a ten year time frame, landscape carrying capacity would be reduced by 30% as a result of forest maturation.

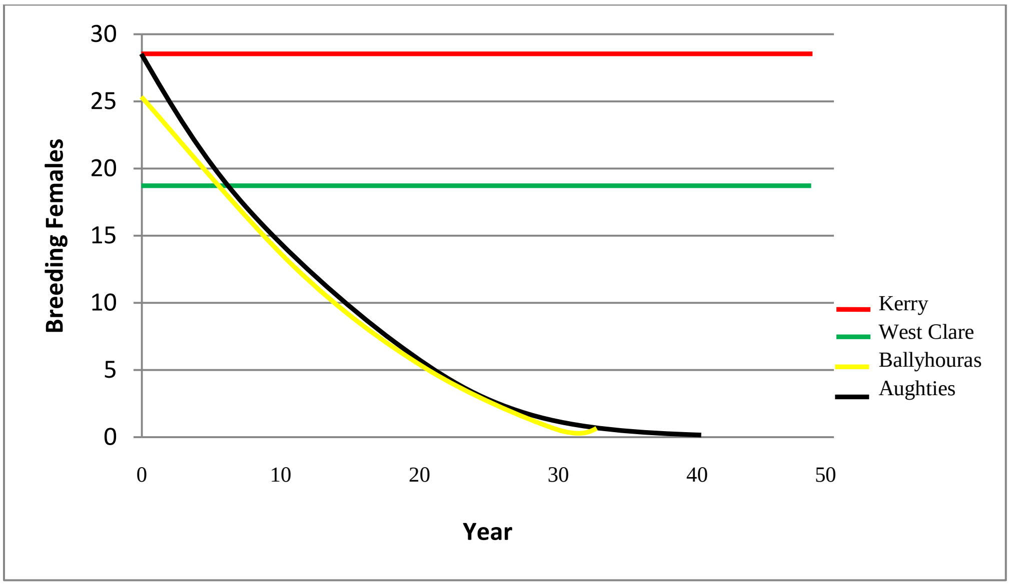

Figure 8.1. Population viability of Irish Hen Harrier breeding areas.

8.8 Surveying for and Working with Hen Harriers in Ireland

A recurring theme throughout this research was to advance the level of knowledge regarding Hen Harriers in Ireland, with a view to disseminating information to those working with the species at home and abroad. By establishing details on nest sites, breeding success and productivity, diet, movements and survival, non-breeding ecology and conservation issues, it is hoped that this body of work has not only provided a better understanding of the Hen Harrier, but also a platform for further research and conservation in the future.

A number of the hypotheses or popular beliefs tested during the course of this research have been rejected, thereby establishing a new realisation of Hen Harrier ecology in Ireland. It should no longer be considered that Hen Harriers winter only in lowland locations or that non-breeding ecology is secondary in importance to breeding ecology. It should no longer be considered that Hen Harriers in Ireland have a propensity to travel south. It should no longer be considered that predation of Hen Harriers in Ireland is not a significant issue. It should no longer be considered that a Hen Harrier seen during the non-breeding season has most likely come from a nearby breeding area. It should no longer be considered that just because the Hen Harrier population here has been downgraded to amber status (Lynas *et al*., 2007), that it is not in danger of reverting to red status or disappearing in parts of Ireland.

This research has established the most definitive chronology of the Hen Harrier's year in Ireland to date, which is summarised in Figure 8.2 and in more detail in Appendix IX. This chronology can be used in informing sensitive approaches to developments or related activities in Hen Harrier areas.

The methods used to find breeding Hen Harriers as part of this research can be replicated by beginning to survey early, starting around mid-March and continuing into April in search of courtship flights and later returning to watch for food passes in late April and May to pin-point nests. Finding non-breeding roosts entails an element of local knowledge regarding suitable habitat, or an ability to interpret aerial photographs, combined at times with casual sightings which may indicate likely locations of roosts.

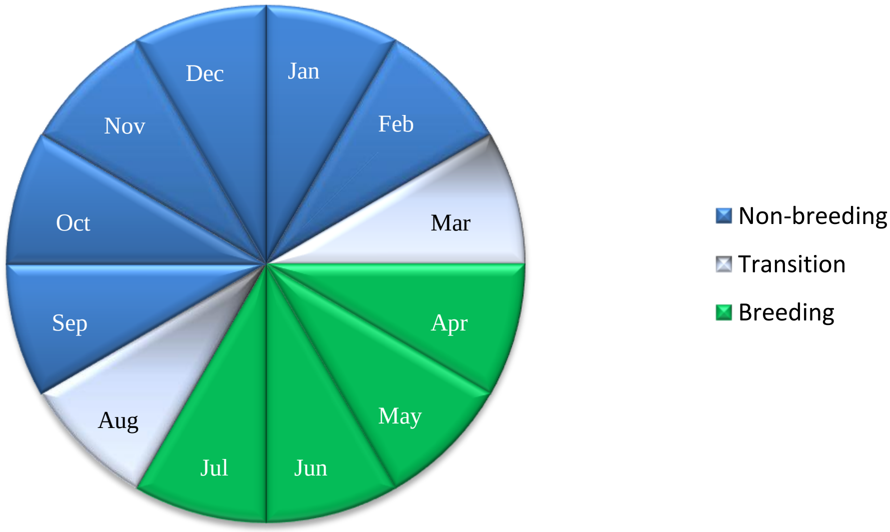

Figure 8.2. Basic chronology of the Hen Harrier's year in Ireland.

8.9 Conservation Recommendations

The decline of many bird populations has been linked to reductions in breeding productivity as a result of habitat loss or degradation (Donazar *et al*., 1993; Tella *et al*., 1998; Robinson *et al.*, 2001; Schmiegelow and Monkkonen, 2002; Fernandez *et al*., 2004; Amar *et al*., 2008). Calls to prioritise the protection and enhancement of natural and semi-natural habitats such as heather/bog and rough grassland have been made across the Hen Harrier's range in Europe (e.g. Amar *et al*., 2005; Cormier *et al*., 2008; Arroyo *et al*., 2009. The following is a list of priority actions that should be taken to bolster the conservation status of Hen Harriers in Ireland:

- Maintain, improve and increase natural and semi-natural habitats, particularly heather/bog, scrub, hedgerows and rough grassland;
- Manage forests in Hen Harrier areas (including designated and non-designated areas) in a way that maximises and optimises the use of open areas and native plant species, particularly through introduction of linear tracts of scrub;
- Diversify the age structure of forest stands in Hen Harrier areas, including delaying replanting after harvesting to extend the period of usefulness for harriers;
- Control predator populations that are causing breeding failure beyond sustainable thresholds or indeed excessive predation at any time of year;
- Educate landowners (and their children) about the Hen Harrier, its conservation status and requirements;
- Protect the most important non-breeding roost sites and their immediate hinterlands;
- Sensitively plan developments within (designated and non-designated) Hen Harrier areas and reject proposals which will have significant adverse impact on Hen Harriers and their habitats.

A holistic approach to upland conservation must be realised. If the fundamentals of upland habitat retention and improvement are met, small birds and small mammals should thrive, along with iconic upland species such as Red Grouse (*Lagopus lagopus hibernicus*) and Curlew (*Numenius arquata*), as well as predators such as Hen Harrier, Merlin (*Falco columbarius*), Sparrowhawk (*Accipiter nisus*), Kestrel (*Falco tinnunculus*) and Peregrine Falcon (*Falco peregrinus*). Essentially, these flagship species are indicators of the well-being of the entire ecosystem (Sergio *et al*., 2005). Sensitive species like the Hen Harrier would neatly fit the concept of 'focal species modelling', whereby the species with the most demanding requirement for various landscape parameters is used to define its minimum acceptable value (Fleischmann *et al*., 2000).

8.10 Further Research

Hen Harrier research is in its relative infancy in Ireland, and what foundations have been laid through the current research should be built upon in the future. Of particular importance will be longitudinal studies, including continued recording of wing-tagged harriers and continued study of existing breeding territories and non-breeding sites. In addition, further research should be pioneered to investigate outstanding issues, particularly:

- Satellite tracking juveniles to gain knowledge of exact routes taken on migration, staging points (with the potential of locating new roosts), and reasons behind a higher mortality rate in males;
- Study of breeding season diet and breeding productivity outside of the Bank Vole (*Myodes glareolus*) range in Ireland;
- Monitoring of diet and breeding productivity in relation to the spread of the recently introduced Greater White-toothed Shrew (*Crocidura russula*);
- Monitoring of the impact on Hen Harrier numbers and distribution by the continued range expansion of Common Buzzards (*Buteo buteo*) and Goshawk (*Accipiter gentilis*);
- Monitoring of potential, if any, effects of climate change;
- Studies of predator populations in Hen Harrier areas (during all seasons);
- Quantifying the extent and effect of habitat fragmentation in Hen Harrier areas;
- Investigating the impacts of wind farms on Hen Harriers, particularly in terms of hunting success and breeding productivity;
- Further investigation of the usage of upland areas for non-breeding;
- Further collaboration between Irish, British and European Hen Harrier researchers. In particular an All-Ireland approach should be encouraged on any future Hen Harrier research in Ireland.

In addition to targeted research, local people and schools should be encouraged to study and document Hen Harriers in their localities.

8.11 Conclusion

From the earliest accounts, the Hen Harrier in Ireland has endured loss of numbers and distribution. Today in a number of areas (including at least one Special Protection Area), prospects for the future are poor. There is only so long a population can continue to wane until a critical point is reached, beyond which there is little or no chance of recovery (Rabinowitz, 1995; Turvey, 2008). Even noted Hen Harrier strongholds have been lost or diminished in the absence of conservation action (Watson, 1977 and 1983; O'Flynn, 1983; Clarke and Watson, 1997; Bergmann, 1998; Meek *et al*., 1998; Amar *et al*., 2003a,b). The issue underpinning the decline of the Hen Harrier has been, and continues to be, habitat loss and degradation. This trend must be halted or reversed if we are to realise a future for this iconic part of Irish wildlife, which has roamed the island for at least 1,000 years (D'Arcy, 1999).

White-tailed Eagle (*Haliaeetus albicilla*), Golden Eagle (*Aquila chrysaetos*), Red Kite (*Milvus milvus*), Goshawk (*Accipiter gentilis*), Common Buzzard (*Buteo buteo*), Osprey and possibly Honey Buzzard (*Pernis apivorus*) and Hobby (*Falco subbuteo*) were all lost from Ireland as breeding species (D'Arcy, 1999; Golden Eagle Trust, 2008). Significant strides are now being made to re-introduce the first three on this list, while Goshawk and Common Buzzard are making a natural re-colonisation. However, one of the most vital points to remember about harriers is that if they are lost, they do not only join the beleaguered list of our lost birds, but are essentially lost forever. There is little or no hope of reintroduction, given the reason for their loss would be irrevocable loss of habitat. The Marsh Harrier (*Circus aeruginosus*) was once the most abundant of Ireland's larger raptors (Watters, 1853), yet in the 20th Century disappeared as a breeding species. It is sincerely hoped that this research and its findings are used to ensure this does not happen to our one remaining harrier.

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Appendices

Appendix I.

Bird Species Recorded in the Main Habitats of the Hen Harrier's Breeding Grounds in Ireland

Species	Scientific Name	Restock	Clearfell	Heath /Bog	Intensive Grass	New Forest	Rough Grass	Riparian	Scrub/ Hedge	Forest Track	Turbary
Blackbird	*Turdus merula*	•			•	•		•	•	•	•
Blackcap	*Sylvia atricapilla*	•							•		
Blue Tit	*Cyanistes caeruleus*	•			•	•	•	•	•	•	
Bullfinch	*Pyrrhula pyrrhula*								•		
Chaffinch	*Fringilla coelebs*								•	•	
Chiffchaff	*Phylloscopus collybita*								•	•	
Coal tit	*Periparus ater*					•			•		
Crossbill	*Loxia curvirosta*									•	
Dipper	*Cinclus cinclus*							•	•		
Dunnock	*Prunella modularis*	•	•			•			•		
Goldcrest	*Regulus regulus*	•							•		
Goldfinch	*Carduelis carduelis*								•		
Grasshopper Warbler	*Locustella naevia*							•	•		
Great Tit	*Parus major*		•						•		
Greenfinch	*Carduelis chloris*								•		
Grey Wagtail	*Motacilla cinerea*							•	•		
House Sparrow	*Passer domesticus*								•		
Kingfisher	*Alcedo atthis*							•			
Linnet	*Carduelis cannabina*								•		
Meadow Pipit	*Anthus pratensis*			•		•	•			•	
Pied Wagtail	*Motacilla alba*	•	•						•	•	
Reed Bunting	*Emberiza schoeniclus*							•			
Robin	*Erithacus rubecula*	•			•		•		•	•	
Red Grouse	*Lagopus lagopus*			•							
Sedge Warbler	*Acrocephalus schoenobaenus*							•			
Siskin	*Carduelis spinus*	•							•	•	
Skylark	*Alauda arvensis*			•	•	•	•		•		•
Snipe	*Gallinago gallinago*			•							•
Song Thrush	*Turdus philomelos*	•				•	•		•		
Starling	*Sturnus vulgaris*				•		•		•		
Stonechat	*Saxicola torquata*	•		•		•	•	•	•	•	•
Swallow	*Hirundo rustica*	•	•	•	•	•	•	•	•	•	•
Wheatear	*Oenanthe oenanthe*						•		•		
Willow Warbler	*Phylloscopus trochilus*	•		•		•	•	•	•	•	•
Wren	*Troglodytes troglodytes*	•	•	•		•			•	•	•

Appendix II. Data Recorded on Hen Harrier Field Observations in 2007 and 2008.

Date

Weather

Vantage Point

O.S.I. Map No.

Time of watch (from - until)

Duration of watch

Harrier seen (male/female/juvenile)

Where seen

Time first seen

Time out of sight

Activity

Habitat

Duration of Hunting

Habitat Hunted

Comments

Other Raptors

Other Birds of Note (incl. predators/competitors)

Appendix III. Photographs used as a reference for aging Hen Harrier chicks.

Appendix IV.

Non-breeding Roost Watch Recording Sheet

Irish Hen Harrier Winter Survey

Please return to Barry O'Donoghue, Ballynabrennagh, Tralee, Co. Kerry or email harriers@environ.ie

Observer(s)	
Site Name	
Date	
Time of Watch (24hr clock)	
Duration of Watch (minutes)	
Sunset (sunrise) time	

Weather - please mark as appropriate		
Wind Force (dir.)	**Precipitation**	**Temperature**
F 0-3 ( )	Dry	Mild
F 4-6 ( )	Intermittent or Drizzle	Cool
F 7-9 ( )	Constant Rain	Cold
F 9+ ( )	Snow/Hail	Very Cold

Total Number of *Individual* Hen Harriers seen

Other Wildlife of Note

Bird No.	**Hen Harrier Type (Ringtail / Ad. Male etc.)**	**Time of Arrival**	**Direction in from**	**Time of Settling**	**Interaction with other Harriers/Species**	**General Activity**	**Other Comments (e.g. distinguishing features of bird(s)).**

Appendix V.

Non-breeding Roost Details Recording Sheet

Non-breeding Roost Details Recording Sheet

(Preferred) Roost name		Grid reference	
Townland		Elevation	
County (and part of county)		Best vantage point(s) grid reference	
Discovered (person and year)		Distance from Coast	
Regular Observer(s)		Traditional range in numbers (and max)	

Terrestrial Habitat (within 100m radius of roosting area)

Main Habitat	Flora 1 (%)	Flora 2 (%)	Flora 3 (%)	Flora 4 (%)	Flora 5 (%)	Flora 6 (%)	Flora 7 (%)	Flora 8 (%)	Flora 9 (%)

Structural Habitat (within 100m radius of roosting area)

% Bare ground	% Open water	Access Road (Details)	Size of overall Habitat Complex (ha)	Surrounding habitats

Possible Threats (and Likelihood):

Threat	Likelihood (low/med/high)	Already Active? Comments	Protection Status

Roost used by (name species involved across the rows)

Passerines	
Waders	
Ducks	
Gulls	
Swans	
Geese	
Birds of Prey	
Corvids	
Other	

Appendix VI.

Casual Sightings Form

Irish Hen Harrier Winter Survey

Hen Harrier Casual Sightings Form 2007 – 2008. Please Return to Barry O'Donoghue, Ballynabrennagh, Tralee, Co. Kerry or harriers@environ.ie

Observer Name:

Date	Time	Harrier (Brown/Grey)	Where (townland, county, grid ref)	Nearest known/ likely roost	Activity	Travel direction	Habitat	Tags	Comments

Appendix VII.

Wing-Tagging Poster (2009, Front and Back)

Have You Seen These Birds?

Please contact Barry O'Donoghue 087-9110715 or harriers@environ.ie for sightings or information on **Hen Harriers**.
See reverse for details.

Ballyhoura's
(Cork/Limerick) Right **Yellow**

Kerry
Right **Red**

West Clare
Right **Green**

Slieve Aughties
(Clare/Galway) Right **Black**

PLANFORBIO

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Irish Raptor Study Group
Grúpa Staidéir Éan Creiche na hÉireann

Hen Harriers are a large Bird of Prey, rare and threatened in Ireland. Females and young are brown with noticeable patterns underneath and have a white rump on their tail, giving them the name ringtails. Adult males are white/silver with black wing tips with protruding "fingers". A scheme has been initiated to find out where our Hen Harriers are going and whether they return home. Coloured tags on the back of their wings will help tell us this.

Records from the public are the key to this information!

The colour of the left wing tag will tell us what year the bird was born. All birds born and tagged in **2009** have a **YELLOW** tag on their **LEFT** wing. In **2006** this colour was **Blue,** in **2007** it was **Red** **and in** **2008** **it was** **Green**. The tag on the right wing identifies where the bird has come from, one of four places in 2009 (see overleaf). Each individual bird has its own symbol written on both tags.

Tagged birds have been found outside of the four areas where tagging has taken place so keep an eye out! Sightings of non wing-tagged Hen Harriers are also very welcome!

Male Hen Harrier (top) passing food to his Female

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Appendix VIII.

Movements of Hen Harriers Wing-Tagged in the Same Breeding Territory

Case 1. Knocknagashel J and Knocknagashel N

	Knocknagashel J	**Knocknagashel N**
Provenance	Kerry	Kerry
Born	2007	2008
Sex	Female	Female
Number of re-sightings	14	2
Furthest sighted from natal area	127km	42km
Bearing to furthest distance	ESE	N
Greatest Distance between pairing	141km	141km
Notes	Has utilised the same winter roost for 1st, 2nd and 3rd winters, 117km SE of natal area and found breeding as 3 year old, 47km NE of wintering site	Roosted 42km N of her natal area in her first winter

Case 2. Listowel L and Listowel N

	Listowel L	**Listowel N**
Provenance	Kerry	Kerry
Born	2007	2007
Sex	Female	Female
Number of re-sightings	6	4
Furthest sighted from natal area	57km	1km
Bearing to furthest distance	NNE	-
Greatest Distance between pairing	58km	58km
Notes	Attempted breeding in 3rd cy in West Clare, 57km North of natal site	Seen at natal area in 2cy and proven to have bred in 3cy just 1km from natal site

Case 3. Tralee S and Tralee I

	Tralee S	**Tralee I**
Provenance	Kerry	Kerry
Born	2007	2009
Sex	Female	Male
Number of re-sightings	1	1
Furthest sighted from natal area	21km	125km
Bearing to furthest distance	NNE	E
Greatest Distance between pairing	104km	104km
Notes	Found dead 21km NNE of natal site in 1st winter	Found dead 125km E of natal site in 1st winter

Case 4. Lissycasey 7 and Lissycasey 7/Skomer Saith

	Lissycasey 7	**Lissycasey 7/Skomer Saith**
Provenance	West Clare	West Clare
Born	2008	2009
Sex	Female	Female
Number of re-sightings	8	25
Furthest sighted from natal area	133km	295km
Bearing to furthest distance	SE	SE
Greatest Distance between pairing	208km	208km
Notes	Observed roosting at two communal winter roosts in her first winter.	Migrated across St. George’s channel and spent 1st winter in Wales before succumbing to harsh weather on what is believed to have been her return journey to Ireland.

Case 5. Doneraile C and Doneraile L

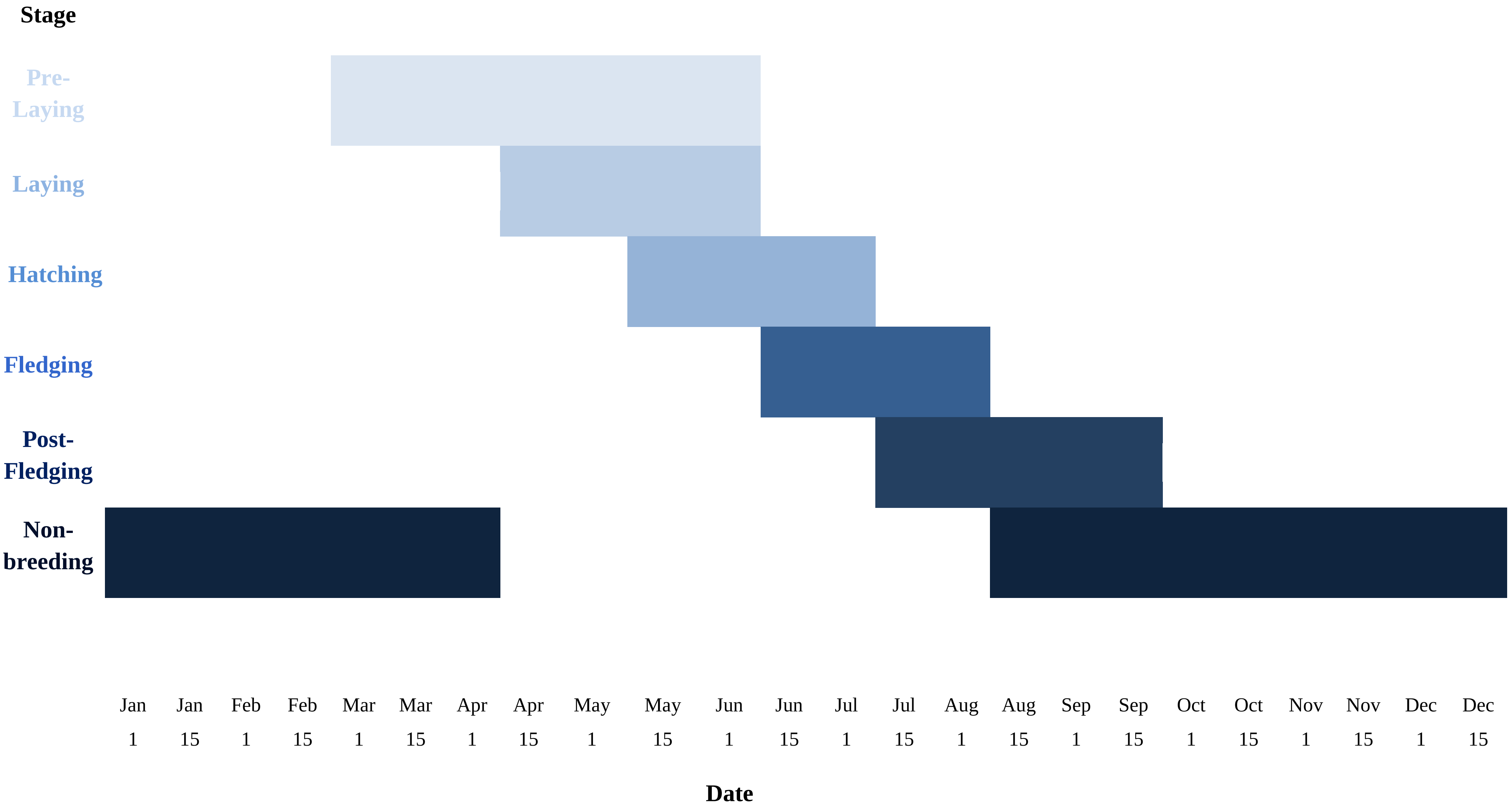
	Doneraile C	**Doneraile L**
Provenance	Ballyhouras	Ballyhouras
Born	2009	2009
Sex	Female	Female
Number of re-sightings	5	16
Furthest sighted from natal area	85km	120km
Bearing to furthest distance	NW	N
Greatest Distance between pairing	152km	152km
Notes	Seen at winter roost 85km to NW and attempting to enter breeding population on neighbouring mountain ranges in 2^{nd} cy	Established home winter territory 120km N of natal site in her first winter.

Case 6. Mountshannon T and Mountshannon V

	Mountshannon T	**Mountshannon V**
Provenance	Slieve Aughties	Slieve Aughties
Born	2009	2009
Sex	Female	Female
Number of re-sightings	3	4
Furthest sighted from natal area	132km	175km
Bearing to furthest distance	S	NE
Greatest Distance between pairing	260km	260km
Notes	Established home winter territory 132km S of natal site in her first winter	Established home winter territory 175km NE of natal site in her first winter

Appendix IX.

Detailed Chronology of the Hen Harrier's Year in Ireland


Stage
Pre-Laying
Laying
Hatching
Fledging
Post-Fledging
Non-breeding
Jan 1
Jan 15
Feb 1
Feb 15
Mar 1
Mar 15
Apr 1
Apr 15
May 1
May 15
Jun 1
Jun 15
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
Nov 1
Nov 15
Dec 1
Dec 15
Date

Young Female Hen Harrier on her first breeding attempt, Cordal, Co. Kerry 2007.

My, what a good day for a, walk outside
I'd like to get to know you a little better,
God knows that I really tried