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The Ecology of the Song Thrush, *Turdus philomelos* Br., in Ireland.

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Thesis submitted for the degree of Ph.D. to the National University of Ireland, Cork.

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To Eire and her Song Thrushes

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Thesis Summary

1. Over the last 30 years, western European Song Thrush populations have declined with the steepest decline recorded on British farmland. Changes in agricultural practices have been implicated in these population declines.
2. Ireland is an agriculturally dominated landscape but changes in agriculture here have occurred on a relatively slower rate and scale.
3. Little is known about the ecology of the Song Thrush in Ireland, even though it is not classified as a species of conservation concern here. Some decline is thought to have occurred but the current breeding population appears to be stable and widespread.
4. In light of these facts, this study investigated various aspects of Song Thrush ecology in relation to the Irish landscape from 2001-2003.
5. The breeding season extended from mid March to late June, where mean clutch size was 4.1 and number of fledglings was 3.7. There were very few third broods. Daily nest survival rates were calculated for egg stage 0.9362, incubation stage 0.9505 and nestling stage 0.9609. Most nest failures were due to avian predation at both egg and chick stages.
6. Most nests were located 1.3 - 2.4m from the ground at trees, bushes or hedgerow. Clutch size was significantly higher on farmland than garden & parkland and woodland, and the number of fledglings was significantly lower in nests in trees than hedgerow and bush sites. Daily nest fail rates were significantly higher at tree sites and partly concealed nests. Nesting areas had significantly denser vertical vegetation than non-nesting areas.

7. Mercury and the organochlorine HEOD were the most common contaminants in Song Thrush eggs and livers. However concentrations and occurrence were low and of no apparent biological or ecological concern.
8. The presence of breeding Song Thrushes was influenced by mixed surrounding farmland, the absence of grass surrounding farmland, ditches, especially wet ones, tall dense vegetation and trimmed boundaries. Song Thrush winter densities were predicted by ditches, either wet or dry, low thin vegetation and untrimmed boundaries. Winter densities were almost double that of the breeding season, probably due to the arrival and passage of migrating Song Thrushes through the country, especially in November.
9. Changes in Irish agriculture did not differ significantly in areas of Song Thrush breeding population stability and apparent decline during 1970 – 1990. Even though the current breeding population heavily uses farmland, woodland, human and scrub habitats are more preferred. Nevertheless no farmland habitat was avoided, highlighting a positive relationship between breeding Song Thrushes and Irish agriculture. This appears to be in contrast with findings between breeding Song Thrushes and British agriculture.
10. These findings are compared with other studies and possible influences by agricultural intensification, climate, latitude and insular syndrome are discussed. Implications for conservation measures are considered, especially for areas of decline. Even though Song Thrushes are currently widespread and stable here, future environmental consequences of longer-term changes in Irish agriculture and perhaps climate change remain to be seen.

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Chapter 1: General Introduction



The Song Thrush, *Turdus philomelos* Br., is distributed across the upper and middle latitudes of west and central Palearctic, extending from Ireland to Lake Baykal and from montane Southern Spain and Iran up to 70°N (Cramp 1988, Simms 1989, Tomialojć 1997). It is found in habitats with cool, humid and windy climate but avoids those with very dry, warm and persistent frost and/or snow conditions (Cramp 1988, Tomialojć 1997). Three races exist in the western Palearctic, *philomelos* in continental Europe, *clarkei* in Britain, Ireland and adjacent mainland and *hebridensis* in Outer Hebrides and Skye (Cramp 1988). While the species is regarded as a forest bird of both deciduous and coniferous forests, especially in north-east, east and central Europe, it has adapted to the conversion of western European lowlands to agricultural, industrial and urban uses by using other habitats such as small woods, parklands, hedgerow and gardens (Dycrz 1969, Cramp 1988, Tomialojć 1997).

The species usually has two to three broods from March to July with clutches of two to six eggs (Silva 1949, Myers 1955, Snow 1955, Dycrz 1963, Pikula 1969, Wesolowski & Czapulak 1986, Cramp 1988, Schnack 1991, Weidinger 2001). While breeding territories are maintained by monogamous pair bonds, resident birds are otherwise solitary or in small feeding and roosting groups and migrant birds form large loosely coordinated flocks (Cramp 1988). Song Thrushes do not forage as far out into open fields as other thrushes (Cramp 1988). Grassland is also an important foraging habitat along with non-cropped habitats such as field boundaries

and woodland edge (Murray 2004, Peach *et al.* 2004), especially of earthworms, *Lumbricus*, and snails, *Helix* (Gruar *et al.*, 2003, Murray, 2004).

Conservational concern

Over 75% of Song Thrush populations breed and winter within Europe (Tucker & Heath 1994). The European breeding population is currently classified as ‘secure’ (BirdLife International, 2004), but some breeding populations in different European countries have experienced a decline between 1970-1990 (Tucker & Heath 1994). During this period breeding population fluctuations have been noted in France, a slow decline has been found in the Netherlands and a severe decline has occurred in Britain where it is currently regarded as a species of conservation concern (Tucker & Heath 1994, Gibbons *et al.* 1996). In fact, the long-term decline (*i.e.* 1970-2001) in the UK has been approximately 52% (Eaton *et al.* 2004), where the largest decline has occurred on farmland with a lesser decline in woodland (Thomson *et al.* 1997, Baillie *et al.* 2002). However, the present breeding population in the UK appears to be recovering with a 13% increase between 1994-2002 (Eaton *et al.* 2004, Newton 2004).

The declines of some western European farmland bird populations appear to be driven by landscape changes resulting from corresponding changes in agricultural practices, primarily instigated by the EU Common Agricultural Policy (CAP) (Fuller *et al.* 1991, Fuller *et al.* 1995, Pain *et al.* 1997, Tucker & Dixon 1997, Chamberlain *et al.* 2000, Gates & Donald 2000, Vickery *et al.* 2001, Benton *et al.*

2002, Chamberlain 2002, Donald *et al.* 2002, Newton 2004). At a demographic level, reduced survival rates of juvenile birds especially during their first winter seem to have played a role in the breeding population decline in Britain (Thomson *et al.* 1997, Siriwardena *et al.* 1998, Robinson *et al.* 2004). While winter frosts have contributed to the decline, other environmental causes remain unknown with changes in farming practices, land drainage, pesticides and predation potential contenders (Thomson *et al.* 1997, Robinson *et al.* 2004). Food limitation in a declining Song Thrush population in Southeast England has been implicated as a possible factor behind fewer breeding pairs and nesting attempts (Gruar *et al.* 2003). This limitation in food resources for breeding Song Thrushes is probably due to changes in agricultural practices, especially in arable dominated areas of Britain where the loss of hedgerow, scrub, woodland, grassland and the widespread use of under-field drainage have been identified as key factors behind their food shortage and subsequent population declines in such areas (Gruar *et al.* 2003, Peach *et al.* 2004).

The situation in Ireland

Breeding population trends in Ireland are unclear due to the lack of long-term data, although some decline is thought to have occurred between 1970-1990 (Tucker & Heath 1994) with some contraction in breeding distribution also indicated (Sharrock 1976, Gibbons *et al.* 1993). That said, the recently (1998) established national bird-monitoring programme, Countryside Bird Survey, suggests that the breeding Song Thrush population is currently stable and widely distributed in Ireland (Coombes

2003). Unlike Britain, the Song Thrush is not classified as a species of conservation concern in Ireland (Newton *et al.* 1999), but little is known about its ecology here.

Additionally, Ireland differs to Britain and mainland Europe in several environmental aspects, which could have different consequences for Song Thrush populations here. These differences include the following:

(1) Ireland's smaller size has resulted in lower habitat diversity and species diversity including predator species (Hutchinson 1989, Sleeman 1989, Aalen *et al.* 1997), which could have implications on predator pressure for open nesting bird species like the Song Thrush.

(2) Ireland has a wetter and milder climate than other European countries including England, especially southeast England (Keane 1986, Bowen 1973, Chandler & Gregory 1976, Hulme & Barrow 1997), giving Ireland a relatively 'aseasonal' climate. The implications for Song Thrushes in this case include foraging opportunities, especially for their favoured earthworm (*Lumbricus*) (Gruar *et al.* 2003, Murray 2004), and over-winter survival since Song Thrushes are knowingly affected by winter frosts (Baillie 1990, Thomson *et al.* 1997, Robinson *et al.* 2004).

(3) The geographical position of Ireland on the western fringe of Europe and the island effect or 'insular syndrome' may also have implications for Song Thrush breeding including smaller clutch size, later breeding, lower breeding productivity,

higher population density (Lack 1947, Blondel 2000) as found in other Irish passerine species studies (Smiddy *et al.* 1995, Smiddy & O'Halloran 1998, Fennessy 2001, Cummins & O'Halloran 2003).

(4) Finally, the Irish landscape is dominated by agriculture, which has been implicated in the decline of some farmland bird species including the Song Thrush, but agriculture here has experienced a relatively lower rate and scale of agricultural change and intensification in comparison to other Western European countries, including the UK (Cabot 1985, Lysaght 1989, Stanners & Bourdeau 1995, Aalen *et al.* 1997).

This study

Therefore this study, being the first one in Ireland to investigate the ecology of the Song Thrush in detail, attempts to bridge some of the gaps in knowledge that currently exist on the interaction of the Song Thrush with the Irish environment.

Knowing the importance found for multi-spatial scales in ecological studies including birds (Baillie *et al.* 2000, Hill & Hamer 2004, Brennan & Schnell 2005), this study was conducted at different spatial scales, from intensive (Chapters 2 & 3) to intermediate scale (Chapters 4 & 5) and finally national scale (Chapter 6).

Ecological aspects of the Song Thrush in Ireland were investigated by this study as follows:

Chapter 2: The Breeding Biology of the Song Thrush, *Turdus philomelos*, in an island population.

This chapter investigates the basics of Song Thrush breeding by describing the timing of breeding, clutch size and number of nestlings hatched and fledged, assess nesting success and investigate growth development of nestlings in Song Thrush. Nests were monitored intensively and extensively for three consecutive breeding seasons. The results are compared to other European countries and differences discussed in light of agricultural intensification, climate, latitude and insular syndrome.

Chapter 3: The influence of nesting habitat on breeding Song Thrushes, *Turdus philomelos*.

This chapter describes the nesting habitat of a stable Song Thrush breeding population, investigates its influence on breeding and examines what habitat variables influence Song Thrushes in choosing a nest site by comparing habitat variables in nesting areas with random non-nesting areas. Nesting habitat data were collected from intensively monitored sites and extensively monitored sites as part of the Song Thrush breeding survey in Chapter 2. The results show that nesting habitat significantly influences Song Thrush nest site choice, breeding output and daily nest failure rates and the implications of these results on Song Thrush conservation strategies are discussed.

Chapter 4: Mercury and organochlorine contamination in the Song Thrush, *Turdus philomelos*, a passerine species representing the terrestrial ecosystem.

The occurrence and concentrations of Mercury and organochlorine contaminants are examined in Song Thrush eggs and livers. Egg samples were collected in conjunction with the Song Thrush breeding survey in Chapter 2 at the intensively monitored sites and liver samples were taken from freshly dead specimens found at the same intensive study sites and random locations around Co. Cork. The results find that contamination levels are low and of no apparent biological or ecological concern for Song Thrushes here and provide a baseline for mercury and organochlorine contamination levels in the Irish terrestrial environment for use in future monitoring studies.

Chapter 5: The influence of farmland habitat and season on the presence and density of Song Thrushes, *Turdus philomelos*.

This chapter investigates the influence of farmland use, field boundaries and season on the presence and density of Song Thrushes. Song Thrushes and habitat variables were surveyed on 19 lowland farms during the breeding and winter season of 2002 to 2003. The results show that different habitat variables are important in predicting breeding presence and winter densities, although ditches remain important during both seasons. Trends shown by the results for winter densities are used to explain patterns in the movement of migratory Song Thrushes. The implications of the results on conservation measures benefiting Song Thrush populations all year round are considered.

Chapter 6: Changes in agriculture and its influence on breeding Song Thrush, *Turdus philomelos*, populations in Ireland.

This chapter relates long term changes in Song Thrush breeding distribution with changes in agriculture, investigates changes in recent breeding distribution, calculates current habitat specific densities and assesses current breeding habitat use and preferences of breeding Song Thrushes. The results show the relatively positive relationship that exists between breeding Song Thrushes and Irish agriculture and comparisons are made with studies in Britain. Factors that may explain the positive interaction that exists between Irish agriculture and breeding Song Thrushes and differences between Ireland and Britain are considered.

Chapter 7: Concluding remarks.

This chapter brings the major findings of this research together with particular reference to the influences of environmental differences between Ireland and other European countries. It also considers the future direction of Song Thrush research here and highlights possible future changes in the Irish landscape that need to be monitored.

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Chapter 2:
**The Breeding Biology of the Song Thrush, *Turdus philomelos*, in an
island population.**



This has been accepted for publication in Bird Study and is presented in the format of this journal.

Capsule Breeding characteristics were explained by agricultural intensification, climate, latitude, and insular syndrome.

Aims To describe the timing of breeding, clutch size and number of nestlings hatched and fledged, assess nesting success and investigate growth development of nestlings in Song Thrush.

Methods Nests were monitored intensively in County Cork, southwest Ireland, and extensively countrywide by volunteers. The number of nesting attempts, location, surrounding habitat, nest height above ground and sea level, date of first egg, nesting stage, clutch size, number of chicks hatched and fledged and causes of nest failure, daily nest survival, FPA (fledglings per attempt), ROA (reproductive output per attempt) and seasonal productivity were recorded.

Results Data collected from 100 nests during 2001-2003 were available for analysis. The breeding season extended from mid March to late June. Only 3% of nests represented third broods. Mean clutch size was $4.1 (\pm 0.62)$, number of hatchlings was $3.7 (\pm 0.92)$ and number of fledglings was $3.7 (\pm 0.89)$. Clutch size and brood size, at hatching and fledging, significantly differed with month, year, nesting attempt, latitude and altitude. FPA was calculated as 0.75 and ROA as 1.13. Seasonal productivity was calculated as 2.7 young fledged from 3.7 nesting attempts. Daily nest survival rates were: egg stage $0.9362 (\pm 0.0126)$, incubation stage $0.9505 (\pm 0.0121)$ and nestling stage $0.9609 (\pm 0.0096)$. First broods had higher, though not significantly, daily failure rates than second broods during all nest stages. Weather did not have any significant effects on nest survival or

outcome. Most nest failures were due to predation at both egg and chick stages.

Avian predation was more common than mammalian.

Conclusion Differences in breeding biology characteristics between Ireland and other European countries may be explained by agricultural intensification, climate, latitude and insular syndrome. The data presented can be used as a baseline for future monitoring and may also help in conservation measures in areas of decline.

Introduction

The decline in some farmland bird populations across Western Europe over the last 30 years has been widely documented (Fuller *et al.* 1991, Tucker & Heath 1994). Changes in agricultural practices with corresponding changes in landscape appear to be driving these declines (Fuller *et al.* 1995, Tucker & Dixon 1997, Chamberlain *et al.* 2000, Chamberlain 2002, Vickery *et al.* 2001). The Song Thrush is now classified as a species of conservation concern in Britain (Gibbons *et al.* 1996), though not in Ireland (Newton *et al.* 1999). In Britain its population has declined rapidly on farmland (65%) but less so in woodland (Thomson *et al.* 1997, Baillie *et al.* 2002) with a long-term trend indicating a drop by 52% (Eaton *et al.* 2004). However, recent monitoring in Britain indicates that the population is now increasing (Newton 2004). At a demographic level, the population decline in Britain seems to have been driven by changes in survival of juvenile birds especially during their first winter (Thomson *et al.* 1997, Siriwardena *et al.* 1998, Robinson *et al.* 2004). Food limitation in a declining Song Thrush population in Southeast England

has also been implicated as a possible factor behind fewer breeding pairs and nesting attempts (Gruar *et al.* 2003).

Little is known about the ecology of the Song Thrush in Ireland and population trends are unclear due to the lack of long-term data, although some decline may have occurred 1970-1990 (Tucker & Heath 1994). However, a national bird-monitoring programme (Countryside Bird Survey), established in 1998, suggests that Song Thrush populations in Ireland remain widely distributed and stable (Coombes 2003). The lack of trend data, especially pre 1998, together with changes in Irish agricultural practices, which have occurred at a slower rate and reduced scale than other Western European countries (Cabot 1985, Lysaght 1989, Stanners & Bourdeau 1995, Aalen *et al.* 1997), provides an opportunity for baseline data on the species which may help conservation measures in areas where it is declining. Accordingly, some key aspects of the breeding biology of the Song Thrush in Ireland, an island population, are reported for the first time. We describe the timing of breeding, clutch size, number of nestlings hatched and fledged. We also assess nesting success for different nesting periods and describe the development of nestling growth.

STUDY SITES

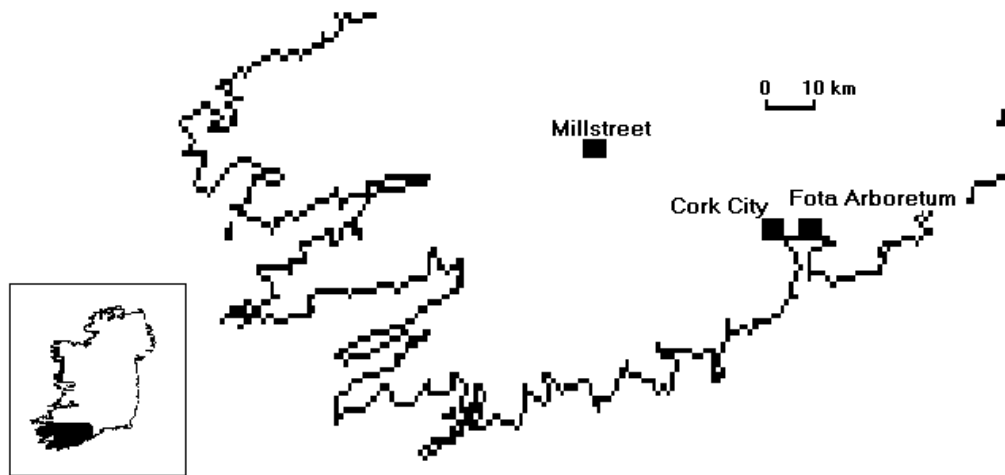
During the 2002 and 2003 breeding seasons three sites were monitored intensively (*i.e.* intensive study sites) and two sites at a lower intensity (*i.e.* extensive study

sites) in County Cork, Ireland. A national request to birdwatchers countrywide to record nesting attempts was also undertaken from 2001-2003. All observers were asked to submit nest details in a similar format to the British Trust for Ornithology's (B.T.O.) Nest Record Scheme (N.R.S.) (see Crick *et al.* 2003). Few data were collected during 2001 because of restrictions imposed by the risk of Foot and Mouth disease.

Intensive Study Sites

The main study sites were Fota Arboretum, east Cork, Millstreet Country Park and Willowbrook farm, both northwest Cork, Ireland (Figure 1). Fota Arboretum ($51^{\circ}53.5'N$, $8^{\circ}18.2'W$) is a low-lying (0-10 m above sea level) recreational area, consisting of gardens and parkland with many shrubs and mature native and non-native trees. Disturbance to nest sites was apparently low. Millstreet Country Park ($52^{\circ}1.3'N$, $10^{\circ}0.8'W$) consists of about 200 hectares of bog-land, wet and improved grassland, parkland, gardens and plots of coniferous forests. Nesting attempts in coniferous forest plots located in one section (210-270 m above sea level) of the park were monitored. These sitka spruce, *Picea sitchensis*, dominated plots were 12-15 years old and had very low disturbance during the nesting season. Willowbrook farm ($52^{\circ}2.4'N$, $10^{\circ}3.3'W$) is approximately 3 km southeast of Millstreet town, Co Cork. This intensive cattle farm is situated at 160-170 m above sea level and is mainly surrounded by other intensive cattle farms. The area monitored for Song Thrush nests consisted of a mixed coppice situated beside a disused house and farmyard.

Figure 1: Location of intensive study areas in County Cork, Southwest Ireland



Extensive Study Sites

Extensive study areas consisted of two sites near Cork City and a random selection of sites countrywide where observers had recorded nests. The two sites near Cork City were Fota Wildlife Park and Glinny farm. Fota Wildlife Park ($51^{\circ}53.5'N$, $8^{\circ}18.8'W$), adjacent to Fota Arboretum, consists of parkland, some mixed coppice with some bush and shrub cover throughout the park. Glinny farm ($51^{\circ}47.2'N$, $8^{\circ}28.4'W$) is approximately 2 km northeast of Riverstick, south Cork. This very low intensity farm system had tillage and grassland in 2002 and mostly grassland in 2003. Part of the farm consisted of deciduous coppice and marshland, lying about 70 m above sea level and is surrounded by intensive tillage and grassland. Data on nests countrywide were collected randomly by appealing to bird watching enthusiasts and ringers to contribute information on Song Thrush nests encountered.

METHODS

Nest Searching

Nest searching took place from early March to late July, each year, and involved a mixture of cold searching and observing parental behaviour. Caution was taken to minimise risk of predation or desertion by not leaving obvious tracks to and from nests, approaching each nest slowly and cautiously, minimizing both frequency of visits and time spent at an occupied nest, especially when adult(s) became alarmed.

Collection of Data

The following data were recorded: nest location, surrounding habitat, nest height above ground, date of first egg, nesting stage, clutch size, number of hatchlings and fledglings. In cases of predation, an attempt was made to identify the likely predator by looking for clues (Sleeman 1989, Bang 2001). The maximum number of visits to any nest between its incubation and fledgling stages was eight. For each chick, the following details were recorded: weight (g), tarsus length (mm), wing length (mm) and age (day), which was assessed by examining feather growth and/or back calculation from published details of breeding biology (Silva 1949, Pikula 1969, Cramp 1988). Where possible two measurements of each chick were made. In some cases nestlings were measured on three occasions. Each chick was fitted with a unique B.T.O. ring and two colour rings for ease of identification.

Nest Recording by Observers

Volunteers provided the following details: location (i.e. locality name and grid reference), nest height above ground and sea level, surrounding land use (e.g. farmland, forestry etc.) and nest site (e.g. tree, building etc.). For each visit the following details were recorded: date, nesting stage (e.g. nest building, laying etc.) and, if applicable, clutch size, number of chicks hatched and fledged and causes of nest failure.

Assignment of Nesting Attempts to specific Breeding Pairs

At the intensive study sites we attempted to ring breeding adults in order to identify nesting attempts with breeding pairs but this proved unsuccessful. However, within

the study areas most nesting attempts occurred in clusters throughout the season and knowing that other nests within the study area were occupied at the same time, we were able to confidently assign most nesting attempts to a breeding pair and record each nesting attempt for the 2002 and 2003 breeding seasons.

Calculation of First Egg Date & Timing of Breeding

If first egg date was unknown it was back-calculated using published works (Silva 1949, Pikula 1969, Cramp 1988) and information on the nest stage(s) observed and/or the age of chicks. The timing of first, second and third nesting attempts for 2002 and 2003 were determined by examining the nesting trend of known nesting attempts observed at our intensive study sites. Nests from intensive study sites were used, as the methodology applied in nest searching and assigning nesting attempts with a breeding pair was consistent in both years. Nests from extensive study sites and countrywide were assigned as first or second nests if their first egg dates coincided with the timing found in the intensive study sites, otherwise they were classed as unknown and excluded from further analysis.

Daily Nest Survival & Failure

Nesting success was determined by calculating nest survival on a daily basis using the Mayfield method (Mayfield 1961, 1975). Daily nest survival probabilities were calculated for:

- (i) egg period – defined as the period from when the first egg was laid to when the first chick hatched (i.e. laying and incubation).

(ii) incubation period – defined as the period from when the last egg was laid to when the first chick hatched.

(iii) nestling period – defined as the period from when the first chick hatched to the when the last chick fledged.

(iv) overall - defined as the whole nesting period from laying to fledging.

An average laying period of 4 days (i.e. an egg per day) and both incubation and nestling periods of 13 days each was used (Silva 1949, Pikula 1969, Cramp 1988).

The estimator that the Mayfield method derives has been shown to be a maximum likelihood estimator, (Johnson 1979, Hensler & Nichols 1981, Hensler 1985). When calculating observation period, all the assumptions of Mayfield (1961 and 1975) were adhered to and where the outcome of the nesting attempt was uncertain, data from the final observation period were excluded but data from earlier observation periods were included (Crick *et al.* 2003).

Nest Productivity

Hatching success was calculated as: total no. of hatchlings/ total no. of eggs. The number of fledglings per attempt (FPA) (after Peach *et al.* 1999, Siriwardena *et al.* 2000) and reproductive output per attempt (ROA) (after Paradis *et al.* 2000) were calculated as follows:

$$\text{FPA} = \text{CS} \times \text{CER} \times (1 - \text{EFR})^{\text{ED}} \times (1 - \text{NFR})^{\text{ND}}$$

CS = clutch size

CER = chick:egg ratio

$1-\text{EFR}^{\text{ED}}$ = daily survival probability during egg period

$1-\text{NFR}^{\text{ND}}$ = daily survival probability during nestling period

$\text{ROA} = \text{BS} \times (1-\text{DFI})^{\text{IT}} \times (1-\text{DFN})^{\text{NT}}$

BS = maximum brood size at hatching

$1-\text{DFI}^{\text{IT}}$ = daily survival probability during incubation period

$1-\text{DFN}^{\text{NT}}$ = daily survival probability during nestling period

Seasonal productivity per pair (*i.e.* number of fledged chicks per pair per season) and number of nesting attempts per pair per season were also calculated (calculations pers. comm. Will Peach) incorporating data where we had assigned nesting attempts with breeding pairs in the intensive study areas.

Weather Data

The influence of weather on nest survival and outcome, success or failure, was examined. Daily rainfall (mm) and temperature (°C) ranges in the 5-day period (after Snow 1955a, Myers 1955) prior to nest outcome were available from the Monthly Weather Bulletin (Met Eireann 2001, 2002 and 2003) for the breeding seasons (April-July) of 2001-2003. Failure in this case was restricted to nests where desertion occurred and did not include predated nests.

Nestling growth analysis

As outlined above, nestling weight, tarsus and wing lengths and age of every nestling handled were recorded when collecting general breeding biology data. These data were recorded at all intensive study sites and some extensive study sites. Tarsus and wings lengths were not taken for nestlings under 4 days of age to avoid any physical damage. Given that these data were recorded in conjunction with the collection of general breeding biology data, repeat measures per nestling were limited in order to minimise the overall number of visits to a nest and thereby minimise any risk of predation or desertion. In addition, most nestlings could only be measured once before predation or fledging prevented re-measures. In total nestlings from 24 broods were measured and analysed for growth. Nestlings from nine broods were measured twice, while nestlings from three broods were measured on three occasions.

Statistical Analyses

Analyses of breeding parameters were undertaken with logistic regression models using Generalized Linear Models (GLMs) (after Peach *et. al.* 1999, Aebischer 1999, Siriwardena *et. al.* 2000) as available in the PROC GENMOD feature of SAS (Release 8.2). This analysis uses maximum-likelihood ratio statistics to test for significance (SAS 2000). Extensive analysis of breeding biology in relation to habitat is not considered here and both 2001 nests and third nests overall were excluded from extensive analysis due to small sample sizes. In all cases univariate models were conducted as it was felt that the unbalanced dataset and small sample sizes involved did not support complex models without compromising the value of the data.

First egg dates, clutch sizes and number of chicks at hatching and fledging were analysed using identity link function with normal error distribution incorporated into a Type I analysis for each model. Differences in daily nest failure rates, for egg, incubation and nestling periods, between year and nesting attempt were analysed using logit link function with binomial error distribution incorporated into a Type I analysis for each model, where daily fail rates were modeled as the proportion of survival (0) or failure (1) and the total number of nest observation days. Generalized Linear Modeling was also used to test if weather conditions influenced overall nest survival (i.e. laying to fledging). Midpoints of overall, maximum and minimum rainfall and temperature ranges were used since the actual daily figures were not available. The models were constructed as before with daily fail rate as the response

variable where failure rate was combined from egg laying to last fledged chick. Nest outcome (successful=0; failure=1) was analysed with overall rainfall and temperature where outcome was a binary dependent variable (after Tyler and Green 2004). In addition, both nest outcome and nest failure were analysed as binary dependent variables against year.

Nestling growth (i.e. tarsus, wing and weight) was modeled using the non-linear mixed effects procedure in S-Plus (Version 6.2) (after Hartley *et al.* 2000). Nestling growth was described using a logistic equation^A used by Hartley *et al.* (2000). The data are limited by the fact that too few measures were taken per nestling, where most nestlings were measured only once, to make this analysis more robust. As a consequence, data for tarsus length and wing length were treated as if the data were independent to allow for calculation of growth parameters. In the case of body weight enough data were available to group the data by brood but not by chick.

RESULTS

Overall

Data from 100 nests, collected during the 2001-2003 breeding seasons, were available for analysis. From 93 nests where outcome was known, 55% failed and 45% succeeded to fledge at least one chick. We found no association between nest outcome (*i.e.* failure or success) and year, 2002-2003, (d.f. = 1, $\chi^2 = 0.04$, $p > 0.80$).

First Egg Date & Timing of Breeding

Generally, the breeding season extended from mid-March to late June. The first egg date for first broods in 2003 (9th April) was significantly later than in 2002 (29th March) (d.f.=1; $\chi^2 = 9.94$; $p < 0.01$). First egg date for second broods did not differ significantly between 2002 (19th May) and 2003 (22nd May) (d.f.=1; $\chi^2 = 0.73$, $p > 0.30$). Overall, the breeding season was dominated by two nesting attempts with only 3% third attempts.

Clutch Size

Clutch data from 56 nests were available. Mean clutch size was 4.11 (± 0.62) (Table 2), highest in April (4.33 ± 0.49 ; $n=15$) and lowest in June (3.75 ± 0.71 ; $n=8$) with April clutches being significantly larger than June clutches (d.f.=1; $\chi^2 = 5.31$; $p < 0.03$). Most clutches (61%) had four eggs.

We found a significant difference in median clutch size between first and second nesting attempts for 2002 and 2003 (Table 1). Clutch size for first attempts in 2003 was significantly greater than in 2002 and second attempts in both 2002 and 2003 (d.f.=3; $\chi^2= 11.25$; $p<0.02$) (Table 1). First clutches were significantly larger than second clutches (d.f.=1; $\chi^2= 4.69$; $p<0.04$) (Table 1). In addition, clutches in 2003 were significantly larger than those in 2002 (d.f.=1; $\chi^2= 5.93$; $p<0.02$) (Table 1).

A significant difference in clutch size was found with nesting attempts from the north, west, south and southeast of the country (*i.e.* latitude). Clutches from the north (4.50 ± 0.76 ; $n=8$) and west (4.46 ± 0.52 ; $n=13$) were significantly larger (by 0.6 egg when combined) than those from the south (3.93 ± 0.55 ; $n=27$) and southeast (3.78 ± 0.44 ; $n=9$) (d.f.=3; $\chi^2= 14.26$; $p<0.01$). Nesting attempts located 160-300m above sea level (*i.e.* altitude) had significantly smaller clutch sizes (3.43 ± 0.53 ; $n=7$) than those located 0-50m (4.00 ± 0.55 ; $n=27$) and 51-100m (4.42 ± 0.51 ; $n=19$) above sea level (d.f.=2; $\chi^2= 16.8$; $p<0.01$) and clutch sizes located 51-100m above sea level were significantly larger than those located 0-50m above sea level (d.f.=1; $\chi^2= 6.69$; $p<0.01$).

Number of Hatchlings

Hatching success was 89.6%, using nests where both hatchling number and egg number were known ($n=35$). An overall total (2001-2003) of 53 nests produced a mean of $3.66 (\pm 0.92)$ hatchlings (Table 1). The majority (73.6%) of nests produced three to four hatchlings. As with clutch, the number of hatchlings was highest in

April (4.13 ± 0.64 ; $n=15$), being significantly higher than both May (3.22 ± 1.06 ; $n=18$) ($d.f.=1$; $\chi^2=7.98$; $p<0.01$) and June (3.44 ± 0.88 ; $n=9$) ($d.f.=1$; $\chi^2=4.84$; $p<0.03$).

Brood size at hatching was significantly greater in first broods in 2003 than in 2002 and second broods in 2002 and 2003 ($d.f.=3$; $\chi^2=16.26$; $p<0.01$) (Table 1). The number of hatchlings in first broods was significantly greater than second ones ($d.f.=1$; $\chi^2=9.77$; $p<0.01$) (Table 1). There was no significant difference found in the number of hatchlings between 2002 and 2003 ($d.f.=1$; $\chi^2=1.86$; $p>0.10$) (Table 1).

Brood size at hatching did not significantly differ with latitude ($d.f.=3$; $\chi^2=0.23$; $p>0.90$) or altitude ($d.f.=2$; $\chi^2=1.2$; $p>0.50$).

Number of Fledglings

The overall (2001-2003) mean number of fledglings produced from 39 nests was $3.69 (\pm 0.89)$ (Table 1). Three to four fledglings were produced in 79.5% of nests. The highest mean number of fledglings occurred in March (4.0 ± 0.63 ; $n=6$).

The number of fledglings from first broods in 2003 was significantly higher than those of 2002 and second broods in 2002 and 2003 ($d.f.=3$; $\chi^2=9.13$; $p<0.03$) (Table 1). Again first broods had a significantly higher number of fledglings than second

broods (d.f.=1; $\chi^2= 7.15$; $p<0.01$) (Table 1). The number of fledglings did not differ significantly between the nests of 2002 and 2003 (d.f.=1; $\chi^2= 1.72$; $p>0.10$) (Table 1).

Some significant differences in latitude and altitude were found, where the number of fledglings produced in the north of the country was significantly higher (4.33 ± 0.2 ; $n=6$) than those in the south of the country (3.43 ± 0.81 ; $n=21$) (d.f.=1; $\chi^2= 5.34$; $p<0.03$) and nests located 51-100m above sea level had significantly more fledglings (3.91 ± 0.67 ; $n=12$) than those located 160-300m above sea level (3.27 ± 0.79 ; $n=11$) (d.f.=1; $\chi^2= 4.91$; $p<0.03$).

Table 1: Mean (\pm s.d.) first egg date (where January 1=day 1), clutch size, number of hatchlings and fledglings for Song Thrush breeding attempts in Ireland for different years and nesting attempts. * denotes significance at $p < 0.05$. The letters A-H refer to the variables that differ significantly (i.e. A to A, B to B *etc.*); in all cases the variable with the highest value is significantly higher than the other(s). Sample sizes are given in parentheses and nesting attempts with insufficient sample size for analysis are excluded.

	First egg date	Clutch size	No. of hatchlings	No. of fledglings
Overall: 2001-2003	120.58 \pm 26.05 (n=77)	4.12 \pm 0.62 (n=56)	3.66 \pm 0.92 (n=53)	3.69 \pm 0.80 (n=39)
Year: 2002	120.39 \pm 29.96 (n=31)	3.88 \pm 0.52* ^D (n=25)	3.50 \pm 0.74 (n=22)	3.50 \pm 0.65 (n=14)
2003	119.67 \pm 25.79 (n=37)	4.30 \pm 0.67* ^D (n=27)	3.82 \pm 0.90 (n=28)	3.80 \pm 0.89 (n=20)
Nest attempts (2002-2003): First nests	94.72 \pm 12.30 (n=32)	4.20 \pm 0.52* ^C (n=20)	3.96 \pm 0.64* ^F (n=23)	3.88 \pm 0.62* ^H (n=16)
Second nests	140.50 \pm 9.33 (n=26)	3.79 \pm 0.58* ^C (n=14)	3.21 \pm 0.85* ^F (n=19)	3.21 \pm 0.70* ^H (n=14)
2002 attempts: First	88.08 \pm 4.61* ^A (n=13)	3.80 \pm 0.35* ^B (n=8)	3.50 \pm 0.53* ^E (n=8)	3.50 \pm 0.58* ^G (n=4)
Second	139.20 \pm 9.93 (n=15)	3.89 \pm 0.60* ^B (n=9)	3.36 \pm 0.81* ^E (n=11)	3.25 \pm 0.46* ^G (n=8)
2003 attempts: First	99.26 \pm 13.89* ^A (n=19)	4.41 \pm 0.51* ^B (n=12)	4.20 \pm 0.56* ^E (n=15)	4.00 \pm 0.60* ^G (n=12)
Second	142.27 \pm 8.57 (n=11)	3.60 \pm 0.55* ^B (n=5)	3.00 \pm 0.93* ^E (n=8)	3.17 \pm 0.98* ^G (n=6)

Nest Productivity & Number of Nesting Attempts

Overall we calculated FPA as 0.75 fledglings produced per nesting attempt and ROA as 1.13 chicks produced per nesting attempt. Seasonal productivity per breeding pair was calculated as 2.7 fledged chicks produced from 3.7 nesting attempts (including repeat attempts).

Daily Nest Survival & Failure

The overall daily nest survival rates for the different nesting stages were as follows: egg stage 0.9362 (\pm 0.0126; n=54), incubation stage 0.9505 (\pm 0.0121; n=46) and nestling stage 0.9609 (\pm 0.0096; n=50). The overall (i.e. laying to fledging) nesting success rate across all years and habitat was 19.4%. No significant differences were found in daily failure rates during egg, incubation and nestling periods across year (d.f.=1; χ^2 = 0.13, 0.78, 0.06 (respectively); $p>0.05$), although daily failure rates in 2003 were lower across all nest stages than 2002 but especially during egg and incubation stages (Figure 2), resulting in overall nesting success of 18% in 2002 and 23% in 2003. Again no significant differences were found in daily failure rates during the three nesting periods and nesting attempt (d.f.=1; χ^2 = 0.31, 2.84, 0.76 (respectively); $p>0.05$) even though second nesting attempts had consistently lower failure rates across all nest periods than first nesting attempts (Figure 3), resulting in overall success of 24% for first nests and 38% for second nests.

No significant difference was found between nest outcome and overall rainfall or temperature and between nest survival and overall, minimum and maximum rainfall or temperature.

Figure 2: Daily failure rates (\pm 95% C.I.s) of the Song Thrush in Ireland during different nest stages for 2002 and 2003. Sample sizes are given in parentheses. Note that 2001 is not illustrated due to small sample size ($n=4$).

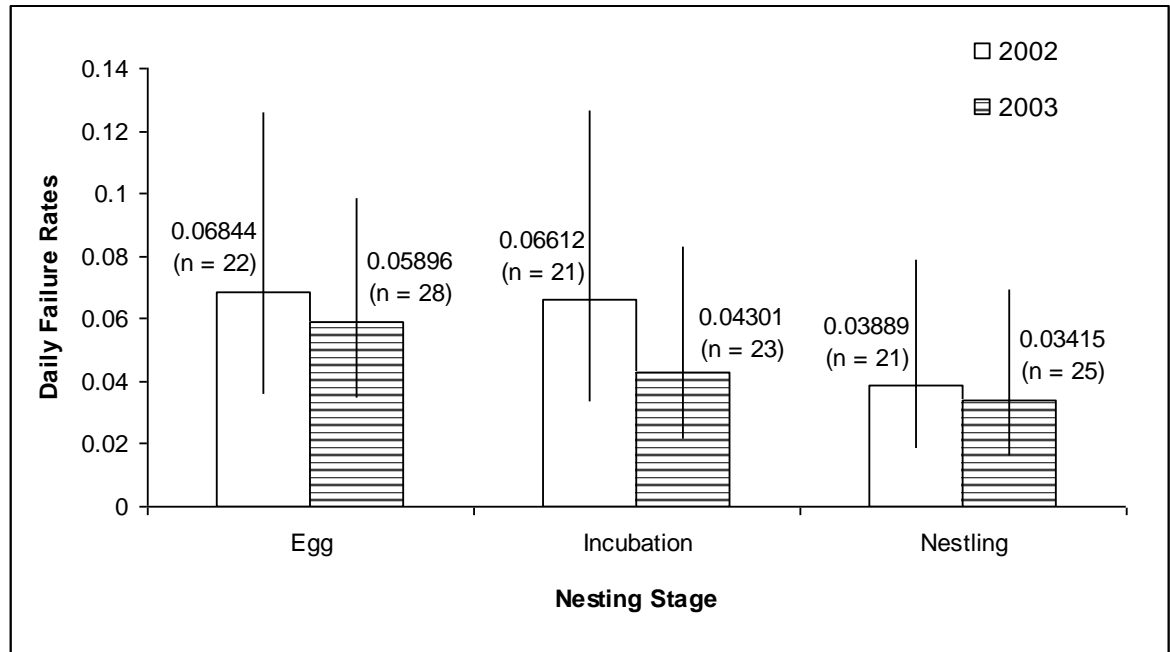
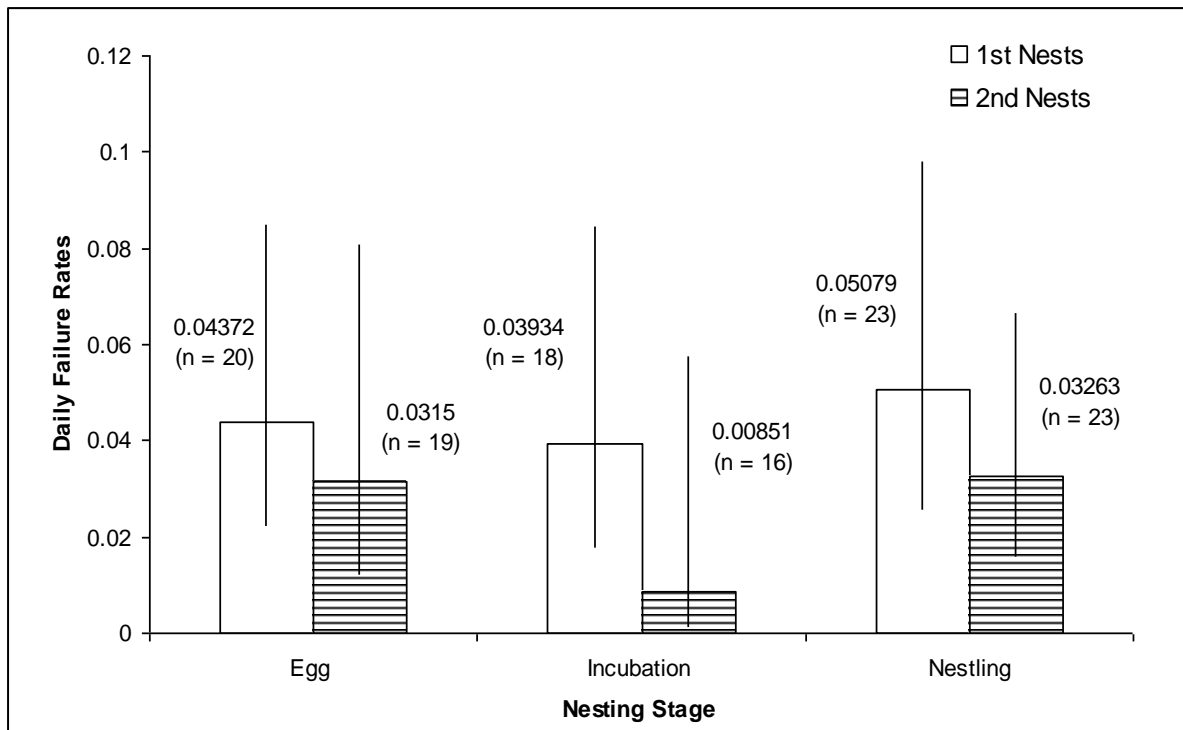


Figure 3: Daily failure rates (\pm 95% C.I.s) of the Song Thrush in Ireland during different nest stages for first and second nests. Sample sizes are given in parentheses.



Desertion and predation rates

Most failure was due to avian predation during the egg stage (Table 2). We found no association between year, 2002-2003, and cause of failure (*i.e.* desertion or predation) (d.f. = 1, $\chi^2 = 2.50$, $p > 0.10$).

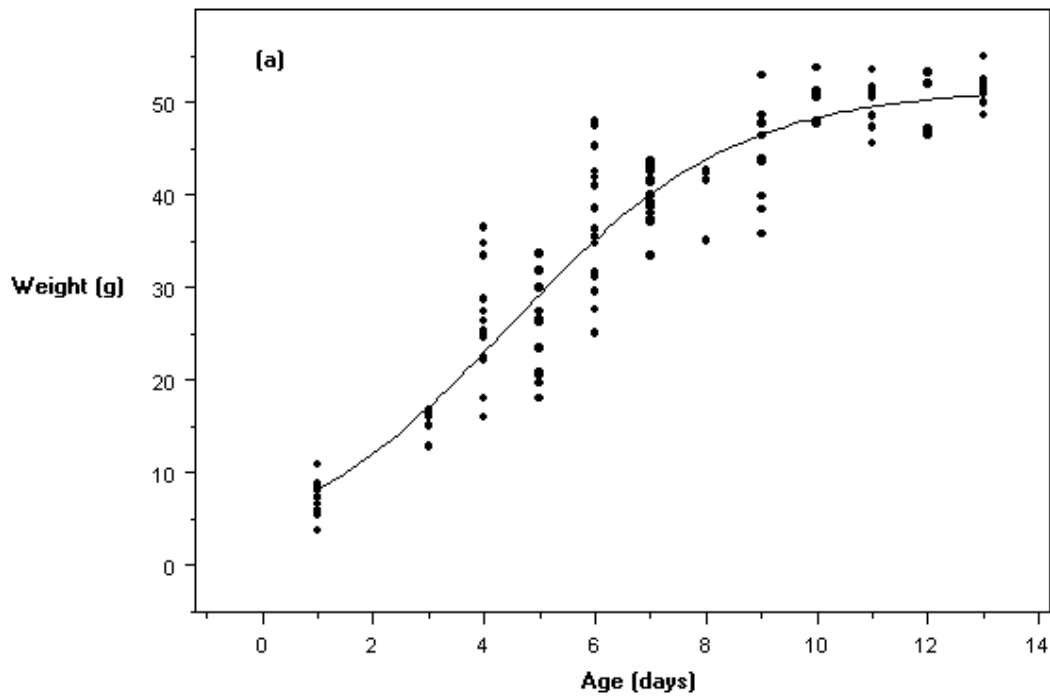
Table 2: Causes of failure in Song Thrush nests in Ireland 2001-2003.

Cause of failure	Nest stage	Freq.	% Freq. (per nest stage)	% Freq. (per failure)	% Freq. (per predation)
Desertion	Egg Chick	11 4	24.4 8.9	33.3	n/a
Avian predation	Egg Chick	13 10	28.9 22.2	51.1	76.6
Mammalian predation	Egg Chick	6 1	13.3 2.2	15.5	23.3
Total		45	100	100	100

Nestling growth development

Growth curves for weight, tarsus length and wing length were generated separately (Figures 4 (a), (b) and (c)). Nestling weight increases steadily up to day nine after which the curve levels off (Figure 4 (a)). The growth curve for tarsus development (Figure 4 (b)) increases steadily like weight, though not as steeply and does not level off as clearly as the weight curve. Nestling wing growth differs from the other growth curves by showing an almost linear fit over the age range for which data were available (Figure 4 (c)). Growth parameters derived from the non-linear logistic regression are available in Table 3.

Figure 4: Growth curves of song thrush nestlings for body weight (a), tarsus length (b) and wing length (c) against age (days). Samples sizes (i.e. number of nestlings measured) are 127, 96 and 84 respectively.



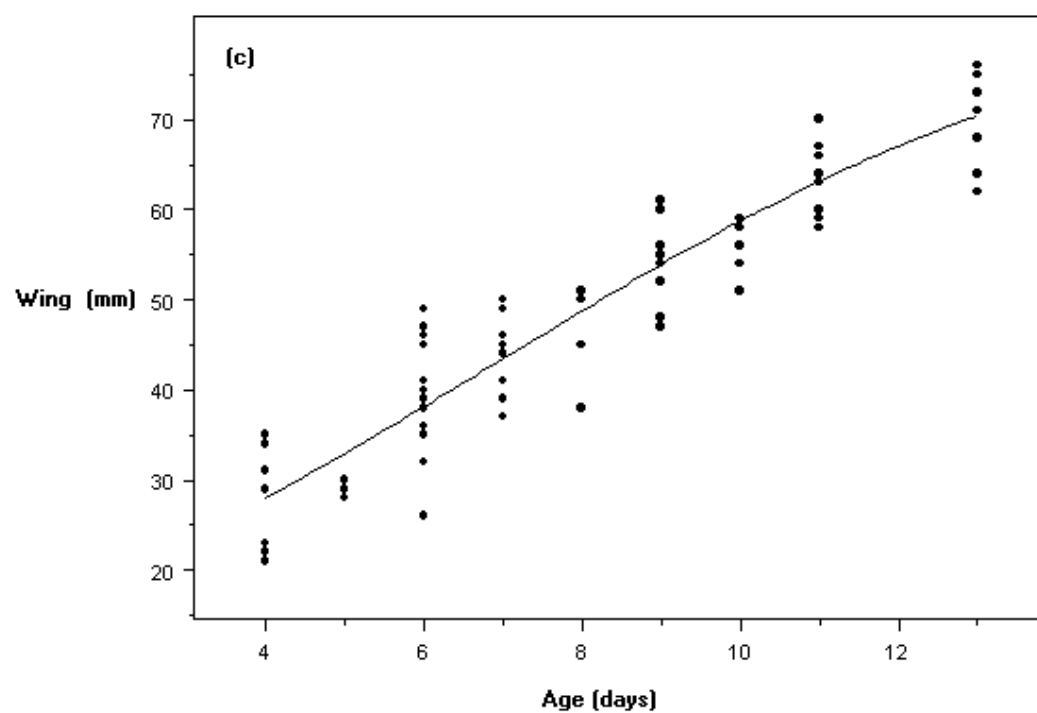
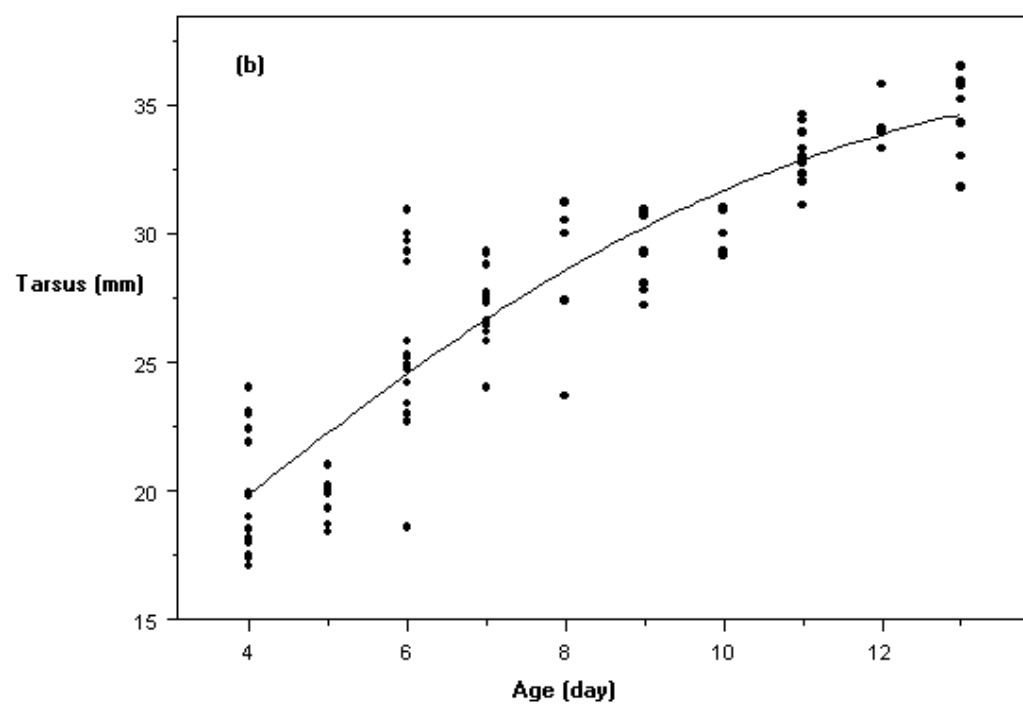


Table 3: Growth parameters (\pm s.e.) of song thrush nestlings derived from non-linear logistic regression for body weight (g), tarsus length (mm) and wing length (mm) against age (days). Samples sizes (i.e. number of nestlings measured) are 127, 96 and 84 respectively.

Parameters	Weight	Tarsus length	Wing length
Asymptote (A)	52.46 ± 0.97	37.64 ± 2.02	85.89 ± 7.95
Shape constant (B)	2.33 ± 0.13	0.93 ± 0.16	1.72 ± 0.13
Growth constant (k)	0.50 ± 0.03	0.26 ± 0.04	0.25 ± 0.04

DISCUSSION

This is the first study of the Song Thrush in Ireland, the most westerly population in Europe. While some European countries have been able to quantify population changes in their Song Thrush populations, the situation in Ireland is unclear (Tucker & Heath 1994). A small decline in the breeding population is thought to have occurred but this is based on provisional data (Tucker & Heath 1994). While both of the Breeding Atlas projects (Sharrock 1976, Gibbons *et al.* 1993) show that the Song Thrush is widely distributed in Ireland, its abundance is uncertain. Changes in the breeding status of the Song Thrush in Ireland between both Breeding Atlas projects (Sharrock 1976, Gibbons *et al.* 1993) suggest a contraction in breeding range of 11%. Whether this breeding contraction represents a decline in range and/or abundance is uncertain given the methods employed, but it is likely that some decline in abundance has occurred in those study squares.

Recent monitoring data in Ireland, through the Countryside Bird Survey (C.B.S.) (equivalent to Breeding Bird Survey in Britain), indicates that Song Thrushes are currently widely distributed and stable here (Coombes 2003). Some preliminary analysis of C.B.S. data suggest that Song Thrush distribution has changed from occurring in 81% of study squares (>300 1 X 1 Km squares) in 1998 to 87% in 2003 (Coombes 2003), although it must be remembered that these data only account for the population since 1998.

Despite uncertainty of population trends in Ireland pre-1998, any decline in the breeding population during 1970-1990 is not at the same scale as U.K. (see Tucker & Heath 1994). Differences between Song Thrush populations of Ireland and Britain probably lie in the fact that Song Thrushes in Britain have experienced their most rapid decline on farmland (Thomson *et al.* 1997, Baillie *et al.* 2001, Peach *et al.* 2004). While changes have occurred in Irish agriculture, these changes have not occurred at the same intensity, rate or scale as Britain, especially England, and other European countries (Cabot 1985, Lysaght 1989, Stanners & Bourdeau 1995, Aalen *et al.* 1997), with the consequence that the Irish landscape has a denser network of field boundaries (Lysaght 1989, Moles & Breen 1995, Aalen *et al.* 1997). Therefore the Song Thrush data presented here provide some very valuable data for comparisons with declining populations elsewhere.

Timing of breeding

The length of the breeding season in Ireland was quite similar to Britain and other European countries (Table 4), but seems to start and finish about two to three weeks earlier than other European countries (Silva 1949, Myers 1955, Snow 1955a, 1955b, Pikula 1969, Wesolowski & Czapulak 1986, Weidinger 2001). Given that Myers (1955) found that Song Thrush breeding in Britain began after March temperatures reached approximately 4.4°C, differences in the onset of breeding between other European countries (as in Table 4) and Ireland are probably due to differences in average Spring temperatures where, for example, average minimum temperatures in Austria and Czech Republic vary -3.8-1.6°C from February to March in comparison

to 3.3-3.8°C for Ireland (www.goeurope.about.com/od/historicclimate/). We also found differences between years, where breeding in 2003 began significantly later than in 2002, which is not unusual and has been noted to occur in geographical areas within the same country and between different habitats (Myres 1955, Dycz 1963, Wesolowski & Czapulak 1986). In this study, nesting was dominated by two nesting periods (including repeat attempts) with only 3% of nests occurring during the third nesting period, indicating that the Song Thrush in Ireland has very few third broods.

Clutch size

The overall mean clutch size in this study is very similar to Britain (Silva 1949, Snow 1955a) and smaller than other European countries (Table 4). Despite these differences, the range in clutch size is similar where clutches of 4 and 5 eggs are predominant (Silva 1949, Snow 1955a, Dycz 1963, Pikula 1969, Wesolowski & Czapulak 1986, Schnack 1991). Clutch size varied seasonally (monthly) peaking midway, a trend also reflected in other Song Thrush studies (Silva 1949, Snow 1955a, Pikula 1969, Wesolowski & Czapulak 1986) and other passerine species (Lack 1947). Significant differences were found here between months, with April clutches being larger than those laid in June. Pikula (1969) also found significant monthly differences where April and May clutches were larger than June and clutches in May larger than April. However, Schnack (1991) did not find significant monthly variation. The most likely explanation for this mid-seasonal peak appears to be related to availability of food resources (Lack 1947, Ludvig *et al.* 1995) where the first brood is hatched before conditions are optimal for raising nestlings (Crick

et al. 1993). We also found that clutch size varied significantly between years and between first and second nesting attempts, with first clutches being larger. While other studies did not specifically focus on first and second nests, many have found a trend of decreasing clutch size through the breeding season (Silva 1949, Snow 1955a, Pikula 1969, Wesolowski & Czapulak 1986, Schnack 1991).

We found that clutch size varied significantly with latitude, a trend that mirrors differences in clutch size between northern and southern latitudes in general (Lack 1947). In addition, clutch size significantly differed with altitude but it is worth noting that the majority of nests located 51-100m were also located in the north or west of the country, indicating that altitude and latitude are confounded and should be received with caution. However, as previously mentioned, any effect between these two variables, and all other variables for that matter, cannot be separated given the unbalanced dataset and small sample sizes involved especially with latitude and altitude.

Hatchlings & Fledglings

As expected, with the differences in clutch size mentioned above, the number of hatched young and fledged in this study is lower than mainland Europe (Table 4). The range of brood sizes in Britain (Silva 1949) is quite similar to this study, but the average fledgling number per successful brood (i.e. nesting productivity per successful attempt) was higher in this study than in Britain (Thomson & Cotton 2000). The number of hatchlings and fledglings varied seasonally, where the

number of hatchlings was significantly higher in April than May and June. Pikula (1969) also found a similar trend of peaking at the beginning (i.e. March) of the breeding season with brood size at hatching. As with clutch size, the number of hatchlings and fledglings varied significantly between first and second broods, the former being higher. While brood sizes at fledging also varied with latitude and altitude, small sample sizes involved with these variables make it difficult to separate any confounding effects that may exist and subsequently interpretation of these results should be viewed with caution. As already stated in clutch analyses, confounding effects for other variables cannot be separated either given the data involved. In general, hatching and fledgling rates are higher in this study than others (Silva 1949, Snow 1955b, Pikula 1969) with the exception of Snow's (1955b) hatching rate, which is only slightly higher (91-96%).

Nesting productivity & number of nesting attempts

Despite this study showing that productivity per successful attempt is higher here than in Britain (*i.e.* average number of fledged chicks; Table 4), overall nest productivity (ROA and seasonal productivity) appears to be lower (Table 5). In fact, overall seasonal productivity in Ireland is more similar to a declining farmland Song thrush population in Britain during 1995-1997 (Table 5). The lower nesting productivity experienced here may be due to higher over-winter survival of Song Thrush in Ireland, which is much milder than Britain. Especially given that Song Thrush survival is knowingly affected by winter frosts, which are less frequent in Ireland (Baillie 1990, Robinson *et al.* 2004). Additionally, O'Connor (1986) pointed

out that if fewer individuals of a resident species, which is limited by over-winter survival (*e.g.* Song Thrush), survive the winter in a ‘seasonal’ environment (*e.g.* Britain), then it might be expected that individuals surviving to the following breeding season will have greater resources available, and consequently higher breeding productivity. So the mild Irish winter combined with higher Song Thrush over winter survival and lower available resources in the breeding season may explain the lower overall nesting productivity experienced in Ireland than in Britain.

On the other hand the number of nesting attempts (including repeat attempts) undertaken per breeding pair per year in this study is more similar to a stable farmland Song Thrush population in Britain (Table 5). Of course caution must be exercised when interpreting the results for nesting productivity and number of nesting attempts as the dataset involved is small. Nonetheless, the data presented here are useful in gaining an understanding of Song Thrush ecology in Ireland.

Latitudinal differences and Insular syndrome

While the variation found in this study between clutch size and latitude should be viewed with caution, the pattern has nonetheless been documented for many passerine species (Lack 1947). Many hypotheses have been offered for this trend including food limitation, environmental stability, seasonal fluctuation and prey diversity (Lack 1947, Cody 1966, Owen 1977, Ricklefs 1980). In addition, we found that clutch sizes in Ireland are smaller than countries in Eastern Europe, which again is a trend noted by Lack (1947) where clutch size increases from west

to east across Europe. Another confounding factor in this aspect is the island effect or ‘Insular Syndrome’ where clutch size is often smaller on islands than the mainland (Lack 1947, Blondel 2000). This study confirms this trend with respect to the mainland of Europe, but not with the island of Britain. Other insular traits include later breeding, smaller clutches, lower breeding productivity, reduced dispersal, higher population density, expansion of niche breadth and species depauperisation (MacArthur *et. al.* 1972, Reed 1981, Blondel *et. al.* 1988, Blondel 2000). This study shows that Song Thrush populations in Ireland conform to some of these insular traits, such as lower nest productivity in comparison to Britain, but not others, such as earlier laying dates. Interestingly, other passerine species studies in Ireland, namely on Grey Wagtail (*Motacilla cinerea*), Dipper (*Cinclus cinclus*), Stonechat (*Saxicola torquata*) and Robin (*Erithacus rubecula*), also show that some insular traits are adhered to (Smiddy *et al.* 1995, Smiddy & O’Halloran 1998, Fennessy 2001, Cummins & O’Halloran 2003a).

Daily survival & failure rates

Even though 45% of nests successfully fledged at least one chick, this is an inflated measure of success since nests that failed undetected in the earlier stages of the nest cycle are under-represented (Snow 1955b, Mayfield 1961). Using Mayfield’s method (Mayfield 1961 and 1975) for calculating nest success, which takes the detection bias into account, nesting success (from laying to fledging) in this study declines to a more realistic value of 19.4%. Daily egg and chick survival probabilities calculated here compare reasonably well with other studies in Britain

(Table 5), with daily egg survival consistently lower than Britain but daily chick survival is less consistent, being lower than one British study (Paradis *et al.* 2000) and higher than another (Baillie 1990). Some of these differences may be explained by subtle differences in methodology in calculating nesting success, where Baillie (1990) calculated survival for individual eggs and chicks while this study and Paradis *et al.* (2000) calculated nest survival during these two nest periods. But any differences due to using egg/chick number or nest number will be small when considering a bird species that suffers little partial nest loss (Mayfield 1961), such as the Song Thrush (this study, Silva 1949, O'Connor & Shrubb 1986), and usually loses a whole brood. This study found that first broods suffered higher failure rates than second broods, although not significantly, the trend is still clear and has been noted by other authors for Song Thrush (Dycrz 1963, Pikula 1969, O'Connor & Shrubb 1986). This trend is probably related to increased nest cover and decreased predation pressure as the season progresses (O'Connor & Shrubb 1986) and may explain to some extent the significantly bigger clutch and brood sizes also experienced by first broods in this study. As found in other species studies (Cummins & O'Halloran 2003a, Tyler & Green 2004), neither nest survival nor outcome here was significantly influenced by temperature or rainfall.

Desertion & predation rates

Desertion and predation rates found here (Table 2) are very similar to other studies (Silva 1949, Snow 1955b, Dycrz 1969, Pikula 1969, Wesolowski & Czapulak 1986). The majority of nest failure was due to predation and mostly occurred during the

egg period, as found in many other studies (Silva 1949, Snow 1955b, Dycrz 1969, Pikula 1969, Wesolowski & Czapulak 1986). Interestingly, a more recent study of Song Thrushes on British farmland suggests that predation accounts for approximately 80% of nest failure (pers. comm. Will Peach), a much higher rate than found here. However, it must be remembered that this rate is based on farmland habitat only whereas our rate is based on different habitats combined, which may explain the difference, to some degree, between the two studies. That said, the difference still seems quite high and an additional factor in explaining it may lie in the higher agricultural intensification experienced in Britain, which has probably resulted in a more fragmented landscape with higher predation rates in comparison to Ireland.

While the identity of predator species in this study was unknown, clues at nest sites indicate that predation was predominantly avian with the remainder mammalian. Despite Corvid diet studies having mixed conclusions with some finding passerine eggs and nestlings being more important in their diet (Holyoak 1968) than others (Owen 1956, Tatner 1983), Corvids are the most likely avian predator (Bang 2001) and were identified as the main predator of Song Thrush nests in peripheral parks in Poland by Dycrz (1969). This is further emphasised by Nilsson *et al.* (1985) who found that thrush, *Turdus spp.*, nests closer to corvid nests suffered significantly higher egg losses. In addition, Paradis *et al.* (2000) found Song Thrush nest failure rates significantly higher when corvids were more abundant while Stoate & Szczur

(2001) found that the abundance of Carrion Crows, *Corvus corone*, and Magpies, *Pica pica*, had a consistent negative relationship on Song Thrush nest survival.

Nestling growth development

Ideally for this analysis we should have been able to group the data by individual chick and then by brood. Due to limitation in the data resulting from too few measures per nestling, we were unable to do this. Consequently we could only group the weight data by brood and had to treat the tarsus length and wing length data as if it were independent, which obviously was not the case. Nonetheless we generated growth curves for each measurement and found some very interesting points. In general, nestling development seems fast, especially body weight as noted by Török (1985) for Song Thrush nestlings and in comparison to other species (See Royle *et al.* 1999). Many factors probably influence this fast development including perhaps their open cup nests coupled with high predation rate. Interestingly these growth curves are quite similar to another passerine species in Ireland, the Stonechat, *Saxicola torquata*, (Cummins & O'Halloran 2003b) where weight for both species begins to level off at approximately the same age despite size differences between the two species. In this study nestling wing growth appeared to show an almost linear growth pattern for the age ranges measured but it is important to note that the later age ranges are not as represented and this fact probably results in this linear pattern.

Conclusions

Song Thrushes in Ireland share some breeding biology characteristics with other populations in Britain and mainland Europe but differ in others. The population in Ireland since 1998 appears to be widespread and stable. Population trends pre-1998 are unclear although some decline is thought to have occurred but not at the same scale as Britain. The lower level of agricultural intensification experienced in this country in comparison to other European countries such as Britain, resulting in a more complex landscape in terms of available habitat, may explain differences in population declines. Avian predators cause the majority of predation on Song Thrush nests where the most likely predator species are corvids. In this study first nesting attempts were consistently significantly larger than second nesting attempts in respect of clutch size, and number of hatchlings and fledglings but had higher failure rates, although these differences in failure rates were not significant. This may suggest that bigger clutch and brood sizes experienced by first broods may be used to offset higher failure rates. While Song Thrushes here had higher productivity per successful attempt than Song Thrushes in Britain, other measures of productivity were lower. This lower productivity, in comparison to Britain, may be due to differences in over-winter survival of Song Thrushes between the two countries due to our milder climate. This study also indicates that the Song Thrush population here displays some insular traits but not others, as found with other Irish passerine populations.

Table 4: Summary of Song Thrush breeding parameters from some European countries. Ireland: this study; Britain: Silva (1949) Snow (1955a & b) Thomson & Cotton (2000) Paradis *et al.* (2000) Baillie (1990); Austria: Schnack (1991); Czech Republic: Pikula (1969) Weidinger (2001); Poland: Dycz (1963) Wesolowski & Czapulak (1986); n/d=no data available.

	Ireland	Britain	Austria	Czech Rep.	Poland
Timing of breeding	mid march to late june	early march to mid july	april to july	early april to early july	early april to early july
Clutch size					
Mean	4.1	4.1	4.1 (city) 5.1 (wood)	4.5 n/d	4.4 n/d
Range (dominant)	3-5 (4)	2-5 (4)	2-6	2-6 (4 & 5)	2-6 (5)
Seasonal peak	mid season	mid season	early season	mid season	mid season
Hatchling no.					
Mean	3.7	3.7		4.0	
Range (dominant)	1-5 (4)	1-6 (4)	n/d	n/d	n/d
Seasonal peak	mid season	mid season		early season	
Fledgling no.					
Mean	3.7	3.3	4.1	n/d	n/d
Seasonal peak	early season	mid season	n/d		

Table 5: Daily nest survival rates during different nest stages, nest productivity (ROA and seasonal productivity) and number of nesting attempts per breeding pair for the Song Thrush in Ireland (This study) and Britain (Baillie 1990, Paradis *et al.* 2000 and pers. comm. Will Peach).

Nest Stage	This study	Baillie	Paradis <i>et al.</i>	Peach
Daily egg survival (laying. & incub)	0.9362	0.9686	-	-
Daily incubation survival	0.9505	-	0.962	-
Daily chick survival	0.9609	0.9461	0.976	-
Reproductive output per attempt (ROA)	1.13	-	1.628	-
Seasonal productivity	Overall: 2.7	-	-	Stable pop.: 4.2-4.8 Declining pop.: 1.8-2.5
Number of nesting attempts per season	Overall: 3.7	-	-	Stable pop.: 3.9-4.8 Declining pop.: 2.5-3.0

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ENDNOTES

A. $Y=A/[1 + \exp (B - kt)]$

Y=body weight, tarsus length or wing length

A =asymptotic weight, tarsus length or wing length

B =shape constant

k =growth constant

t =age (days)

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Chapter 3:

The influence of nesting habitat on breeding Song Thrushes, *Turdus philomelos*.



This has been submitted into Bird Study and is presented in the format of this journal.

Capsule Nesting habitat significantly influences Song Thrush nest site choice, breeding output and daily nest failure rates.

Aims To describe nesting habitat of a stable Song Thrush breeding population, investigate its influence on breeding and examine what habitat variables influence Song Thrushes in choosing a nest site by comparing habitat variables in nesting areas with random non-nesting areas.

Methods Nesting habitat data were collected throughout Ireland as part of a Song Thrush breeding survey 2001-2003 from intensively monitored sites in County Cork and by volunteers at extensively monitored sites countrywide.

Results Most nests were located 1.3 - 2.4m from the ground. Nests built in April were significantly higher than those built in May. Nest sites were at trees, bushes or hedgerow and we highlight the role of garden habitat for nesting. Clutch size was significantly higher (\pm standard deviation) on farmland (4.5 ± 0.7) than garden & parkland (4.0 ± 0.5) and woodland (4.0 ± 0.6). The number of hatched chicks was significantly greater in hedgerow (4.1 ± 0.9) than trees (3.2 ± 0.7) but not bush (3.7 ± 0.9), while the number of fledged chicks was significantly lower in nests in trees (3.2 ± 0.7) than hedgerow (4.2 ± 0.8) and bush sites (3.8 ± 0.7). We found significant differences in daily nest fail rates across different nest periods with both nest site (tree, bush, hedgerow) and nest concealment (partly concealed and well concealed). Nesting areas had significantly denser vertical vegetation than non-nesting areas.

Conclusion Dense vertical vegetation is an important deciding factor for Song Thrushes when choosing a nest site and may be an important consideration in conservation measures striving to maintain or restore Song Thrush populations.

Introduction

Various resources can limit breeding bird populations including the availability of nesting sites (Newton 1994 a & b). Consequently, nesting habitat has been identified as a conservation tool for endangered bird species such as the Eurasian Black Vulture in Greece (Poirazidis *et al.* 2004). In Britain, the Song Thrush, *Turdus philomelos*, population has declined by 52% (Eaton *et al.* 2004) with the largest decline on farmland (65%) and slower decline in woodland (Thomson *et al.* 1997, Baillie *et al.* 2002) over the last 30 years. The Song Thrush is now classified as a species of conservation concern in Britain (Gibbons *et al.* 1996), although recent monitoring indicates some population recovery (Newton 2004). The importance of nesting cover for Song Thrushes has been recently highlighted by Peach *et al.* (2004a & b). In fact Peach *et al.* (2004a & b) emphasize the importance of restoring suitable nesting cover adjacent to suitable foraging areas through conservation policies in order to halt the decline of Song Thrush populations in rural Britain.

Population trends for the Song Thrush in Ireland are unclear due to the lack of long-term data but some decline is thought to have occurred 1970-1990 (Gibbons *et al.*

1993, Tucker & Heath 1994). However, the Song Thrush is not regarded as a species of conservation concern in Ireland (Newton *et al.* 1999). This is confirmed by recent (post 1998) national bird monitoring through the Countryside Bird Survey (CBS), which indicates that the current breeding population is widespread and stable (Coombes 2003). In fact the current breeding population here appears to be better off than that in Britain where, for example, in 2002 the Song Thrush was recorded in 86% of CBS survey squares (Coombes 2002) in Ireland in comparison to 74% in the equivalent Breeding Bird Survey (BBS) of the same year in the UK (Raven *et al.* 2003).

Given the current favourable conservation status of the Song Thrush in Ireland, we had a unique opportunity to describe nesting habitat of Song Thrushes, investigate its influence on breeding output and daily nest failure rates and examine what habitat variables influence Song Thrushes to nest in a particular area. By providing an insight into the relationship between Song Thrushes and their nesting environment, this study will also help conservation measures elsewhere, especially in areas of breeding population decline.

Study sites

Nesting habitat data were collected in conjunction with a Song Thrush breeding biology survey 2001-2003 from extensively monitored sites countrywide and

intensively monitored sites in County Cork, Ireland (Chapter 2). Three intensive study sites were located in County Cork at Fota Arboretum (51°53.5'N, 8°18.2'W), Millstreet Country Park (52°1.3'N, 10°0.8'W) and Willowbrook farm (52°2.4'N, 10°3.3'W). These study sites consisted of garden/parkland, coniferous forests and mixed coppice respectively. Extensive study areas consisted of two sites in County Cork at Fota Wildlife Park (51°53.5'N, 8°18.8'W) and Glinny farm (51°47.2'N, 8°28.4'W) and a random selection of sites countrywide where volunteers recorded nests. Full description of these study sites can be found in Chapter 2.

Methods

Data collection

Volunteers conducted an extensive nesting habitat survey at extensive study sites countrywide. In 2002 and 2003, we undertook an intensive nesting habitat survey at the intensive study sites, where additional habitat information was recorded. All breeding parameters used in the following analysis (*i.e.* clutch size, number of hatch and fledged young and nest failure rates) were collected from a breeding survey as described in Chapter 2. Nest failure was determined by calculating nest failure on a daily basis using the Mayfield method (Mayfield 1961, 1975).

Extensive nesting habitat survey

Volunteers recorded the following nesting habitat data: nest height above ground (m), dominant habitat feature at nest site (*e.g.* tree, bush), dominant habitat

surrounding nest site (*e.g.* farmland, woodland), nest concealment (*i.e.* well concealed, partly concealed, exposed), location (*i.e.* rural, urban, suburban), level of night-time light at nest site (*i.e.* well lit, dimly lit, total darkness) and level of ground slope at nest site (*i.e.* flat/gentle, sloping, steep incline).

Intensive nesting habitat survey

In addition to the above data, the following data were recorded in an intensive survey: height of dominant habitat feature at nest site, minimum and maximum distance of nest site to outer edge of dominant habitat feature, percentage density of vegetation over (*i.e.* horizontal) nest, average percentage cover of horizontal vegetation 1m from nest, average vegetation density surrounding (*i.e.* vertical) the nest, percentage ground vegetation cover (*i.e.* bare soil, wood, dead or live vegetation) within 1 metre radius of nest site, percentage tree and bush/shrub cover within 5 metre radius of nest site.

An intensive nesting habitat survey was conducted on 40 nests. In order to gain insight into what habitat variables are important to Song Thrushes when choosing a nest site, we also conducted a survey on an equivalent number of non-nesting sites (*i.e.* 40). A stratified random approach was used in choosing these non-nesting survey sites. Stratification was achieved by choosing areas that had shown no evidence of nesting since the previous year. In the field we randomly chose the actual survey site within these non-nesting areas by blindly throwing an item (the same item in all cases) and using its landing position as the centre of the survey site.

The same habitat data recorded in the nesting sites were also recorded in these non-nesting ones with obvious exceptions (*e.g.* nest height from ground). In all cases trees 5m or less in height were classed as bush/shrub (after Crick 1992). The intensive habitat survey was conducted at the end of the breeding season and in all cases the same observer took the habitat measurements. Standard methods, adapted from Bibby *et. al.* (1993), were used in measuring habitat (See Table 1). However, the methods used for assessing horizontal and vertical vegetation density at nesting and non-nesting sites are now described in detail.

Table 1: Summary of habitat parameters with corresponding units of measure and methods employed for nesting habitat survey of Song Thrush nests in Ireland.

Habitat parameter	Units of measure	Method
1. Nest height above ground 2. Height of dominant habitat feature at nest (excl. tree height, see below) 3. Distance to outer edge of dominant habitat feature	cm or m	Measuring tape or stick
4. Tree height	degrees	Clinometer (at 20m distance)
5. Horizontal vegetation density 6. Vertical vegetation density	% %, cm	By eye using cylindrical tube By eye using chequered vegetation density board and measuring tape
7. Ground vegetation cover (within 1m radius) 8. Tree & bush/shrub cover (within 5m radius)	%	By eye (with radius marked out)

Vegetation density at nest site

To assess horizontal vegetation density, we looked through a cylindrical tube (*i.e.* sighting tube; internal diameter of 4.5cm; length of 11cm) and estimated percentage cover of vegetation by eye. An estimate of vegetation cover was recorded both over the nest survey site and at four positions 1m from the nest survey site, each position 90° from the next. The four percentage values recorded 1m from nest survey site were averaged to give an overall value for analysis. For consistency, each horizontal vegetation density estimate was taken with the cylindrical tube 1m from the ground.

To assess vertical vegetation density we placed a chequered vegetation density board (18 x 18cm) at four positions at the nest survey site, each position 90° from the next. An observer then moved away from the board, in a perpendicular line, until 50% of it was covered with vegetation. The distance (cm) between the observer and the board was then recorded, where lower distance values indicated higher vegetation density and vice-versa. The four distance values recorded at each nest survey site were averaged to give an overall value for analysis.

Statistical analyses

Analyses of nesting habitat variables and breeding parameters were undertaken with logistic regression models using Generalized Linear Models (GLMs) (after Peach 1999, Aebischer 1999, Siriwardena 2000) as available in the PROC GENMOD feature of SAS (Release 8.2). This analysis uses maximum-likelihood ratio statistics to test for significance (SAS 2000). In all cases univariate models were conducted as it was felt that the unbalanced dataset and small sample sizes involved did not support complex multivariate models without compromising the value of the data. Nesting habitat data for all years (2001-2003) were combined for analysis and significant ($p < 0.05$) results are reported. Non-significant results are outlined in Appendices 1-3.

Clutch sizes and number of chicks at hatching and fledging were analysed with nest height above ground, dominant surrounding habitat, dominant habitat feature at nest site, nest concealment and rural & suburban location using identity link function with normal error distribution incorporated into a Type I analysis for each model. A similar approach was used to compare nest height above ground with dominant surrounding habitat, dominant habitat feature at nest site, month, nest concealment and rural & suburban location. Daily nest failure rates, for egg (*i.e.* laying and incubation), incubation (*i.e.* period from when the last egg was laid to when the first chick hatched), nestling (*i.e.* period from when the first chick hatched to when the last chick fledged) and all (*i.e.* egg laying to fledging) periods were analysed with

nest height above ground, dominant surrounding habitat, dominant habitat feature at nest site, nest concealment and rural & suburban location using logit link function with binomial error distribution incorporated into a Type I analysis for each model, where daily fail rates were modeled as the proportion of survival (0) or failure (1) and the total number of nest observation days.

The additional habitat data collected from the intensive nesting habitat survey were used to compare habitat variables between nesting and non-nesting areas using Mann-Whitney tests throughout. To avoid the use of inter-correlated variables, we used a Spearman's rank-order correlation to identify such variables and removed these from subsequent analysis. The variables subsequently analysed were (i) height of dominant habitat feature at nest survey site, (ii) maximum distance of nest survey site to outer edge of dominant habitat feature, (iii) average vertical vegetation density at nest survey site (as measured by average distance from chequered vegetation density board to observer as already described), (iv) percentage cover of horizontal vegetation over nest survey site, (v) percentage ground cover of bare soil and (vi) live vegetation within 1m radius of nest survey site.

Results

Nest height above ground

The mean nest height (m) above ground was $1.71 \pm 0.06\text{m}$ ($n = 93$), with most nests located between 1.3 –2.4 m (Figure 1). Nest height differed significantly with the breeding season ($\chi^2=10.96$; d.f.=3; $p<0.05$) where April nests ($1.89 \pm 0.51\text{m}$; $n = 22$) were higher than May nests ($1.50 \pm 0.39\text{m}$; $n = 29$) ($\chi^2=10.71$; d.f.=1; $p<0.01$) but not March ($1.58 \pm 0.53\text{m}$; $n = 12$) or June ($1.62 \pm 0.50\text{m}$; $n = 10$) nests.

Dominant nesting habitat

Approximately 50% of all nests recorded were located within parkland & garden habitats and 41% in woodland and farmland combined (Figure 2). However, since areas of known breeding populations were selected for intensive monitoring this may have led to a bias and over-representation of some habitats, in particular parkland & garden and woodland, and under-representation of others, in particular farmland. So assuming that records submitted by volunteers represent a more random sample, the highest numbers of nests were recorded in farmland (35%) followed closely by parkland & garden (33%) while woodland (16%) diminishes in importance as a nesting habitat (Figure 2). We also found that nests were usually located at trees, bushes and hedgerow, with the majority (40%) in trees (Figure 2).

Figure 1: Percentage height frequency (metres above ground) of Song Thrush nests in Ireland for 2001-2003 (n=91).

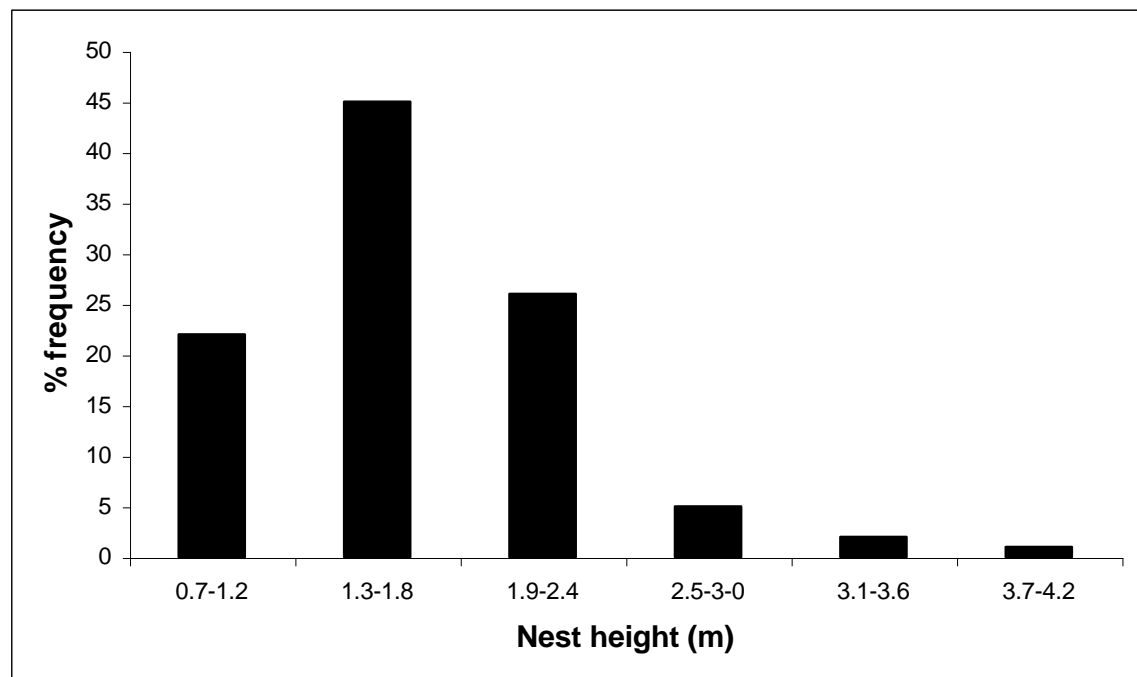
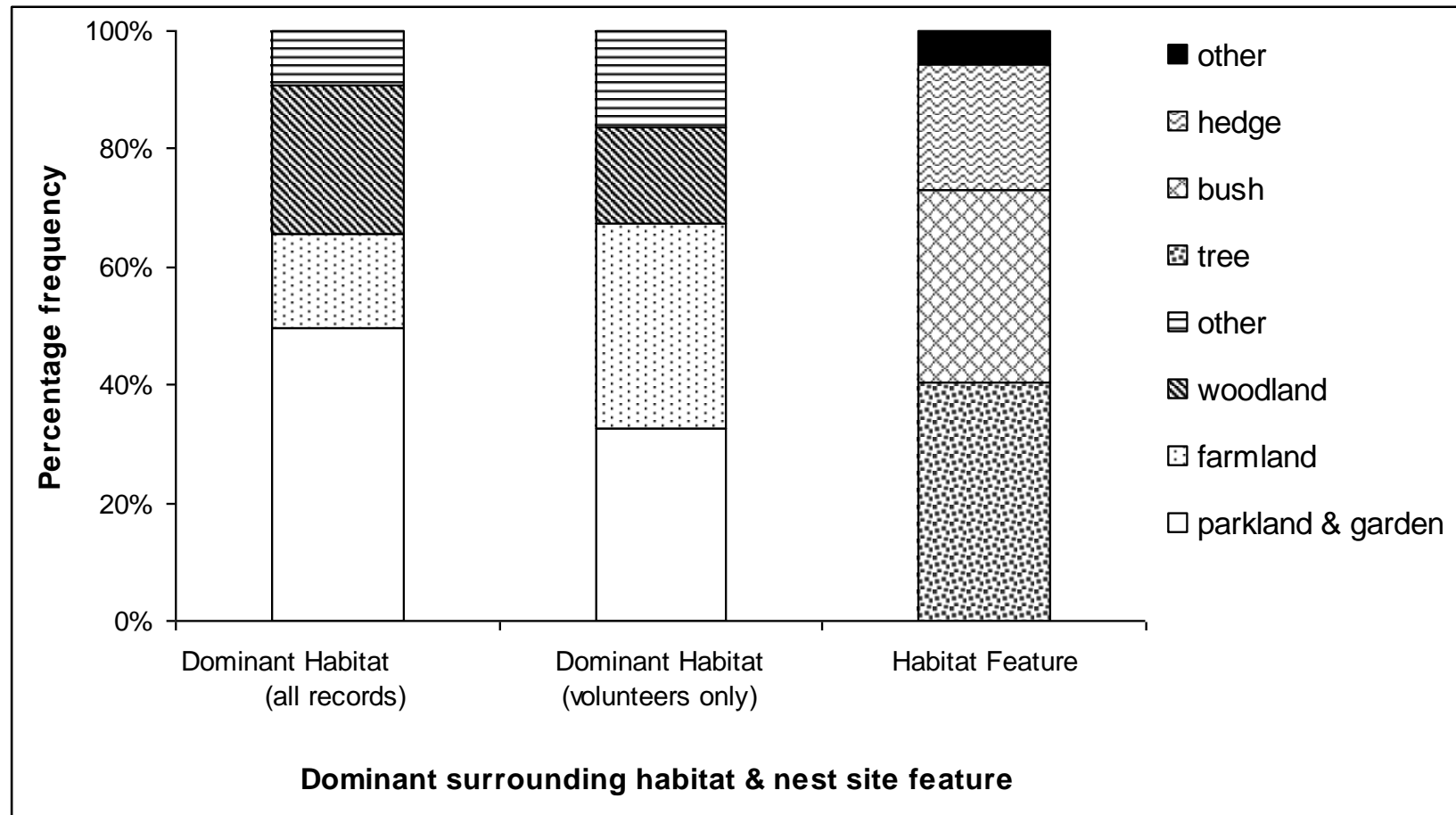


Figure 2: Dominant surrounding habitat, using all records (n=98) and volunteer records only (n=50), and dominant habitat feature at nest site (n=89) for Song Thrush nests in Ireland 2001-2003.



Nesting habitat & breeding parameters

Clutch sizes differed significantly with both dominant surrounding habitat ($\chi^2=8.21$; d.f.=2; $p<0.05$) and dominant habitat feature at nest site ($\chi^2=7.63$; d.f.=2; $p<0.05$). In the former mean clutch sizes in farmland (4.5 ± 0.7 ; $n=11$) were higher than garden & parkland (4.0 ± 0.5 ; $n=32$) and woodland (4.0 ± 0.6 ; $n=12$). In the latter mean clutch sizes in hedgerow (4.4 ± 0.6 ; $n=14$) were higher than tree (3.9 ± 0.4 ; $n=17$) and bush (3.9 ± 0.6 ; $n=22$).

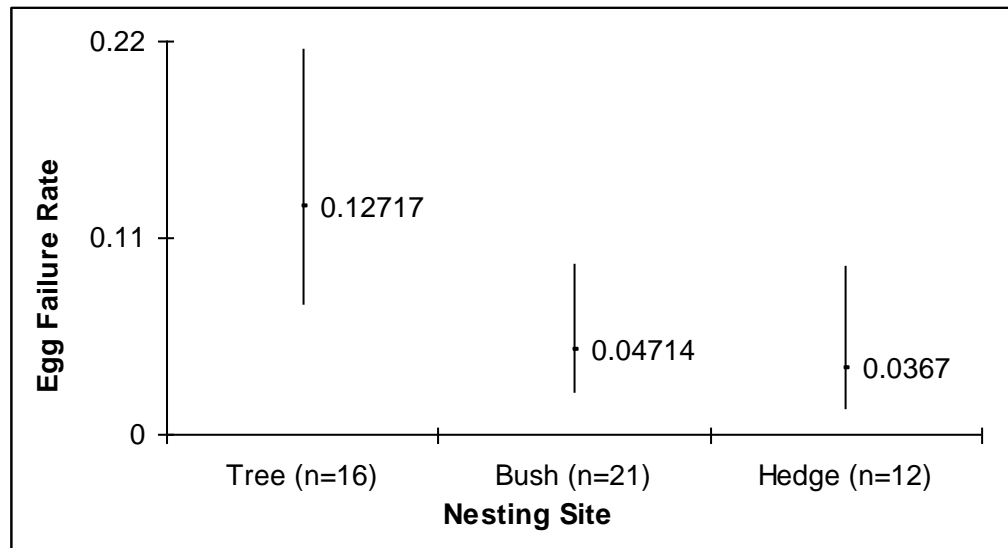
The number of hatched and fledged chicks varied significantly with dominant habitat feature at nest site (hatched chicks: $\chi^2=6.86$; d.f.=2; $p<0.05$; fledged chicks: $\chi^2=10.23$; d.f.=2; $p<0.01$). The mean number of hatched chicks was significantly greater in hedgerow (4.1 ± 0.9 ; $n=13$) than tree (3.2 ± 0.7 ; $n=14$) but not bush (3.7 ± 0.9 ; $n=19$). The mean number of fledged chicks was significantly lower at tree sites (3.2 ± 0.7 ; $n=12$) than hedgerow (4.2 ± 0.8 ; $n=10$) and bush sites (3.8 ± 0.7 ; $n=13$).

Nesting habitat & nest failure rates

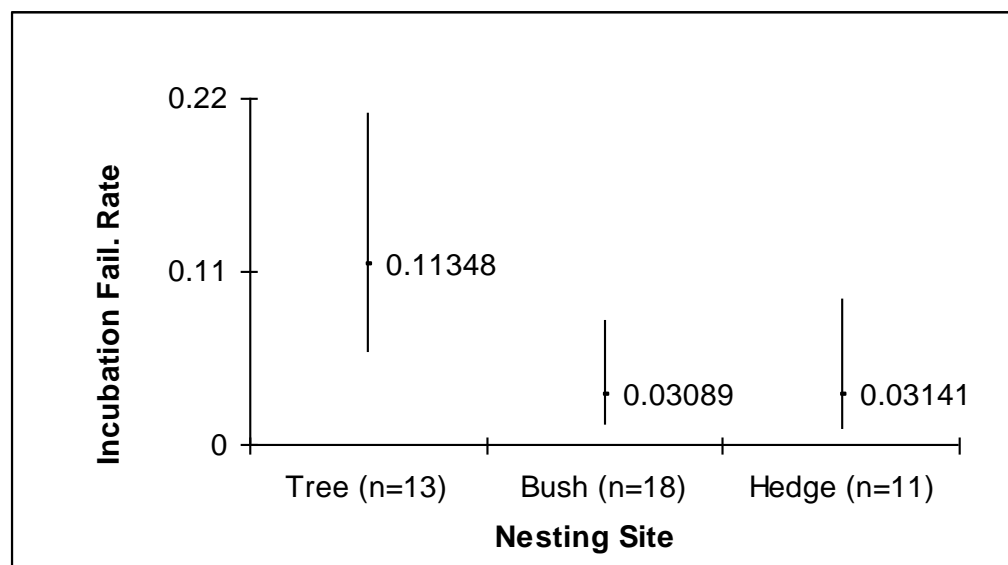
Nest failure rates differed significantly with both dominant habitat feature at nest site (Figure 3 (a-c)) and nest concealment across all nest stages (Figure 4 (a-d)), except nestling stage where only nest concealment significantly differed. In all cases failure rates were higher at tree sites and partly concealed nests (See Figures 3 & 4 for statistical analysis).

Figure 3 (a-c): Egg (a), incubation (b) and all (c) (i.e. egg laying to nestling) failure rates for dominant habitat feature at nest site for Song Thrushes in Ireland 2001-2003. Fail rate values are given with 95% C.I.s. Sample sizes are given in parentheses. $\chi^2=6.92$; 6.41; 10.6; $p<0.05$; $p<0.05$; $p<0.01$ respectively.

(a)



(b)



(c)

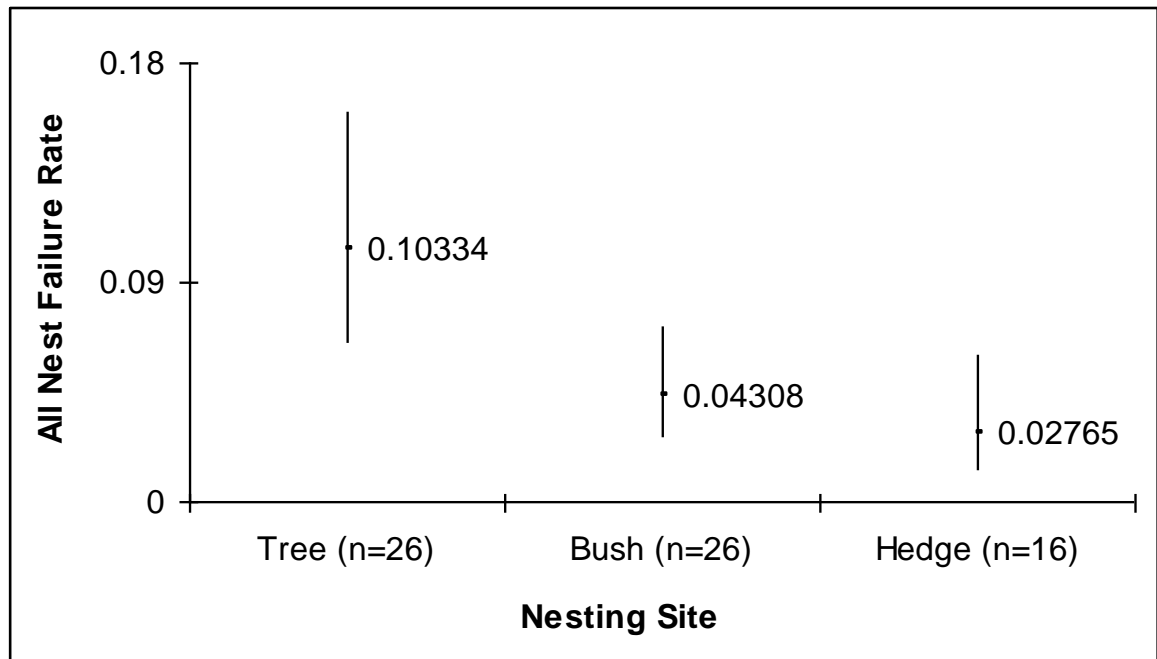
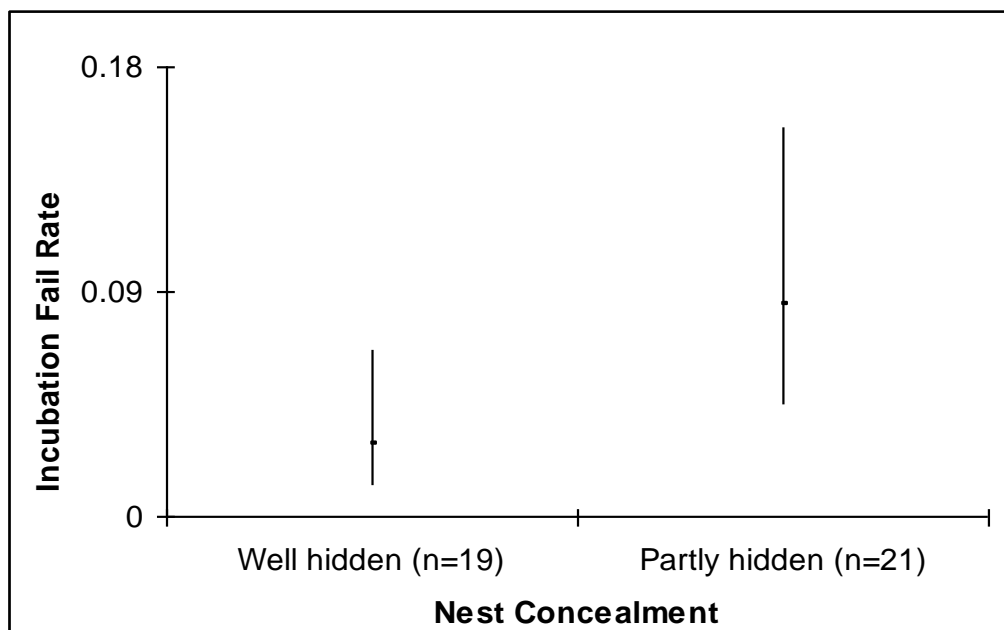


Figure 4 (a-d): Egg (a), incubation (b), nestling (c) and all (d) (*i.e.* egg laying to nestling) failure rates for Song Thrush nest concealment in Ireland 2001-2003. Failure rate values are given with 95% C.I.s. Sample sizes are given in parentheses. $\chi^2=6.92$; 4.26; 10.34; 17.26; $p<0.01$; $p<0.05$; $p<0.01$; $p<0.001$ respectively.

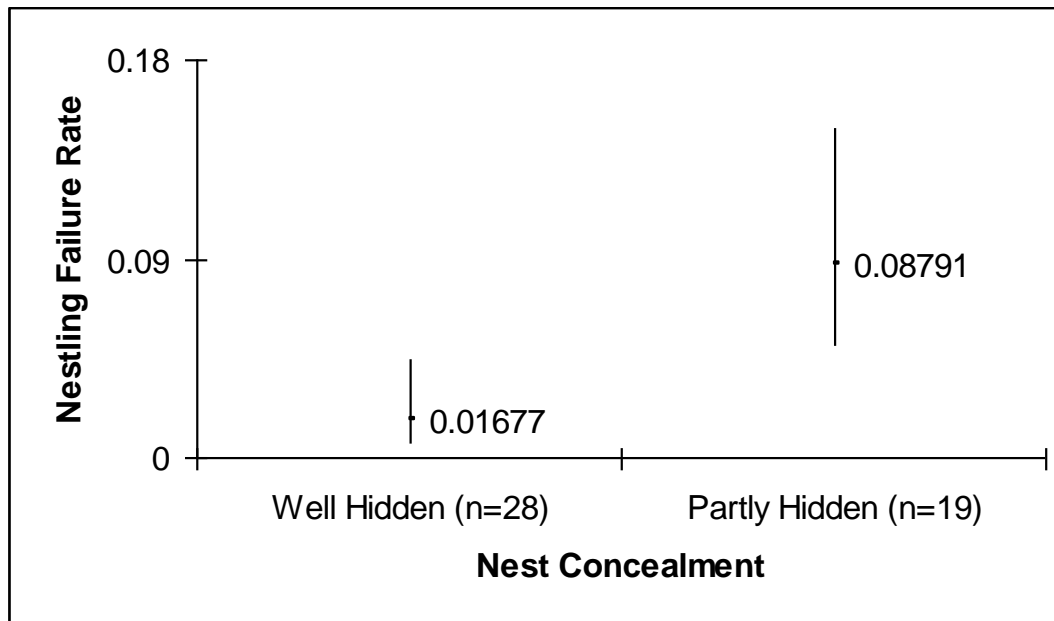
(a)



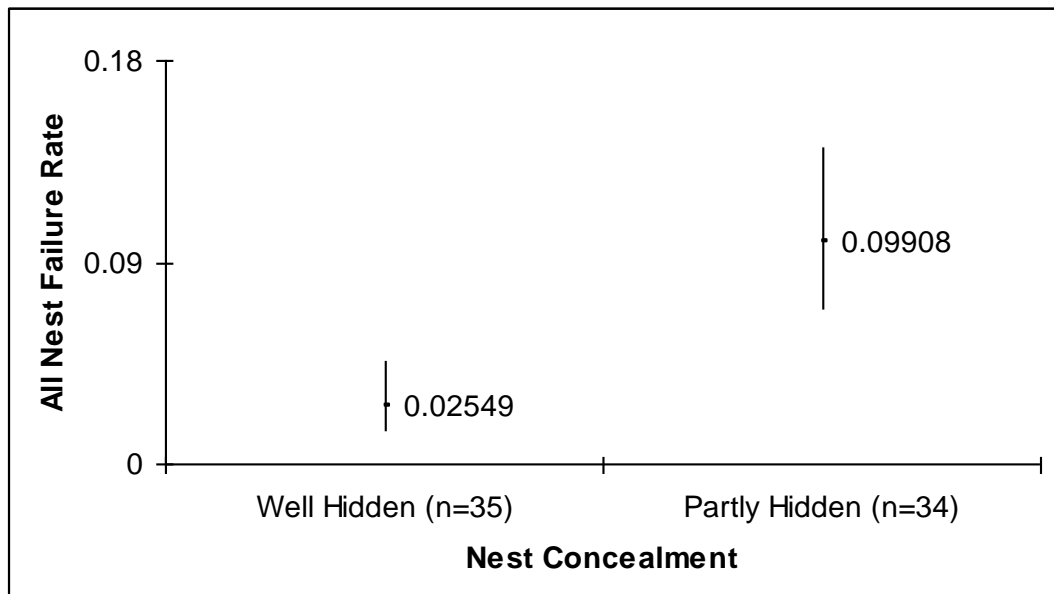
(b)



(c)



(d)



Nesting habitat variables between nesting and non-nesting areas

The only habitat variable to differ significantly between nesting and non-nesting areas was vertical vegetation density ($W=1346.0$; $p<0.01$), where nesting areas had higher vertical vegetation density as indicated by the lower distance recorded between the observer and the chequered vegetation density board in nesting areas (mean \pm sd; $116.2 \pm 73.0\text{cm}$) than non-nesting areas ($178.5 \pm 110.2\text{cm}$).

Discussion

Several studies in the U.K. have highlighted the importance of habitat for breeding Song Thrushes including hedgerow, trees, woody vegetation species, ditches, gardens, woods, grassland and scrub (Arnold 1983, Lack 1992, Green *et al.* 1994, MacDonald & Johnson 1995, Moles & Breen 1995, Parish *et al.* 1995, Sparks *et al.* 1996, Mason 1998, Hinsley & Bellamy 2000, Peach *et al.* 2004a). Many of these habitats are important as nesting sites as acknowledged by Sparks *et al.* (1996) who pointed out that the positive influence of hedge and tree habitat on Song Thrushes found in their study was probably more related to nest sites opportunities than foraging opportunities. More recently in Britain, Peach *et al.* (2004a & b) have highlighted the importance of nesting cover, especially dense woody vegetation, for Song Thrushes in conjunction with close proximity to suitable foraging habitats. Consequently, Peach *et al.* (2004a & b) also highlight the future importance of implementing agri-environment schemes that will restore suitable nesting cover adjacent to suitable foraging areas in a bid to tackle the decline of Song Thrush populations in rural Britain. Given the fact that the breeding population in Ireland is currently widespread and stable (Coombes 2003), we had an opportunity to investigate the relationship between breeding Song Thrushes and nesting habitat and examine what habitat variables influence Song Thrushes to nest in a particular area in the first place. Although some caution must be exercised given the size of

datasets involved, we believe that our findings can contribute to conservation measures elsewhere, especially areas experiencing declines in breeding population.

Nest height above ground

Nest height above ground here is similar to some other Song Thrush studies (Wesolowski & Czapulak 1986; range 1.6-2.0m, Murray 2004; mean 1.52m) and lower than others (Dycrz 1969; range 2.0-3.0m, Schnack 1991; range 2.0-3.5m). Differences in nest height are probably explained by differences in habitat type and structure between the studies since the extent of tree and shrub layer appears to influence Song Thrush nest height (Dycrz 1969). Indeed both Schnack (1991) and Dycrz (1969) noted that Song Thrush nests were built higher in habitats with taller vegetation (*e.g.* forests) than habitats with lower vegetation (*e.g.* parks). Although nest heights in this study varied between dominant surrounding habitat and habitat feature at nest site, these differences proved insignificant. The overall lower nest height found in this study in comparison to others suggest that the Irish landscape has a higher proportion of low standing nesting vegetation. Unlike Murray (2004), we found that Song Thrush nest height differed significantly through the breeding season (*i.e.* monthly) with April nests higher than May nests. Schnack (1991) also found significant monthly differences in nest height, although the trend was different with June and July nests being higher than April ones. Changes in nest height through the season are most likely a reflection of changes in vegetation structure and growth. Some studies (*e.g.* Ludvig *et al.* 1995, Burhans *et al.* 2002, Piper & Catterall 2004) have found significant relationships between nest height and

predation rates. Although this specific relationship was beyond the scope of our study it should be remembered that we did not find daily nest failure rates to differ significantly with nest height.

Dominant nesting habitat

In this study most nests were located in garden & parkland habitat but due to inherent biases in selecting intensive study sites (as already mentioned), this habitat along with woodland are likely to be inflated. Using volunteered data only, we found that the importance of both garden & parkland and woodland habitats for nesting decreased while farmland increased to become the dominant nesting habitat. While it is possible that volunteered nesting data here are still over-representing garden habitat, this study still highlights the importance of gardens and parks for nesting Song Thrushes in Ireland as found in other studies (Gregory & Baillie 1998, Mason 1998, Peach *et al.* 2004a & b). The percentage frequencies of dominant habitat feature at nest site should not suffer from the same biases as dominant surrounding habitat since these features are usually available across all habitat types. Although the usage of these nesting sites is probably more reflective of their availability within the Irish landscape rather than Song Thrush nesting preference. The dominant habitat features found at nest sites in this study (*i.e.* trees, bushes and hedgerow) are not surprising and have been noted by other authors (Cramp 1988, Wesolowski & Czapulak 1986). Other studies have found that Song Thrushes select field boundaries, gardens and woodland for nesting sites and home ranges (Murray

2004, Peach *et al.* 2004a & b) and the habitat features found here are typically found at such habitats.

Nesting habitat & Song Thrush breeding

Although the unbalanced nature of our dataset combined with small sample sizes did not allow for complex multivariate modelling, the univariate models generated in our analysis still provide a useful insight into our data. Overall we found that some aspects of nesting habitat significantly impacted on Song Thrush breeding outcome. In this study clutch sizes were significantly higher in farmland than garden & parkland and woodland. This contrasts with Pikula (1969) who did not find significant differences between woodland and non-woodland habitats in former Czechoslovakia. In Britain, O'Connor & Shrubbs (1986) found similar mean clutch sizes for Song Thrushes on farmland (4.2), woodland (4.1) and suburban habitats (4.1) (comparable to our garden & parkland habitats which mostly consisted of suburban areas) to our study.

Nest sites in trees proved to have an important influence on the breeding parameters of Song Thrushes where clutch size, numbers of hatchlings and number of fledglings were consistently and significantly lower than nests situated in hedgerow or bush. On the other hand, nests in hedgerow had higher clutch sizes while nests in both hedgerow and bushes did not differ significantly with number of chicks at hatching and fledging. Pikula (1969) also noted that nesting sites influenced Song Thrush breeding with more chicks hatched and fledged in nests located in trees and

shrubs 2.5m from the ground and conifers than those in shrubs and trees below 2.5m and deciduous trees, although nest height and predation could be other confounding factors in this case.

The influence of nesting habitat on Song Thrush breeding is also evident in our findings of daily nest failure rates at nest sites and nest concealment. Daily failure rates were significantly higher at tree sites (than bushes and hedgerows) and partly concealed nests (than well concealed nests) across all nest stages except nestling where only partly concealed nests had significantly higher failure rates. Hedgerows have been found to provide significantly higher nesting success than trees in a study of Blackbird nests by Moller (1998) (where the Blackbird species shares similar niches to the Song Thrush and is an open cup nester with similar sized nests to the Song Thrush). Interestingly, another study on Blackbird nests by Hatchwell *et al.* (1995) found that successful nests were significantly less exposed than failed nests where this effect of nest exposure occurred during the laying and incubation stages but not nestling stage.

While Murray (2004) found that daily failure rates during Song Thrush nestling stage were significantly higher for nests located in gardens than those in woods, we did not find any such significant difference even though daily failure rates here were higher in woodland nests than garden nests during the nestling period. Despite the fact that our study did not find significant differences in daily nest failure rates between dominant surrounding habitats, it is interesting to note that farmland nests

in our study had the lowest daily fail rates during egg, incubation, nestling and all periods (see Appendix 2) resulting in an overall (includes laying period) nest success rate of 38% in farmland which compares to 16% in garden & parkland and 19% in woodland. The fact that farmland nests in this study had the lowest failure rates across all nesting stages is surprising, especially as this is the habitat that Chamberlain *et al.* (1995) recorded higher predation rates than woodland and in lowland Britain this is the habitat where the Song Thrush population has declined the most (Thomson *et al.* 1997, Baillie *et al.* 2002).

Snow & Mayer-Gross (1967) found overall (laying to fledging) Song Thrush nesting success in Britain was lowest in woodland (12%) followed by farmland (26%), and highest in garden habitat (53%). On a similar note, O'Connor and Shrubbs (1986) reported that Song Thrush daily egg and chick mortality rates in Britain (during 1962-1980) were highest in both farmland and woodland habitats and lowest in suburban habitats. A more recent study of Song Thrushes in Britain (1995-1997) found that overall nesting success of a stable farmland population varied 26-34% while a declining farmland population varied 17-30% (pers. comm. Will Peach). Therefore this study suggests that Song Thrush nesting success is higher in Irish farmland than British farmland. This difference in nesting success between the two countries is probably due to a combination of factors including extent of agricultural intensification, habitat and climate. Intensification of the Irish agricultural landscape has occurred less intensively and on a smaller scale than Britain (Cabot 1985, Aalen *et al.* 1997, Lysaght 1989, Stanners & Bourdeau 1995).

Consequently, the Irish landscape has a relatively dense network of mostly unmanaged field boundaries (Lysaght 1989, Moles & Breen 1995, Aalen *et al.* 1997). While permanent grassland dominates the landscape of both countries, Ireland has a higher proportion than Britain (See Tucker & Dixon 1997) allowing for greater foraging opportunities, especially for the favoured earthworm (Gruar *et al.* 2003 Peach *et al.* 2004a). In addition Ireland has a wetter and milder climate than England, especially southeast England (Keane 1986, Bowen 1973, Chandler & Gregory 1976, Hulme & Barrow 1997) where for example Irish annual rainfall is up to 20% higher than the open lowlands of England (Keane 1986), again allowing for greater foraging opportunities by creating easier probing opportunities for Song Thrushes of prey items such as earthworms. Therefore the higher nest survival rates found for farmland Song Thrushes in Ireland in comparison to Britain may be due to the Irish landscape providing better nesting and foraging opportunities, both aspects which Peach *et al.* (2004a & b) recommend for future inclusion in British conservation policies that aim to recover rural Song Thrush populations.

Nesting habitat variables between nesting and non-nesting areas

When we assessed nesting habitat variables between nesting and non-nesting areas, vertical vegetation density proved to be significantly higher in nesting areas than non-nesting areas. Dycrz (1963, 1969) noted the importance of dense vegetation cover for Song Thrush nesting through his observations that most Song Thrush nests were located in areas of dense shrub when available. In addition Peach *et al.* (2004a & b) have also recognised the need of dense nesting vegetation for Song Thrushes

and recommend that future agri-environmental policies and schemes should incorporate measures for improving such nesting cover. Blackbird nesting areas have been found to have significantly denser vegetation than non-nesting areas (Hatchwell *et al.* 1995), re-affirming our findings for Song Thrushes in this respect. While this study did not investigate differences in habitat variables between successful and non-successful breeding attempts, Hill (1998) found that successful Song Thrush nests had more rank vegetation (*i.e.* overgrown dense herbaceous that often has an extensive vertical element) surrounding their nests in comparison to its availability in the whole study site, further highlighting the importance of vertical vegetation density surrounding Song Thrush nests.

Conclusions

We found that nesting habitat has an important influence on Song Thrush breeding. Nesting height found in this study indicates that the Irish landscape mostly consists of low standing vegetation. The importance of gardens as a nesting habitat is highlighted along with the significant impacts that nesting habitat can have on Song Thrush breeding. While we found that farmland habitat had an impact on clutch size and nest concealment an impact on daily nest failure rates, we found that tree nesting sites impacted negatively on both breeding output and daily failure rates. Generally hedgerow and bush nesting sites seemed to be equally important in respect of both breeding output and daily nest failure rates, which emphasises the importance of a bush/shrub layer for breeding Song Thrushes and its inclusion into conservation measures being proposed in areas of Song Thrush breeding decline.

Interestingly, failure rates for Song Thrush nests on farmland here seem to generally be lower than those of Britain, where the farmland population has suffered the largest decline overall. Lower agricultural intensification combined with a dense network of mostly unmanaged field boundaries and milder damper weather have probably contributed to differences between Song Thrush nest failure rates in Ireland and Britain. In addition, this study also revealed the importance of dense vertical vegetation in attracting Song Thrushes to choose a nest site, which again should be considered for any conservation measures designed to maintain or recover Song Thrush breeding populations especially in relation to any conservation policies involving the maintenance and or planting of suitable nesting bush/shrub habitat layer.

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Appendix 1: Non-significant ($p>0.05$) GLM test results of Song Thrush breeding parameters and nesting habitat variables.

Mean values are given \pm standard deviation with sample sizes in parentheses. See text refers to variables that significantly differed and are referred to in the text. χ^2 =chi-square statistic; d.f.=degrees of freedom; n/a = not applicable.

Variable	Nest height (m)	Clutch size	Number of Hatchlings	Number of Fledglings
Dominant habitat: <i>Garden & parkland</i> <i>Farmland</i> <i>Woodland</i>	1.80 \pm 0.54 (n=45) 1.48 \pm 0.51 (n=17) 1.76 \pm 0.78 (n=23) $\chi^2=5.88$; d.f.= 2	See text	3.56 \pm 0.94 (n=23) 4.09 \pm 0.94 (n=11) 3.43 \pm 0.81 (n=16) $\chi^2=3.78$; d.f.= 2	3.56 \pm 0.73 (n=16) 4.12 \pm 0.64 (n=8) 3.43 \pm 0.85 (n=14) $\chi^2=4.59$; d.f.= 2
Dominant habitat feature: <i>Tree</i> <i>Bush & shrub</i> <i>Hedgerow</i>	1.86 \pm 0.80 (n=36) 1.60 \pm 0.44 (n=29) 1.59 \pm 0.42 (n=19) $\chi^2=2.42$; d.f.=2	See text	See text	See text
Nest height (m): 0.7-1.2 1.3-1.8 1.9-2.4	n/a	4.08 \pm 0.79 (n=12) 4.21 \pm 0.59 (n=24) 3.94 \pm 0.57 (n=16) $\chi^2=1.82$; d.f.=2	3.54 \pm 0.93 (n=11) 3.83 \pm 0.98 (n=23) 3.60 \pm 0.83 (n=15) $\chi^2=0.95$; d.f.=2	3.78 \pm 0.83 (n=9) 3.80 \pm 0.86 (n=15) 3.50 \pm 0.76 (n=14) $\chi^2=1.20$; d.f.=2
Nest location: <i>Rural</i> <i>Suburban</i>	1.66 \pm 0.62 (n=60) 1.84 \pm 0.61 (n=32) $\chi^2=3.80$; d.f.=1	4.22 \pm 0.70 (n=32) 3.96 \pm 0.47 (n=23) $\chi^2=2.68$; d.f.=1	3.74 \pm 0.88 (n=35) 3.44 \pm 1.03 (n=16) $\chi^2=1.21$; d.f.=1	3.67 \pm 0.80 (n=30) 3.67 \pm 0.87 (n=9) $\chi^2=0.00$; d.f.=1
Nest concealment: <i>Well hidden</i> <i>Partly hidden</i>	1.74 \pm 0.53 (n=43) 1.60 \pm 0.48 (n=40) $\chi^2=0.92$; d.f.=1	4.12 \pm 0.61 (n=24) 4.15 \pm 0.54 (n=26) $\chi^2=0.03$; d.f.=1	3.70 \pm 0.95 (n=30) 3.69 \pm 0.87 (n=16) $\chi^2=0.00$; d.f.=1	3.78 \pm 0.75 (n=27) 3.37 \pm 0.92 (n=8) $\chi^2=1.67$; d.f.=1

Appendix 2: Non-significant ($p > 0.05$) GLM test results of daily nest failure rates at different nest stages (refer to text for definitions) and nesting habitat variables. Upper and lower 95% confidence limits are in parentheses. See text refers to variables that significantly differed and are referred to in the text. χ^2 =chi-square statistic; d.f.=degrees of freedom; n=sample sizes.

Variable	Egg stage	Incubation stage	Nestling stage	All
Dominant habitat: Garden & parkland Farmland Woodland	0.0763 (0.0465-0.1227) 0.0392 (0.0127-0.1146) 0.0567 (0.0215-0.1416) $\chi^2=1.44$; d.f.= 2; n=50	0.0592 (0.0321-0.1065) 0.0408 (0.0132-0.1190) 0.0496 (0.0161-0.1423) $\chi^2=0.37$; d.f.= 2; n=44	0.0378 (0.0190-0.0738) 0.0209 (0.0052-0.0799) 0.0488 (0.0184-0.1229) $\chi^2=1.10$; d.f.= 2; n=47	0.0574 (0.0384-0.0848) 0.0291 (0.0121-0.0679) 0.0525 (0.0264-0.1014) $\chi^2=2.31$; d.f.= 2; n=69
Dominant habitat feature: Tree Bush & shrub Hedgerow	See text	See text	0.0769 (0.0350-0.1608) 0.0397 (0.0190-0.0808) 0.0174 (0.0043-0.0668) $\chi^2=4.13$; d.f.= 2; n=46	See text
Nest height (m): 0.7 - 1.2 1.3 - 1.8 1.9 - 2.4	0.0723 (0.0328-0.1517) 0.0583 (0.0317-0.1050) 0.0430 (0.0162-0.1090) $\chi^2=0.71$; d.f.= 2; n=49	0.0676 (0.0284-0.1523) 0.0358 (0.0150-0.0832) 0.0353 (0.0114-0.1038) $\chi^2=1.24$; d.f.= 2; n=42	0.0250 (0.0063-0.0945) 0.0558 (0.0312-0.0980) 0.0226 (0.0073-0.0678) $\chi^2=2.91$; d.f.= 2; n=50	0.0491 (0.0247-0.0951) 0.0570 (0.0374-0.0858) 0.0310 (0.0149-0.0637) $\chi^2=2.23$; d.f.= 2; n=70
Nest location: Rural Suburban	0.0530 (0.0303-0.0910) 0.0759 (0.0425-0.1318) $\chi^2=0.78$; d.f.= 1; n=53	0.0368 (0.0177-0.0752) 0.0623 (0.0314-0.1196) $\chi^2=1.08$; d.f.= 1; n=45	0.0335 (0.0175-0.0631) 0.0496 (0.0238-0.1005) $\chi^2=0.62$; d.f.= 1; n=50	0.0424 (0.0278-0.0642) 0.0645 (0.0410-0.1001) $\chi^2=1.76$; d.f.= 1; n=73

Appendix 3: Non-significant ($p>0.05$) Mann-Whitney test results of nesting habitat variables between nesting ($n=40$) and non-nesting ($n=40$) Song Thrush areas. Mean values are given \pm 95% confidence interval (C.I.). Note that calculation of 95% C. I. for both horizontal vegetation cover and bare soil was not possible as proportions were >0.9 and <0.1 respectively (denoted by n/a).

Variable	Nesting areas	Non-nesting areas	Test result
Height of dominant habitat feature (m)	6.93 ± 1.63	5.68 ± 1.33	W=1748.0
Maximum distance to edge of dominant habitat feature (m)	18.16 ± 4.26	15.14 ± 3.66	W=1721.0
Horizontal vegetation cover (%)	$99.87 \pm \text{n/a}$	$98.00 \pm \text{n/a}$	W=1682.5
Bare soil (%)	$2.92 \pm \text{n/a}$	$4.25 \pm \text{n/a}$	W=1665.5
Live vegetation (%)	36.90 ± 15.14	40.52 ± 15.41	W=1556.5

Chapter 4:

Mercury and organochlorine contamination in the Song Thrush,
***Turdus philomelos*, a passerine species representing the terrestrial**
ecosystem.



This has been submitted into Biology and Environment: Proceedings of the Royal Irish Academy and is in the format of this journal.

Abstract

Mercury and organochlorine concentrations were examined in thirteen eggs (from eight clutches) and eleven livers (from four adults, six juveniles and 1 nestling) of the Song Thrush (*Turdus philomelos*), in County Cork, southwest Ireland 2001-2003. Two contaminants were consistently recorded in this study, mercury and the organochlorine HEOD (also known as dieldrin or 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-exo-1,4-endo-5,8-dimethanonaphthalene). A third contaminant, DDE, was only recorded in one liver sample. Interestingly no PCBs, DDT, TDE, HCB, HCH were recorded above the limit of detection in any sample. In three clutches, where all eggs were analysed, HEOD occurred in one egg in each clutch and not in all eggs of the same clutch. In all samples HEOD was the most frequently occurring contaminant (42%), while mercury dominated in liver samples (55%) but was completely absent in egg samples. The overall average (arithmetic) mercury concentration ($\mu\text{g/g dw}$ ($\pm 95\%$ C.I.)) detected in liver samples was $0.27 (\pm 0.21)$ while the overall average HEOD concentration ($\mu\text{g/g ww}$ ($\pm 95\%$ C.I.)) in liver samples was $0.01 (\pm 0.01)$ and in egg samples $0.02 (\pm 0.02)$. Variation was found in contaminant concentrations between year, specimen age, location and habitat but none significantly. Overall, contamination levels were found to be low and of no apparent biological or ecological concern. These data provide a baseline for mercury and organochlorine contamination levels in the Irish terrestrial environment for use in future monitoring studies.

Keywords: Organochlorines; Mercury; *Turdus philomelos*; Eggs; Liver; Terrestrial.

Introduction

Organochlorines have been the most harmful insecticides to wildlife (Newton, 1979). These insecticides include the organochlorines lindane (HCH) and DDT along with common agricultural seed treatments such as aldrin and dieldrin (also known as HEOD or 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-exo-1,4-endo-5,8-dimethanonaphthalene) or the heavy metal mercury (Hg) (Newton, 1979). Other organochlorine pollutants include polychlorinated biphenyls (PCBs), which are industrial products commonly found in paints, insulants and lubricants and are consequently released into the environment (Newton, 1979).

All these pollutants are highly persistent in the environment, lipophilic, bioaccumulate within an animal's tissue and biomagnify through food chains (Holden, 1975; Safe *et al.*, 1987; Newton, 1998). Consequently animals high up in the food chain accumulate high concentrations of these contaminants in their tissues (Furness, 1993; Walker *et al.*, 2001), as shown by different studies (Winter & Streit, 1992, Hendriks *et. al.*, 1995, Klemens *et. al.*, 2000 and Bartuszevige *et. al.*, 2002). Different contaminants cause different effects on birds. For example DDT (and its metabolite DDE) and PCBs affect bird reproduction, with the former causing egg-

shell thinning and the latter implicated in delayed breeding, poorer hatching success, and abnormal parental and reproductive behaviour (Peakall, 1970; Barron *et al.*, 1995; Dirksen *et al.*, 1995), while aldrin and dieldrin usually kill birds outright (Newton, 1998). Mercury targets the central nervous system (Stenersen, 2004) and causes other effects such as egg abnormalities, poorer growth, changes in enzyme production and decrease in cardiovascular function (Lundholm, 1995; Boening, 2000).

In Europe organochlorines were increasingly used from the late 1940's to the early 1960's followed by a decline (Newton, 1979). While the more ecologically hazardous organochlorines such as DDT, dieldrin and PCBs have been severely curtailed or banned by different authorities worldwide (Chermisinoff & King, 1994; Aurigi *et al.*, 2000; Walker *et al.*, 2001), organochlorines still make up the ingredients of home, garden and agricultural products (Chermisinoff & King, 1994). The widely recognised poison and environmental pollutant mercury is also still present in some pesticides (Stenersen, 2004). In Ireland, both dieldrin and alkyl mercury based products have been banned from use since 1981 followed by alkoxyethyl and aryl mercury compounds, mercuric oxide and mercurous chloride compounds in 1991 (Pesticide Control Service, 2004). However the high persistency of these compounds still allows significant residues to remain in organisms at higher trophic levels (Walker *et al.*, 2001). Although it must be recognised that studies indicate that organochlorine residues are in decline in the environment while mercury levels have remained largely unchanged or in some cases have increased

(Barrett *et al.*, 1996; Thompson *et al.*, 1998; Aurigi *et al.*, 2000; Braune *et al.*, 2001).

Birds are important indicators of environmental contaminants (Holden, 1975), including passerine bird species (e.g. Eens *et al.*, 1999; Bishop *et al.*, 1995; Støwer Rosten *et al.*, 1998; Kallenborn *et al.*, 1998; Eeva *et al.*, 2000), because of their high level in food chains and subsequent susceptibility to bioaccumulation of pollutants in their tissues (Furness *et al.*, 1993). In addition bird eggs are good bio-monitors since pollutants present in females, including organochlorines and mercury (see Burger, 1994; Aurigi *et al.*, 2000; Braune *et al.*, 2001), are passed to eggs, although residue levels can vary within a clutch (Holden, 1975; Furness, 1993). The Song Thrush is a largely insectivorous (Simms, 1989) resident passerine species that breeds throughout Europe (Tucker & Heath, 1994). Additionally, the Song Thrush has been shown as a species sensitive to contaminants, such as radionuclides (Ortiz *et al.*, 1992; Navarro *et al.*, 1998), and effects, including egg-shell thinning due to possible acidification (Green, 1998; Scharlemann, 2003).

The population of Song Thrushes in Britain has undergone a rapid decline from 1970-1990 while the population in Ireland is thought to have undergone some decline (Tucker & Heath, 1994), although this decline was probably quite limited (Chapter 6), but to date no data have been published on Song Thrush organochlorine and mercury levels. Limited data exist on the occurrence and frequency of organochlorines and mercury in Ireland and most of these data relate to aquatic

systems with few relating to contamination within terrestrial environments (Cabot, 1985; O'Sullivan *et al.*, 1993; Gallagher *et al.*, 1996; Choiseul *et al.*, 1998; Steinböörn & Breen, 1999; Smyth *et al.*, 2000; O'Halloran *et al.*, 2003). Here we report for the first time on contaminant levels in Song Thrushes breeding in Ireland. These data will provide some baseline information on levels of terrestrial contamination in Ireland.

Methods

Study areas & sample collection

In total thirteen egg samples (three eggs from each of two nests, two eggs from one nest and one egg from each of five nests) and eleven liver samples (ten fully grown birds (four adults and six juveniles) and one nestling) were collected opportunistically in Co. Cork from 2001-2003. Addled (i.e. infertile) and deserted eggs were collected, in conjunction with an intensive study on Song Thrush breeding biology (Chapter 2), from nests in Millstreet Country Park, northwest Cork, Fota Arboretum and Fota Wildlife Park, east Cork. Millstreet Country Park (52°1.3'N, 10°0.8'W) consists of about 200 hectares of bog-land, wet and improved grassland, parkland, gardens and plots of coniferous forests. Eggs were collected from nests in coniferous forest plots, dominated by Sitka spruce (*Picea sitchensis*), 210-270 m above sea level (absl) within the park. Both Fota Arboretum (51°53.5'N, 8°18.2'W) and Fota Wildlife Park (51°53.5'N, 8°18.8'W) are situated on Fota Island and consist of low-lying (0-10 m absl) recreational gardens and parkland. Even

though the method of egg collection is non-random, it follows the standard method of egg collection. Livers were taken from freshly dead specimens found at the above study areas or random locations around Co. Cork. Death in these specimens was mainly due to road or window collision or killing by cat. Egg samples were refrigerated (4°C) and liver samples were frozen before samples were sent for analysis.

Sample analysis

Samples were analysed at Monks Wood Laboratory of the Centre for Ecology and Hydrology, United Kingdom. Prior to analysis, samples were stored at -20 °C. Mercury was analysed using cold vapour atomic absorption spectrophotometry after samples were digested by initially heating to 80 °C for 48 hours, followed by cold digestion with nitric acid (ANALAR grade) for 12 hours and finally heating to 120 °C for one hour. The use of condensers prevented the drying out of samples. Sample analysis was undertaken using in house vapour generation kit attached to a Solaar 969 AAS (ThermoFinnigan). Calibration of methods was achieved with a five point multi-level calibration before sample analysis. To allow for rescaling of the calibration line a blank and the top standard were run every six samples.

The following Organochlorines were analysed using gas chromatography with electron capture detector after lipid weight was determined, following an extraction process involving hexane:acetone mixture, and samples subjected to cleanup using alumina column chromatography:

HCB (hexachlorobenzene)

a-HCH (1,2,3,4,5,6-hexachlorocyclohexane, Alpha isomer)

g-HCH (1,2,3,4,5,6-hexachlorocyclohexane, Gamma isomer) (lindane)

p,p-DDE (1,1'-(2,2-dichloroethenylidene) bis (4-chloro)-benzene)

HEOD (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-exo-1,4-endo-5,8-dimethanonaphthalene) (dieldrin)

p,p-TDE (1,1'-(2,2-dichloroethylidene) bis (4-chloro)-benzene)

p,p-DDT (1,1'-(2,2,2-trichloroethylidene) bis (4-chloro)-benzene)

PCB (polychlorinated biphenyls) congeners 8, 18, 29, 28, 31, 52, 101, 77, 149, 123, 118, 114, 153, 141, 105, 138, 187, 183, 126, 128, 167, 171, 156, 199, 157, 180, 201, 170, 169, 189, 194, 205, 206, 209.

Sample analysis was undertaken using split/splitless injection on a Varian 3400 gas chromatograph with electron capture detector and hydrogen as the carrier gas.

Calibration of the instrument was undertaken with a 10 point multi level calibration before sample analysis and calculation of analyte concentrations. The internal standard, dichlobenil, was added to all samples and calibration standards. Response factors and retention times were checked by running a single level calibration standard with each batch of samples. Chromatographic peaks were identified using EZCHROM data system and visually checking each chromatogram to ensure correct identification.

For quality assurance purposes, chicken egg samples were spiked with a known amount of analyte and analysed with the Song Thrush samples. Recovery of spiked

mercury averaged 90.8% where the lower limit of detection was 0.03 µg/g and the mean percent moisture content in liver samples was 71.3 (±1.2) and egg samples 82.6 (±6.7). Recovery of spiked organochlorine averaged; HCB 97%, a-HCH 111%, g-HCH 129%, p,p-DDE 102%, HEOD 71%, p,p-TDE 83%, p,p-DDT 79% while PCB congeners ranged 22-121% and the lower limit of detection (µg/g) was; HCB 0.011, a-HCH 0.018, g-HCH 0.010, p,p-DDE 0.018, HEOD 0.010, p,p-TDE 0.017, p,p-DDT 0.016 while PCB congeners ranged 0.002-0.024 and the mean percent lipid content in liver samples was 0.56 (±0.06) and egg samples 1.05 (±0.52).

Data analysis

In cases where more than one egg was collected and analysed from a nest, the occurrence of contaminants within the clutch was investigated. However, when undertaking the following statistical analysis, one egg from each brood was randomly selected for inclusion in the analysis. Percentage frequency of contaminants, which occurred above the detection limit, was assessed for liver samples, egg samples and both sample types combined for all years and for 2002 and 2003 separately. Overall arithmetic means were calculated with corresponding 95% confidence intervals (C.I.s) per contaminant per sample type, where samples with contaminant levels below detection limits were treated as zeros. Given the non-normal nature of the data, even with transformation, all analysis was undertaken using the Mann-Whitney test. Medians of Hg and HEOD were separately compared between years (i.e. 2002 & 2003). Further analysis, with respect to year, of Hg and HEOD from egg samples and other contaminants were not possible due to small sample sizes or non-detection of contaminants. Since HEOD was the only contaminant that occurred in liver and egg samples, differences in concentrations between both sample types were tested. Differences in mercury and HEOD concentrations in liver samples between juvenile (i.e. post fledging to less than 1 year old) and adult (i.e. more than 1 year old) specimens were examined separately. In addition, residue levels of Hg and HEOD were examined in respect of location and habitat. All statistical analyses were undertaken using Minitab for Windows (Release 12.1).

Results

In total thirteen egg samples (three eggs from each of two clutches, two eggs from one clutch and one egg from each of five clutches) and eleven liver samples (four adults, six juveniles and one nestling) were analysed.

Percentage occurrence of contaminants in samples

Only three contaminants were detected overall, mercury, HEOD and DDE, where DDE was only detected in one liver sample (0.067 ug/g ww) (Figure 1). No mercury was detected in any egg sample and HEOD was the only contaminant that occurred in both liver and egg samples. Interestingly, no sample had detectable concentrations of HCB, a-HCH, b-HCH, TDE, DDT or the 35 PCB congeners already listed. Combining all sample types HEOD occurred most frequently (42%). However looking at liver samples alone mercury was the dominant contaminant (55%). All samples were combined to assess occurrence of contaminants between 2002 and 2003 (Figure 2). The percentage occurrence of mercury did not change whereas HEOD increased from 33% to 50%. DDE occurred only in 2003 and only occurred in one liver sample overall.

Figure 1: Percentage occurrence of Mercury (Hg) and Organochlorines (HEOD & DDE) in Song Thrush liver (n=11) and egg (n=8) samples in southwest Ireland.

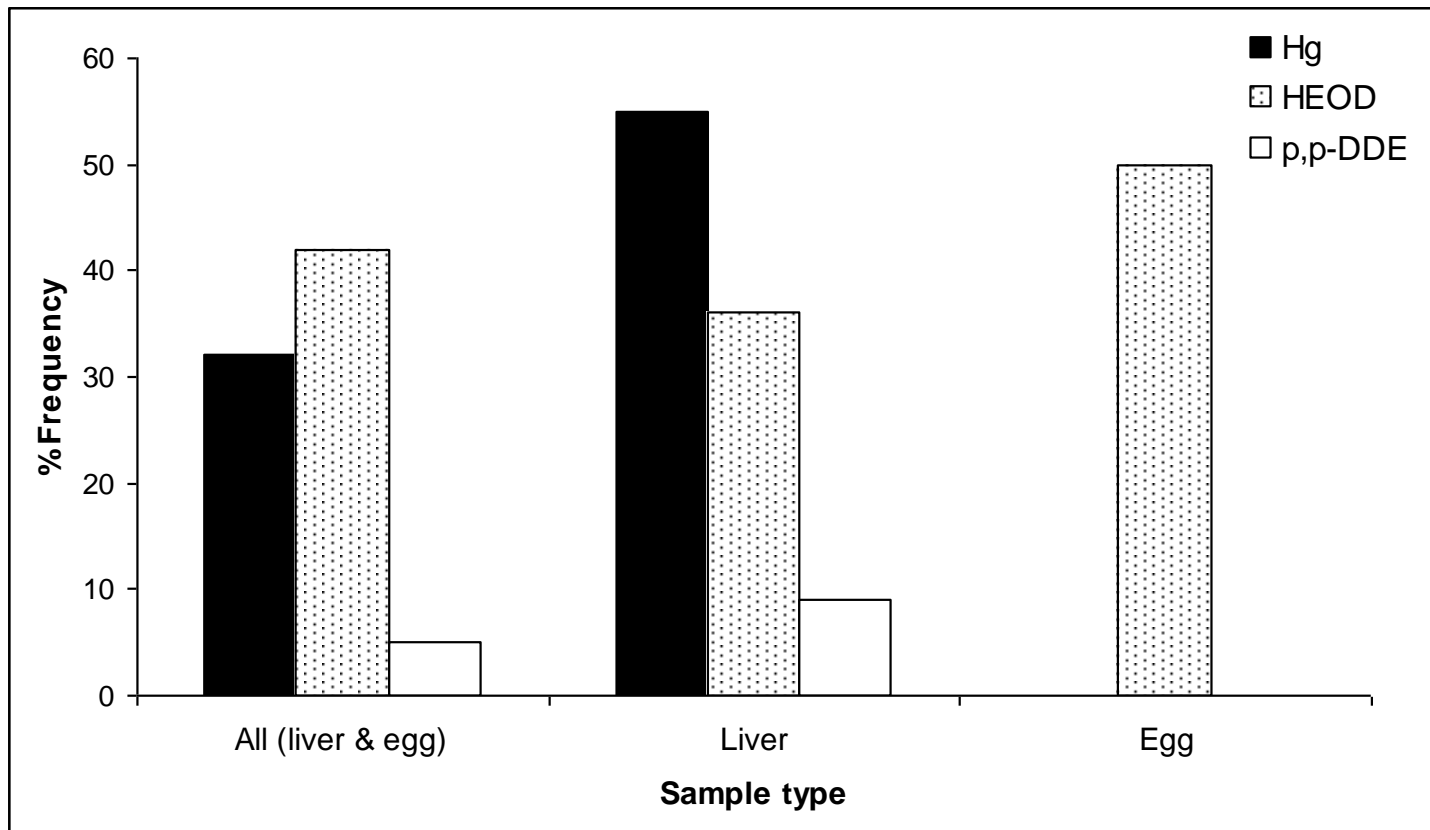
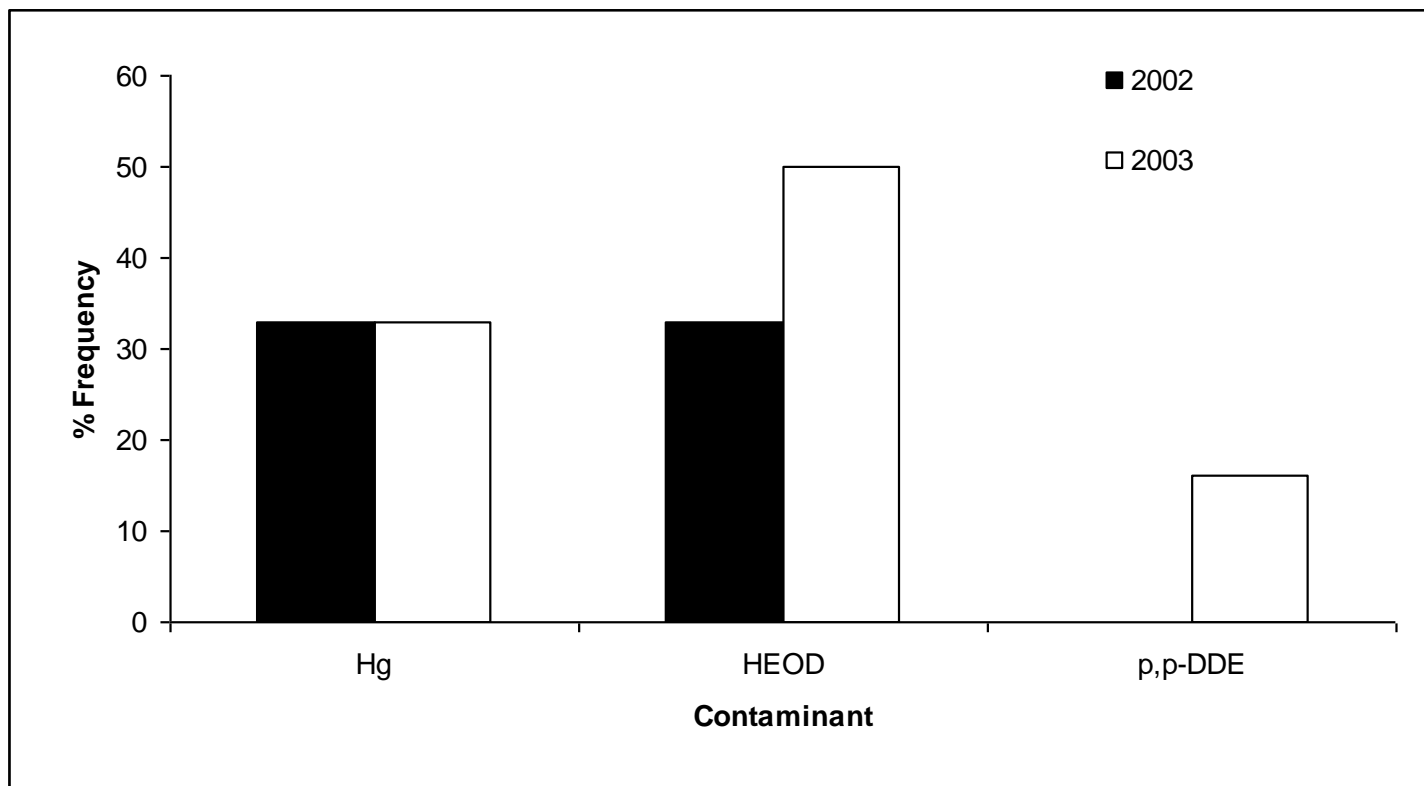


Figure 2: Percentage occurrence of Mercury (Hg) and Organochlorines (HEOD & DDE) in Song Thrush liver and egg samples combined for 2002 (n=12) and 2003 (n=6) in southwest Ireland.



Contaminant concentrations

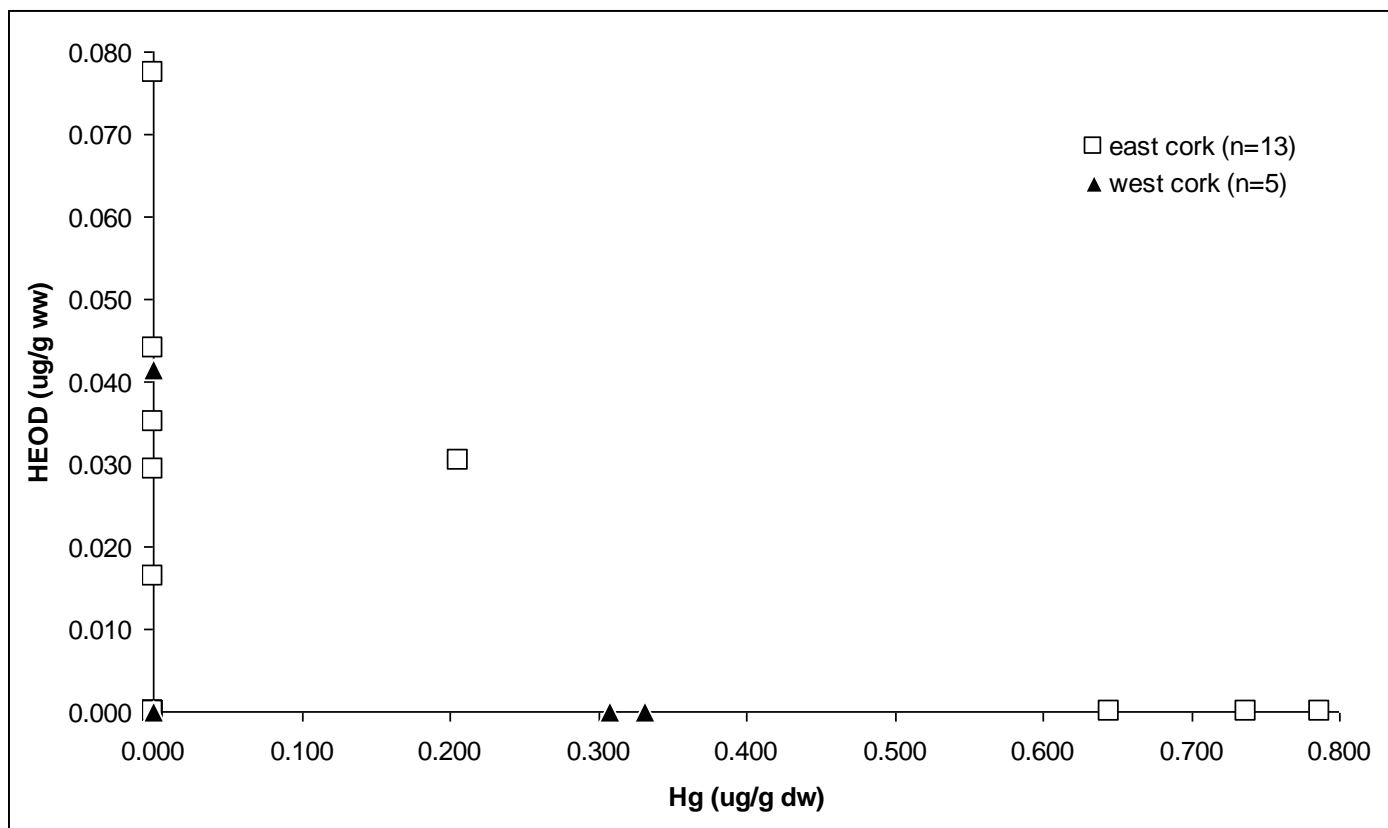
Overall arithmetic means are presented with corresponding 95% C.I.s in Table 1.

Neither mercury nor HEOD concentrations, with all samples combined, significantly differed between 2002 and 2003 (Mann-Whitney: Hg: $W=112.0$; $p>0.10$; HEOD: $W=108.0$; $p>0.10$). HEOD concentrations in egg samples seemed higher than those found in liver samples but not significantly (Mann-Whitney: $W=100.0$; $p>0.10$). Samples from juveniles appeared to have lower concentrations of both mercury and HEOD in their liver than adult specimens but not at significant levels (Mann-Whitney: Hg: $W=32.5$; $p>0.10$; HEOD: $W=31.0$ $p>0.10$), although the differences in mercury are very slight. The relationship of mercury and HEOD concentrations and location is presented in Figure 3 combining both liver and egg sample types together. It is interesting to note that samples generally only have one detectable contaminant and not both, the only exception being in one sample. Samples east of Cork City seem to have higher contaminant levels overall than samples west of Cork City. However no significant differences were found between samples east or west of Cork City in either mercury (Mann-Whitney: $W=122.5$; $p>0.10$) or HEOD concentrations (Mann-Whitney: $W=131.0$; $p>0.10$). Again combining both sample types together, differences in mercury and HEOD concentrations were examined in samples from two habitat types, parkland and coniferous forestry. Even though samples from parkland tended to have higher concentrations than those from coniferous forestry (Table 1), the differences were not significant for either contaminant (Mann-Whitney: Hg: $W=50.5$; $p>0.10$; HEOD: $W=54.5$; $p>0.10$).

Table 1: Summary of overall arithmetic means (\pm 95% C.I.) for Hg (ug/g dw) and HEOD (ug/g ww) concentrations found in Song Thrush samples in Southwest Ireland 2001-2003. Sample sizes are in parentheses. n/d = not detected.

Sample	Mercury (Hg)	HEOD
Overall: <i>Liver (n=11)</i> <i>Egg (n=8)</i>	0.274 ± 0.212 n/d	0.010 ± 0.010 0.022 ± 0.024
Age (liver samples only): <i>Juvenile (n=6)</i> <i>Adult (n=4)</i>	0.290 ± 0.371 0.319 ± 0.494	0.008 ± 0.015 0.015 ± 0.027
Year (all samples): <i>2002 (n=12)</i> <i>2003 (n=6)</i>	0.136 ± 0.154 0.230 ± 0.376	0.014 ± 0.015 0.017 ± 0.020
Location (all samples): <i>East (n=13)</i> <i>West (n=5)</i>	0.183 ± 0.190 0.128 ± 0.218	0.018 ± 0.015 0.008 ± 0.023
Habitat (all samples): <i>Parkland (n=8)</i> <i>Coniferous wood (n=4)</i>	0.098 ± 0.234 0.077 ± 0.244	0.019 ± 0.025 0.010 ± 0.033

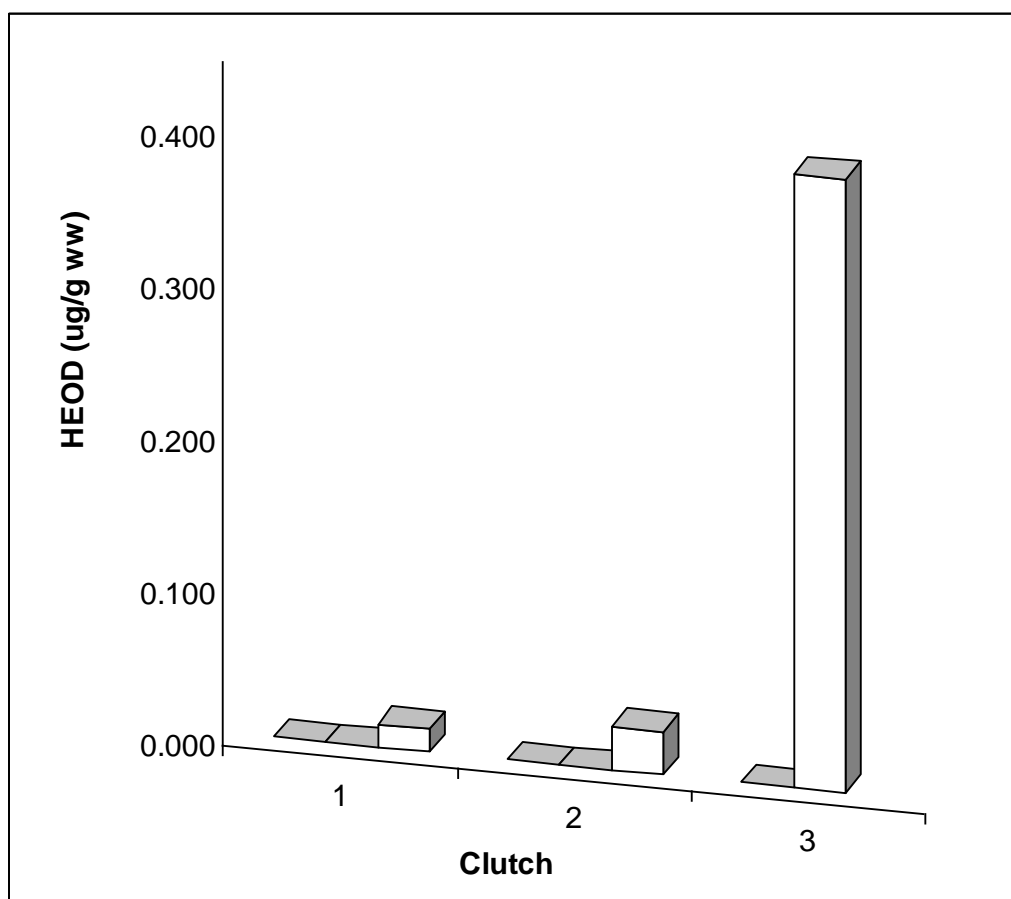
Figure 3: The relationship of mercury and HEOD concentrations (including both liver and eggs sample types) in relation to location, east or west of Cork City. Each point represents a sample where East Cork is represented by Ballymacoda, Loughaderry, Midleton and Fota and West Cork by Millstreet and Blarney.



Egg contamination within same clutch

Even though only 3 clutch samples were available for investigation and HEOD was the only detectable contaminant, it is still interesting to note the consistent trend that one egg from each clutch had detectable HEOD concentrations while the other eggs in the same clutch had no trace levels (Figure 4).

Figure 4: HEOD levels (ug/g ww) within eggs of the same clutch in Southwest Ireland.



Discussion

While there is a possibility that addled eggs may not be representative of pollutant levels in a population, some comparisons of contaminant levels between addled eggs and fertile eggs indicate that the former can have similar levels of contamination as the latter (Furness, 1993). Additionally many studies have recognised addled eggs, including those of passerine species, as suitable bio-monitors of pollutants (e.g. Winter & Streit, 1992; Ormerod & Tyler, 1992; Burger, 1994; O'Halloran *et al.*, 2003). Similarly bird tissue is a good bio-indicator where the liver is commonly used for monitoring since it holds high concentrations of organochlorines and mercury (Holden, 1975; Furness, 1993) and concentrations of metals in bird tissue directly mirror levels of contamination in the environment (Jarvis, 1993). Again many studies have recognised the use of passerine bird livers for investigating pollutant levels in the environment (e.g. Støwer Rosten *et al.*, 1998; Kallenborn, 1998). While studies on environmental contaminants and passerine bird species within a terrestrial context are limited in comparison to aquatic based systems, such studies that incorporate both egg and liver samples to assess mercury and organochlorines are even scarcer to the extent that none could be located by the authors. Even though caution has to be exercised when interpreting results from this study due to small sample sizes, this is a common feature in many contamination studies, mainly due to the costs involved in analysis. Thus while sample sizes are limited, the occurrence, frequency and trends of contaminant levels in this study are comparable to other published studies.

Contaminant occurrence and frequency

In this study two major contaminants were detected, mercury and HEOD. A third contaminant, DDE, was also detected but only in one liver sample. Unlike many other bird studies (Winter & Streit, 1992; Barrett *et al.*, 1996; Dirksen *et al.*, 1995; Kallenborn *et al.*, 1998; Aurigi *et al.*, 2000; Klemens *et al.*, 2000; Braune *et al.*, 2001; Bartuszevige *et al.*, 2002; O'Halloran *et al.*, 2003), other organochlorines such as PCBs, HCB, DDT and HCH were not detected in this study. The percentage occurrence of mercury did not change between 2002-2003 while HEOD increased, but given the samples sizes involved this increase was probably not of significant importance.

Overall HEOD here was the most commonly occurring contaminant (42%) while mercury dominated in the liver samples (55%) but was completely absent from egg samples. A riverine study in southwest Ireland found that the most commonly occurring contaminant in Dipper (*Cinclus cinclus*) bird eggs was DDE (>87%) while HEOD varied in annual occurrence of 35-100% and mercury 10-80% (O'Halloran *et al.*, 2003). A passerine study in the U.S.A. found that dieldrin (ISO common name for HEOD) occurred in 74% of carcasses but DDE dominated overall at 89% (Klemens *et al.*, 2000). Interestingly O'Halloran *et al.* (2003) showed that mercury occurred in Dipper eggs indicating that dippers are exposed to mercury in Ireland and excrete these burdens into their eggs, as found in other bird species (Burger, 1994; Støwer Rosten *et al.*, 1998; Braune *et al.*, 2000). So the absence of

mercury in all egg samples in this study suggests that Song Thrushes either do not excrete mercury during egg formation or are not exposed to mercury burdens in the first place given that mercury based products have been banned from use in Ireland since 1981 and 1991 (Pesticide Control Service, 2004). On the other hand this study did find HEOD levels in egg samples and at higher concentrations (although not significantly) than those in liver samples, perhaps suggesting that HEOD tissue burdens in Song Thrushes here were high enough to warrant excretion and that these burdens are excreted during egg formation.

Contaminant concentrations

A study by Støwer Rosten *et al.* (1998) on passerine bird species within a terrestrial environment found that juvenile livers contained an approximate mercury range of 0.05 to less than 0.15 (ug/g dw) in less polluted areas while samples in an area of mercury production reached approximately 1.8 (ug/g dw). The average mercury concentrations found in liver samples in this study are almost twice the maximum value in the range found in the less polluted areas (i.e. 0.15 ug/g dw) but more than six times lower than the mercury concentrations found in a heavily polluted area of the same study. In Irish dippers HEOD levels varied annually approximately 0.1-2.4 (ug/g ww), where the higher value in the range was thought to be above background levels (O'Halloran *et al.*, 2003). The average HEOD concentrations in Song Thrush eggs here are approximately five times lower than the minimum value found in the range for Irish dippers. Knowing that usage of some mercury based compounds was not banned until 1991 in Ireland (Pesticide Control Service, 2004), and that mercury

occurs naturally in the environment, may provide possible sources of mercury in our Song Thrush samples. In Ireland HEOD (or dieldrin) was banned from use in 1981 while aldrin, which breaks down into HEOD, has been banned since 1988 (Pesticide Control Service, 2004). The presence of HEOD in both Song Thrush eggs and livers, however, suggest that Song Thrushes may currently be exposed to HEOD or aldrin or both or there are some other sources that we are not aware of. However given the low levels of HEOD in question the persistent nature of HEOD and aldrin may explain their presence in the Irish environment and the subsequent presence of HEOD in our egg and liver samples. It would seem therefore that both mercury and HEOD concentrations recorded in this study represent persistent background levels within the Irish terrestrial environment, which do not cause any apparent detrimental biological effects on the Song Thrush population.

Contaminant concentrations with age and location

Generally concentrations of heavy metals tend to be lower in juvenile birds than adults (Furness, 1993). In this study both the heavy metal mercury and HEOD seemed to be lower in juvenile than adult specimens but not significantly. We also show here that contaminant levels seem to vary with location, even though the variation is not statistically significant. Nonetheless there is a tendency for contaminant levels to be higher in areas east of Cork City than those west of Cork City. This reflects a similar trend of increased contaminant residues from west to east noted by O'Sullivan *et al.* (1993) when assessing otter spraints in southern Ireland (mainly Co. Cork) for organochlorine pesticides and PCBs. This west-east

increase in contamination concentrations may be explained by the higher concentrations of industry in Cork City and harbour combined with Ireland's prevailing westerly winds (Keane, 1986). Additionally this study showed that samples from parkland areas had higher contaminant concentrations than those from coniferous plots, although again not significantly. The variation between these two habitats may relate to their usage where parkland areas include extensive gardens and lawns, the past upkeep of which may have included the use of dieldrin and mercury based compounds, thereby possibly resulting in higher contaminant levels. Overall it must be remembered that interpretation of trends in contaminant variation is made difficult by the small sample sizes and requires further study and analysis.

Egg contamination within same nest

This study showed that HEOD residue levels can vary between eggs of the same clutch, as found by others (Holden, 1975; Jarvis, 1993). For example Winter & Streit (1992) found that in a Great Tit (*Parus major*) clutch, early-laid eggs had higher organochlorine concentrations than later-laid ones. This variability of contaminant levels within clutches may be more exaggerated in passerine species than other larger birds, as clutch mass in passerines represents a higher proportion of body mass than other larger species so that egg formation may be more influenced by recently ingested foods and consequently more vulnerable to changes in diet or episodes of pollution (Ormerod & Tyler, 1993).

In conclusion

This study highlights how relatively clean the Irish terrestrial environment is, with respect to environmental contaminants, in comparison to other countries and aquatic systems, even within Ireland. This is not just reflected by the low contaminant concentrations recorded but also by the fact that only two major contaminants were consistently present. These data therefore provide a useful and important baseline for future bio-monitoring studies of the Irish terrestrial ecosystem.

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Chapter 5:

The influence of farmland habitat and season on the presence and density of Song Thrushes, *Turdus philomelos*.



This has been submitted into Agriculture, Ecosystems and Environment and is presented in the format of this journal.

Abstract

Song Thrush populations have declined across western Europe over the last 30 years, most notably in Britain. While long-term trends are unclear for the population in Ireland, the population is currently widespread and stable. Field boundary and land-use characteristics are important influences on Song Thrush breeding and wintering populations. We surveyed 19 lowland farms for Song Thrushes and habitat variables in County Cork, southern Ireland, during the breeding and winter season of 2002 to 2003. We found that mixed surrounding farmland, the absence of grassland surrounding farmland and farmland boundaries consisting of ditches, especially wet ones, tall dense vegetation and trimmed boundaries were important in predicting the presence of breeding Song Thrushes. In contrast to the breeding season, Song Thrush densities during the winter were predicted by farmland boundaries consisting of low thin vegetation and untrimmed boundaries but similar to the breeding season ditches remained important whether wet or dry. Our study also shows that Song Thrush abundance almost doubled in the winter season, most likely due to the arrival and passage of migrating Song Thrushes through the country, especially in November. In light of our findings, we consider farmland habitat management strategies that would most benefit Song Thrush populations all year round in Ireland, and possibly in areas of Song Thrush population decline.

Keywords: Song Thrush; Lowland farmland; Field boundaries; Winter migration; Ireland

Introduction

From the 1970s to the 1990s, the European Song Thrush, *Turdus philomelos*, population has undergone declines, especially in Britain where it has declined by 65% on farmland (Tucker & Heath, 1994; Thomson *et al.*, 1997). Studies have implicated the role of changing landscapes and, in particular, changes in agricultural practices to such bird declines (*e.g.* Fuller *et al.*, 1991; Chamberlain *et al.*, 2000; Benton *et al.*, 2002). Yet farmland provides important habitat for the nesting and feeding requirements of birds including Song Thrushes (O'Connor & Shrubbs, 1986; Lack, 1992). In fact the role of field boundaries, such as hedgerow, in environmental and conservation functions is being increasingly recognised (Hinsley & Bellamy, 2000; Marshall & Moonen, 2002). The importance of field boundary and land-use characteristics for breeding and wintering Song Thrushes has been highlighted (Arnold, 1983; Green *et al.*, 1994; MacDonald & Johnson, 1995; Moles & Breen, 1995; Wilson *et al.*, 1996; Sparks *et al.*, 1996; Gregory & Baillie, 1998; Mason, 1998; Buckingham *et al.*, 1999; Henderson *et al.*, 2004). More recently, studies have specified the particular importance of field boundaries and grassland as both foraging and nesting habitats for breeding and wintering Song Thrushes (Peach *et al.*, 2002; Murray, 2004; Peach *et al.*, 2004a).

Unlike Britain, the Song Thrush is not regarded as a species of conservation concern in Ireland (Gibbons *et al.*, 1996; Newton *et al.*, 1999) and is currently widespread and stable (Coombes, 2003) as indicated by the recently established (in 1998)

national bird monitoring programme, Countryside Bird Survey (CBS). This is despite the fact that Ireland is dominated by farmland (see Stanners & Bourdeau, 1995; Tucker & Dixon, 1997). This stability in Song Thrush population in Ireland may be related to the relatively lower rate and scale of agricultural change and intensification that have occurred here, in comparison to other Western European countries, including the UK (Cabot, 1985; Lysaght, 1989; Stanners & Bourdeau, 1995; Aalen *et al.*, 1997). For example, field boundary loss is believed to be lower here than in Britain or other European countries, with hedgerow loss estimated as 16% between the 1930s and 1980s (Webb, 1988; Aalen *et al.*, 1997) although losses still continue (Murphy, 1997). In Ireland, farm boundary loss (and other valuable wildlife habitats) has been more prominent on intensive farm enterprises such as arable and dairy systems.

Ireland has a heavily enclosed rural landscape where field boundaries are estimated to occupy 1.5% of total land cover (Webb, 1988; Aalen *et al.*, 1997). Hedgebanks (*i.e.* earthen or stone dyke with vegetation such as hedgerow on top) are the most commonly found field boundary on Irish lowland farms, where the vegetation on top is often unmanaged, overgrown and ‘gappy’ (Webb, 1988; Aalen *et al.*, 1997). In general, Ireland has not traditionally planted hedgerows extensively in its landscape, although this varies regionally, and dykes do not always support hedgerow trees very well (Aalen *et al.*, 1997). That said, the density and variety of Irish hedges is unequalled in western Europe (Murphy, 1997). Managed hedgerows in Ireland have been more associated with intensive lowland farming (Aalen *et al.*,

1997), but this is changing with the onset of agri-environment schemes here, such as the Rural Environmental Protection Scheme (REPS), which include hedgerow planting and management. The low coverage of woodland (currently <10%) in the Irish landscape and the dominance of exotic coniferous species add to the importance of field boundaries for wildlife in this country, especially boundaries with woody vegetation species (Webb, 1988; Pithon *et al.*, 2005).

Some Irish based studies have included Song Thrushes as part of their multiple bird species studies on farmland habitat (Lysaght, 1989; Moles & Breen, 1995). To date we are not aware of any Song Thrush habitat-specific study in Ireland, where the benefits of such species-specific habitat surveys have been acknowledged (Chamberlain, 2002). Additionally, very few studies have been published on the interaction of wintering Song Thrushes with field boundaries (*e.g.* Arnold, 1983; Moles & Breen, 1995). Given the current favourable conservation status of the Song Thrush population in Ireland, especially within such an agriculturally dominated landscape, we had an opportunity to investigate possible influences of farmland habitat on Song Thrush presence and density for a breeding and winter season. Our findings will provide further understanding into the relationship between Song Thrushes and the Irish farming landscape and may contribute to conservation measures in areas of Song Thrush decline.

Study sites

During the breeding season of 2002 (*i.e.* late March – August) and the winter season of 2002 and 2003 (*i.e.* October – mid March), 19 farms in County Cork, southern Ireland, were surveyed for Song Thrushes and habitat variables. We surveyed farms belonging to one of four major farm enterprises in Ireland, namely arable, sheep grazing, cattle grazing and mixed (*i.e.* arable and grazing). These four farm enterprises were chosen in order to maximize the representation of habitat variables normally present in the Irish agricultural landscape.

For each farm enterprise, we surveyed five low-lying (*i.e.* <200m above sea level) farms, except for sheep grazing where four farms were surveyed. For the purposes of this study, the surveys were conducted on a field-by-field basis ($n = 97$) within each farm, where each field was identified by its boundary and all fields were adjacent to each other. We avoided surveying fields adjacent to woodland plantations in order to minimize possible complications of edge effects. Where possible, we selected farms within areas dominated by their particular farm enterprises in order to minimize possible influences from surrounding habitat. The main characteristics of the study sites are summarized in Table 1.

Table 1: Main characteristics associated with study sites (\pm standard deviation where appropriate). n=number of farms surveyed. Refer to Appendix 1 for definitions of dyke, ditch and hedgerow.

Farm enterprise	Total area surveyed (Ha)	Total dyke length (m/ha)	Total ditch length (m/ha)	Total hedgerow length (m/ha)	Average field size (Ha)	Average survey area per farm (Ha)
<i>Arable</i> (n=5)	98.3	72.3	18.6	7.6	10.9 \pm 7.2	19.7 \pm 1.6
<i>Sheep grazing</i> (n=4)	76.8	199.4	26.2	3.3	2.6 \pm 2.4	19.2 \pm 2.2
<i>Cattle grazing</i> (n=5)	98.2	173.0	42.4	2.6	3.3 \pm 3.9	19.6 \pm 3.6
<i>Mixed</i> (n=5)	102.3	138.0	29.6	30.5	3.7 \pm 1.6	20.5 \pm 1.1

Methods

Bird surveys

Two bird surveys were undertaken per season at each farm using standard line transect bird census methods (see Bibby *et al.*, 1993). The survey periods during the breeding season were (i) late March to mid June and (ii) late June to mid August and during the winter season (i) mid October to late December and (ii) mid January to mid March. While it is likely that non-breeding adult Song Thrushes were recorded during the breeding season, we considered that these individuals were in the minority and thus assumed that our results for this period were a reflection of the breeding population.

Each survey consisted of walking a transect along every field boundary within each farm, scanning each field with binoculars and recording the location of every adult Song Thrush on a Land Registry map (1:2500) of the farm. Only birds deemed using the habitat within the survey area were recorded. Individuals flying over the survey area were excluded. All maps were modified with any physical changes that had occurred within the farms such as boundary removal. If a Song Thrush was found using more than one field within a farm during a survey, its presence was recorded in each field and used in analysis on a field-by-field basis since Song Thrush usage in relation to habitat was the key focus being investigated here. However for analysis of Song Thrush densities between seasons, only a single registration of the individual was used to avoid double counting.

Surveys commenced within 75 minutes of dawn and were conducted by the same observer throughout. Surveys were only undertaken when weather conditions were suitable (*i.e.* dry, wind no higher than force 4 and good visibility). A minimum period of 30 days was allowed between visits of the same farm within each season and we ensured that survey visits to each farm enterprise were spread across the survey period.

Differences in Song Thrush detectability between farms were not seen as a problem since all farms surveyed consisted of open farmland. However, differences in detectability between complex field boundaries and more simple boundaries were seen as a potential problem, but the survey methods remained consistent across all fields surveyed.

Habitat surveys

A habitat survey was undertaken at each farm during both the breeding and winter season. As before, this survey was carried out on a field-by-field basis as defined by the field boundaries. Habitat variables measured in the survey are outlined in Appendix 1, where field boundaries consisting of livestock fencing or concrete walls were not measured, but were nonetheless recorded as a field boundary. In all cases trees 5m or less in height were classified as bush/shrub (after Crick, 1992). Hedgerow species typical of the areas where our study sites were located included

hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*) and gorse (*Ulex* spp.).

In each field, the main boundary types (*i.e.* hedge, ditch, dyke, grassy margin, river or stream) were identified as existing concurrently (*e.g.* dyke with hedge or dyke with ditch *etc.*) or separately (*e.g.* hedge or dyke *etc.*) and their location recorded on the relevant Land Registry maps (as for bird surveys). Habitat variables were then measured every 200m per boundary type, where a minimum of two measurements was taken for boundaries under 200m in length. In the case of measuring boundary habitat variables, only those in the field boundary facing the interior of the field were measured. All habitat measurements used in subsequent analyses were summed and averaged per field.

Field measurements were taken using measuring tape (for heights and widths), clinometer (for tree heights at a distance of 20m) and compass (field aspect). Lengths of boundaries and adjacent habitats (*i.e.* coppice & scrub, buildings & gardens, roads) were measured from the Land Registry maps using a scaled ruler. Field areas, which were needed to calculate length of boundary types per hectare, were generally available from the Land Registry maps but in cases where this was not possible approximate areas were calculated using a scaled ruler. All measurements, field and map, were taken by the same observer throughout.

Statistical analyses

All statistical analyses were undertaken using Minitab for Windows (Release 12.1). Principal Component Analysis (PCA) was carried out for each season on (i) all habitat variables (*i.e.* field level) and (ii) boundary habitat variables (*i.e.* boundary level) in order to reduce the number of habitat variables for analysis and remove inter-correlation between variables (Sparks, 2000). Using the original variables, this analysis calculates a new set of uncorrelated variables, called scores, which represent the variation present in the original dataset (Watt, 1997; Sparks, 2000). These scores were then used in subsequent analysis instead of the original variables (Sparks, 2000). Since our original dataset included a range of scales and types of measurement, we standardized the data using the correlation matrix option available in PCA so that all variables had equal importance (Sparks, 2000). Principal component scores with eigenvalues greater than two were included in subsequent analyses (after Lehane *et al.*, 2004).

We investigated the relative importance of habitat variables (at field and boundary levels) on Song Thrush presence for each season using binary logistic multiple regression with logit link function. We initially identified the principal components that had significant influence on presence using the default setting of stepwise logistic multiple regression. We then used presence/absence data (*i.e.* 1 or 0) as the dependent variables in a binary logistic multiple regression with the principal component scores as the independent variables.

We also examined the relative importance of habitat variables (at field and boundary levels) on Song Thrush densities (per Ha) per season using linear multiple regression, again after using the default setting of stepwise multiple regression to firstly identify which principal components significantly influenced density. Song Thrush densities were calculated using the maximum observations recorded for both surveys in each season per field. These densities were then used as the dependent variables in a stepwise multiple regression with the principal component scores as the independent variables.

Song Thrush densities (per km²) were calculated per farm using the maximum observation recorded between surveys in each season and ensuring that each bird was only accounted for once. These densities were then compared between breeding and winter season using One-way ANOVA, having checked for normality (Anderson-Darling test) and homogeneity of variance (Levene test). In all cases significance levels were accepted at $p < 0.05$. In reporting our results, we treated each boundary type separately for convenience, but this does not mean that different boundary types did not occur concurrently (*e.g.* ditch and dyke).

Results

Habitat analysis

PCA was firstly undertaken on all habitat variables at field level and secondly at boundary level per season. Analysis at field level during the breeding season resulted in five principal components with eigenvalues greater than two, which accounted for 48.8% of the total variation in the habitat data (Table 2). The habitat variables that strongly defined each principal component are outlined in Table 2. For example, the first component (PC1) was mainly influenced by hedgerow and tree abundance while the second component (PC2) was more influenced by ditch (Table 2). Four principal components with eigenvalues greater than two were identified in the analysis at boundary level during the breeding season, accounting for 44.8% of total variation in the data (Table 3). Here PC1 was again dominated by tree and ditch, with hedgerow and ditch dominating PC2 (Table 3).

Similar trends were found in the data at field level during the winter, where five principal components explained 48.8% of total habitat variation (Table 4). As above, tree abundance, ditch and hedgerow heavily influenced PC1 and PC2 (Table 4). Analysis at boundary level during the winter season resulted in 44.9% of habitat variation being explained by the first four components (Table 5). Habitat variable weightings in this case showed similar trends to the equivalent breeding season analysis for PC1 and PC2 but with opposite trends for both PC3 and PC4 (Table 5).

Table 2: PCA results for first five principal components (PC1-PC5) at field level (n = 35) during the breeding season with relevant eigenvalues, percentage variation, percentage cumulative variation and habitat variable weightings (>0.20) listed in descending order. Refer to Appendix 1 for habitat definitions.

Principle component	PC1	PC2	PC3	PC4	PC5
Eigenvalue	4.48	4.30	3.46	2.71	2.12
Variation (%)	12.8	12.3	9.9	7.7	6.1
Cumulative variation (%)	12.8	25.1	35.0	42.7	48.8
Positive weightings	Hedge length (0.267) Hedge width (0.265) Hedge height (0.260) Gap no. (0.221) Boundary management (0.216) Mixed adjacent (0.201)	Ditch width (0.377) Ditch mid-layer (0.327) Wet ditch (0.311) Mixed adjacent (0.274) Bush/shrub % (0.224)	Ditch length (0.343) Ditch mid-layer (0.291) Ditch width (0.232) Dry ditch (0.221)	Arable adjacent (0.342) Grassy margin (0.249)	Dyke width (0.310) Aspect (0.290) Berry species (0.267) Mid-layer height (0.243) Dry ditch (0.227)
Negative weightings	Tree no. (-0.334) >50% ivy (-0.328) Tree % (-0.293) <50% ivy (-0.286) Grass adjacent (-0.254)	Grass adjacent (-0.267) Dyke length (-0.261)	Tree no. (-0.276) >50% ivy (-0.272) Tree % (-0.239) Boundary management (-0.239) <50% ivy (-0.233) Dyke width (-0.222) Hedge height (-0.222) Hedge width (-0.219) Tree height (-0.207)	Interior use (-0.386) Hedge length (-0.330) Gap no. (-0.305) Bush/shrub % (-0.268) Grass adjacent (-0.253) Mid-layer height (-0.204)	Field layer % (-0.420) Mid-layer % (-0.325) Townland length (-0.268) Road length (-0.240) Grassy margin (-0.217)

Table 3: PCA results for first four principal components (PC1-PC4) at boundary level (n = 30) during the breeding season with relevant eigenvalues, percentage variation, percentage cumulative variation and variable weightings (>0.20) listed in descending order. Refer to Appendix 1 for habitat definitions.

Principle component	PC1	PC2	PC3	PC4
Eigenvalue	4.35	3.59	3.39	2.11
Variation (%)	14.5	12.0	11.3	7.0
Cumulative variation (%)	14.5	26.5	37.8	44.8
Positive weightings	Tree no. (0.381) >50% ivy (0.356) <50% ivy (0.349) Tree % (0.345) Ditch width (0.272) Wet ditch (0.241) Ditch mid-layer (0.227)	Hedge length (0.347) Bush/shrub % (0.347) Ditch width (0.322) Hedge width (0.295) Hedge height (0.280) Ditch mid-layer (0.278) Gap no. (0.264) Wet ditch (0.246)	Hedge width (0.294) Hedge height (0.290) Hedge length (0.257) Tree no. (0.249) >50% ivy (0.246) Tree height (0.243) Boundary management (0.239) Gap no. (0.236) Tree % (0.221) <50% ivy (0.210)	Mid-layer height (0.425) Bush/shrub % (0.268) Bare earth % (0.220)
Negative weightings		Dyke width (-0.246)	Ditch length (-0.316) Ditch mid-layer (-0.266) Dry ditch (-0.206)	Field layer % (-0.384) Mid-layer % (-0.367) Grassy margin (-0.331) Road length (-0.268) Townland length (-0.250)

Table 4: PCA results for first five principal components (PC1-PC5) at field level (n = 35) during the winter season with relevant eigenvalues, percentage variation, percentage cumulative variation and habitat variable weightings (>0.20) listed in descending order. Refer to Appendix 1 for habitat definitions.

Principle component	PC1	PC2	PC3	PC4	PC5
Eigenvalue	4.48	4.32	3.44	2.71	2.11
Variation (%)	12.8	12.4	9.8	7.7	6.0
Cumulative variation (%)	12.8	25.2	35.0	42.7	48.8
Positive weightings	Hedge length (0.253) Hedge width (0.251) Hedge height (0.247) Boundary management (0.216) Gap no. (0.212)	Ditch width (0.372) Ditch mid-layer (0.329) Wet ditch (0.322) Mixed adjacent (0.291) Bush/shrub % (0.238)	Ditch length (0.341) Ditch mid-layer (0.279) Ditch width (0.223)	Arable adjacent (0.341) Grassy margin (0.249)	Dyke width (0.295) Berry species (0.294) Mid-layer height (0.243) Aspect (0.242) Dry ditch (0.214)
Negative weightings	Tree no. (-0.348) >50% ivy (-0.339) Tree % (-0.306) <50% (-0.302) Grass adjacent (-0.229)	Grass adjacent (-0.288) Dyke length (-0.268)	Tree no. (-0.280) >50% ivy (-0.275) Tree % (-0.248) Boundary management (-0.242) <50% ivy (-0.240) Hedge height (-0.228) Hedge width (-0.226) Dyke width (-0.224) Tree height (-0.215)	Interior use (-0.386) Hedge length (-0.331) Gap no. (-0.306) Bush/shrub % (-0.269) Grass adjacent (-0.253) Mid-layer height (-0.204)	Field layer % (-0.423) Mid-layer % (-0.333) Townland length (-0.267) Road length (-0.242) Grassy margin (-0.204)

Table 5: PCA results for first four principal components (PC1-PC4) at boundary level (n = 30) during the winter season with relevant eigenvalues, percentage variation, percentage cumulative variation and variable weightings (>0.20) listed in descending order. Refer to Appendix 1 for habitat definitions.

Principle component	PC1	PC2	PC3	PC4
Eigenvalue	4.37	3.60	3.40	2.11
Variation (%)	14.6	12.0	11.3	7.0
Cumulative variation (%)	14.6	26.6	37.9	44.9
Positive weightings	Tree no. (0.375) >50% ivy (0.349) <50% ivy (0.346) Tree % (0.340) Ditch width (0.277) Wet ditch (0.274) Ditch mid-layer (0.235)	Bush/shrub % (0.350) Hedge length (0.335) Ditch width (0.324) Ditch mid-layer (0.288) Hedge width (0.280) Hedge height (0.265) Wet ditch (0.261) Gap no. (0.253) Ditch length (0.207)	Ditch length (0.304) Ditch mid-layer (0.243)	Field layer % (0.388) Mid-layer % (0.375) Grassy margin (0.332) Road length (0.269) Townland length (0.249)
Negative weightings		Dyke width (-0.256)	Hedge width (-0.323) Hedge height (-0.307) Hedge length (-0.277) Tree height (-0.253) Gap no. (-0.251) Tree no. (-0.246) Boundary management (-0.242) >50% ivy (-0.241) Tree % (-0.223) <50% ivy (-0.210)	Mid-layer height (-0.420) Bush/shrub % (0.266) Bare earth % (0.219)

Relationship between farmland habitat and breeding Song Thrushes

At field level, Song Thrush breeding presence was positively affected by PC2 and negatively affected by PC3 (Table 6). This result indicates that breeding Song Thrushes use farmland habitat consisting of wide wet ditches with tall mid-layer, mixed surrounding farmland, high proportion of bush & shrub layer, absence of surrounding farmland dominated by grassland and short dyke length (see Table 2). It also highlights that the presence of breeding Song Thrushes is negatively influenced by farmland containing low tree height and abundance, untrimmed boundaries, narrow dykes and low standing narrow hedgerow. Analysis at boundary level found a positive relationship between Song Thrush presence and PC3 (Table 6). This result emphasizes the importance of tall, wide and long hedgerow, many tall trees, trimmed boundaries, more gaps and dry ditches of short length with low standing mid-layer (see Table 3) for breeding Song Thrushes. On the other hand, breeding densities were neither influenced at field nor boundary level.

Relationship between farmland habitat and wintering Song Thrushes

Analysis of the presence of Song Thrushes in winter did not reveal any influence of habitat variables. However, PC3 was found to show a positive relationship with winter densities at the field level (Table 6). This suggests that long, wide ditches with tall standing mid-layer, low tree height and abundance, unmanaged boundaries, low standing narrow hedgerow and narrow dykes positively influence wintering densities (see Table 4). When habitat variables at boundary level were considered with winter densities, a positive influence was found with PC3 (Table 6). This result

emphasizes the importance of long ditches with tall standing mid-layer, narrow and low standing hedgerow of short length, low tree height and abundance, fewer gaps and unmanaged boundaries in predicting Song Thrush winter densities (see Table 5).

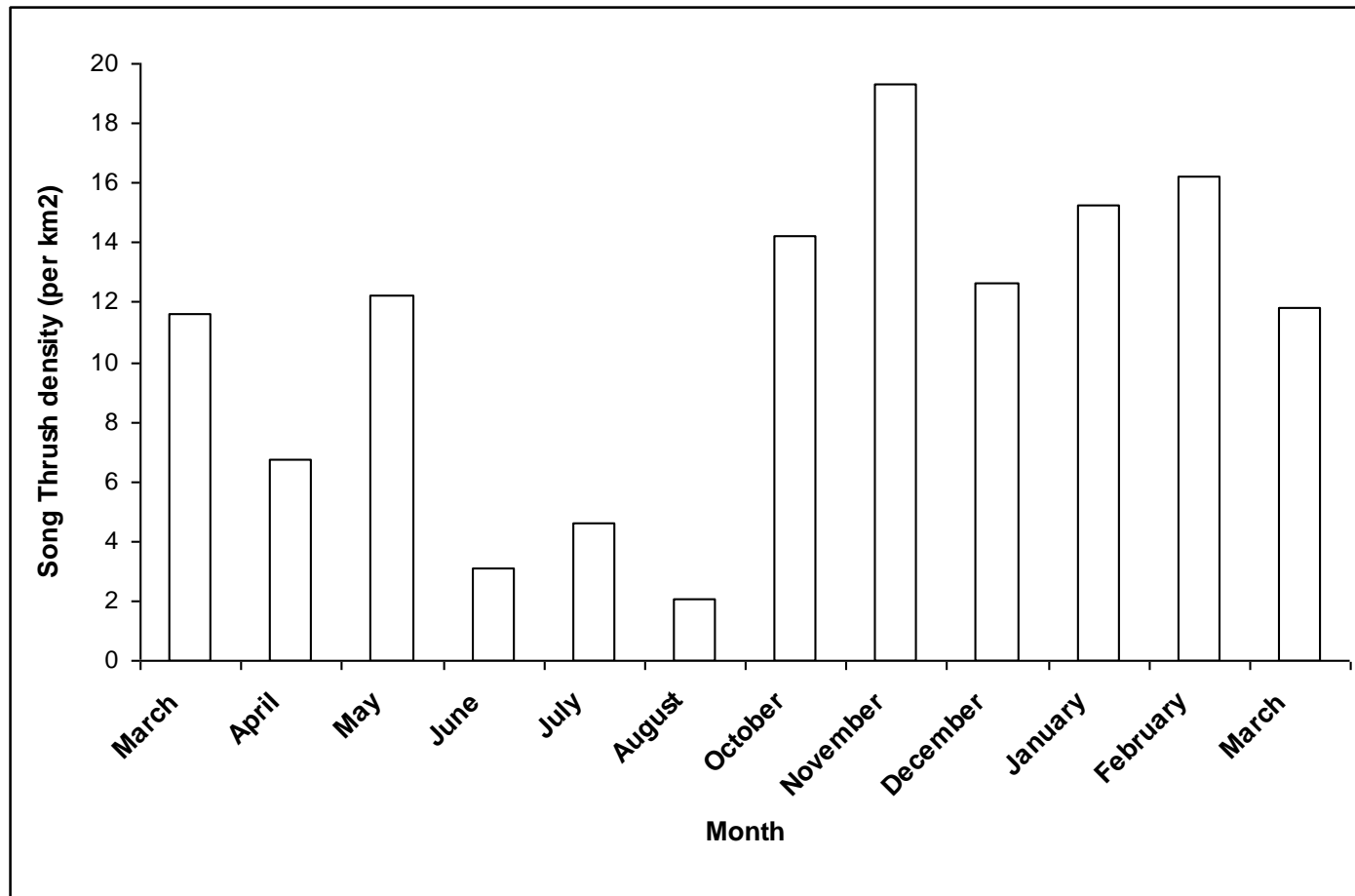
Table 6: Results of multiple regression analyses on Song Thrush presence and densities in relation to habitat variables during breeding and winter seasons. * denotes significance at $p < 0.05$ level.

Variable	Field level	Boundary level
Breeding presence	$y = -(1.000) + (0.269)PC2^* - (0.259)PC3^*$ $s = 0.44$ $R\text{-sq} = 10.08$	$y = -(0.948) + (0.265)PC3^*$ $s = 0.45$ $R\text{-sq} = 4.58$
Winter densities	$y = (0.337) + (0.068)PC3^*$ $s = 0.47$ $R\text{-sq} = 6.88$	$y = (0.337) + (0.057)PC3^*$ $s = 0.47$ $R\text{-sq} = 4.77$

Comparison of breeding and wintering densities

Mean Song Thrush densities (per km²) were significantly higher during the winter season (19.23) than the breeding season (10.74) ($F=8.13$; d.f. between groups=1; d.f. within groups=36; $p<0.01$). This trend is clearly seen by examining Song Thrush density per month throughout the duration of the study (Figure 1). Monthly fluctuations in density are also evident, especially during the breeding season with one major peak apparent during the winter season in November (Figure 1).

Figure 1: Overall relative Song Thrush density (per km²) recorded for each month 2002 - 2003.



Discussion

As already mentioned, there are very few Irish studies that have investigated the relationship of Song Thrushes with farmland habitat and we are unaware of any Song Thrush habitat-specific study here. Furthermore, very few studies have been published on the interaction of wintering Song Thrushes with field boundaries in comparison to ones involving breeding Song Thrushes. Even though the methodology used in this study did not allow for the calculation absolute densities (see Bibby *et al.*, 1993), the main aim of this study was to investigate the influence of farmland habitat variables on Song Thrush populations during the breeding and winter seasons, for which relative densities and presence/absence data used by this study were sufficient.

The relatively small farm sizes and field areas (*e.g.* see Table 1), and often structurally complex field boundaries largely determined the area of the farms as found by other Irish studies such as Lysaght (1989) and Moles & Breen (1995). Where possible, we selected farms within areas dominated by their particular farm enterprise in order to minimise possible influences from surrounding habitat. However this was not always possible, especially given the relatively small farm size in Ireland where the average size is 32 hectares with almost half of all farms less than 20 hectares (pers. comm. Teagasc). This was a particular problem for arable, which encompasses a relatively small proportion of Irish farming as evident in 2002 where it only accounted for 9.7% of total Irish agricultural land (Central

Statistics Office, 2003), which contrasts to the amount of arable in English agriculture in 2003 of >45% (DEFRA, 2005).

Notwithstanding these issues, we were very careful to only record birds using the habitat being surveyed and excluded birds where any doubt existed. Therefore the results of this study provide an important insight into the interactions between both breeding and wintering Song Thrushes and the Irish farming habitat. Our findings may help in conservation measures elsewhere, especially in relation to field boundary management sympathetic towards Song Thrush conservation all year round, such as boundary trimming on rotation or ditch maintenance.

Relationship between farmland habitat and breeding Song Thrushes

As found in other studies (*e.g.* Fuller *et al.*, 1997; Moles & Breen, 1995) no habitat variables were successful in predicting Song Thrush breeding densities. However, the presence of breeding Song Thrushes was predicted by the specific characteristics of several habitat variables, thereby highlighting their importance for breeding Song Thrushes. At the field level, the presence of Song Thrush was positively influenced by wide wet ditches with tall vegetation cover, mixed farming landscape, high level of bush & shrub cover, the absence of grassland dominated farming landscape and short dyke lengths. However, low standing trees, low tree abundance, untrimmed boundaries, narrow dykes and low standing narrow hedgerow negatively influenced

presence. At the boundary level we found that tall, wide and long hedgerows, tall trees, high tree abundance, trimmed boundaries, high gap number and dry ditches of short length with low standing vegetation cover were important variables in attracting breeding Song Thrushes in the first place. While differences in the priority of habitat variables exist between the two levels, many overlaps do occur.

Mixed farming landscape

We found that a mixed farming landscape, with an absence of a grass dominated landscape, were positive influences on the presence of breeding Song Thrushes. This follows a similar trend found in Chapter 6 where Song Thrushes breeding in Ireland preferred mixed farmland to grassland. Interestingly, Peach *et al.* (2004b) have found that Song Thrush breeding densities can decline in some grass dominated (> 40% grassland) areas in England and perhaps this trend is reflected here. We also know that in Britain, permanent pasture was amongst the least preferred foraging habitats by Song Thrushes during the breeding season, although grassland is still a heavily used foraging habitat at the same time (Murray, 2004; Peach *et al.*, 2004a).

However, looking at the main characteristics of our study sites (Table 1) we see that mixed farmland had the highest occurrence of hedgerow and second highest occurrence of ditch, two habitat variables that we found especially important in predicting Song Thrush presence during the breeding season. Therefore, in this

study, habitat structure may be the key factor in explaining the importance of surrounding mixed farmland.

Knowing that arable areas are strongly avoided by Song Thrushes in Britain during the breeding season (Murray, 2004; Peach *et al.*, 2004a), it may seem curious that the absence of surrounding grassland was highlighted in this study instead of the absence of surrounding arable. However as arable land is now very scarce (< 10%) in Ireland, surrounding arable landscapes were poorly represented in our data. While the positive influence of a mixed farming landscape to a grassland dominated landscape is probably true for breeding Song Thrushes here, the same cannot be said for arable over grassland. This is confirmed by the fact that Song Thrushes breeding in Ireland have been shown to prefer grassland to arable (Chapter 6).

Ditches

In keeping with our findings on ditches, Arnold (1983) highlighted the importance of ditches for breeding Song Thrushes while Peach *et al.* (2004a; 2004b) reported on the specific importance of wet ditches for foraging Song Thrushes during the breeding season. In fact, Peach *et al.* (2004b) suggest the inclusion of ditch creation and ditch maintenance measures in agri-environment schemes in the UK aimed at conserving species like the Song Thrush, further highlighting their importance. The Song Thrush is a ground-probing species, especially of earthworms and snails (Gruar *et al.*, 2003; Murray, 2004), and wet ditches probably provide soft soil that is

easy to probe especially in times of dry or frosty weather (Lack, 1992). Also earthworm abundance close to ground surface is enhanced by wetter soil (Peach *et al.*, 2004a), indicating that the damp micro-habitat of wet ditches improves Song Thrush prey availability. Therefore the importance of wet ditches as a foraging habitat for both provisioning and non-provisioning Song Thrushes during the summer is not surprising.

Our study also specified the importance of ditch width and tall vegetation (often gorse, *Ulex* spp., in our study sites) for wet ditches, both elements that should enhance foraging opportunities for Song Thrushes. Interestingly, Lack (1992) reported that in a case of ditch management on a Yorkshire farm, there was less impact and quicker recovery by insectivorous species including the Song Thrush where more vegetation was left than vice-versa. This study also showed that dry ditches were only an influence in Song Thrush breeding presence when they were short in length and had low standing vegetation. This probably reflects the lower suitability of dry ditches as foraging habitats than wet ditches, although in times of dry weather they probably provide better foraging opportunities than surrounding open farmland especially if they have vegetation.

Tall, dense cover

High bush & shrub cover, tall trees, high tree number and tall, wide long hedgerows positively influenced Song Thrush presence during the breeding season in this

study. The fact that we found low standing trees, low tree abundance and low standing narrow hedgerow were negatively associated with presence, emphasizes the particular importance of these two variables on breeding Song Thrushes. The importance of such tall and dense cover for breeding Song Thrushes has been highlighted by various studies (*e.g.* Arnold, 1983; Lack, 1992; Green *et al.*, 1994; MacDonald & Johnson, 1995; Moles & Breen, 1995; Sparks *et al.*, 1996). The importance of these habitat variables here are undoubtedly related to Song Thrush nesting since a study in Ireland found that nesting occurred in trees, bushes or hedgerow (This study; Chapter 3). In addition, the same study showed that Song Thrush nesting areas had significantly denser vertical vegetation than non-nesting areas (This study; Chapter 3), further highlighting the importance of tall dense cover for breeding Song Thrushes. In addition, tall trees are also important as song-posts for Song Thrush males (Cramp, 1988).

Dykes

The negative influence found by this study between presence and narrow dykes may be related to tall dense habitat variables, where narrower dykes would probably support poorer bush & shrub cover, fewer trees, and narrower hedges. On the other hand, the positive influence of short dyke length on presence appears contradictory as it might be expected to support a lower proportion of bush & shrub cover, fewer trees and shorter hedgerow. Looking at our dataset we cannot see any particular associations between short dykes and other habitat variables. Perhaps, in this case

the inclusion of short dyke length is more related to the original separation of short and long dykes in the PCA on habitat variables rather than having any real influence on Song Thrushes. That said, we cannot exclude the possibility that some other unknown factor(s) may be involved here.

Boundary management & gaps

In this study we found that trimmed boundaries were a positive influence on the presence of Song Thrushes during the breeding season. This is not surprising given the facts that Song Thrushes are known to favour dense nesting vegetation (Chapter 3) and hedgerow trimming can encourage dense re-growth (Murphy, 1997). We also found that higher gap number had a positive influence on Song Thrush breeding presence, which may be related to the fact that boundaries in our study sites with high gap number tended to also have hedgerow.

Relationship between farmland habitat and wintering Song Thrushes

In contrast to the breeding season, Song Thrush winter presence was not explained by any of the habitat predictors but winter densities were positively related, at field level, to long, wide ditches with tall standing vegetation, low tree height and abundance, unmanaged boundaries, low standing narrow hedgerow and narrow dykes. The same trends were mirrored in our analyses at the boundary level, where

density was positively related to long ditches with tall standing mid-layer, narrow and low standing hedgerow of short length, low tree height and abundance, fewer gaps and unmanaged boundaries.

Ditches

Ditches in this study were just as important during the winter season as the breeding season, as also found by Arnold (1983). In this case, long wide ditches with tall standing vegetation influenced winter density regardless of whether they were wet or dry (both had similar positive principal component weightings <0.20). On the other hand, Moles & Breen (1995) found a negative relationship between Song Thrush winter abundance and extent of dry ditch. Such differences between our study and Moles & Breen (1995) could be related to differences in other factors such as climate conditions during both studies. Similar to the breeding season, the use of ditches here is more than likely related to better foraging opportunities during dry or frosty weather (Lack, 1992). Again, the characteristics of ditch length, width and vegetation height would enhance such foraging opportunities while perhaps also providing more opportunities for shelter from the winter weather.

Low, thin cover

In contrast to the breeding season, winter densities were positively related to low thin vegetation cover as evident by the positive relationship with low tree height, low tree abundance and short narrow low standing hedgerow. These results emphasize the shift

in priority for Song Thrushes between the breeding and non-breeding seasons. We also found that narrow dykes positively influenced winter density, which could be seen as in agreement with the above results as narrow dykes may support poorer vegetation cover and fewer trees. This favouring of a more open farming landscape during the winter could also be related to the importance of grassland for foraging (Peach *et al.*, 2002), even though grassland in itself did not feature strongly in our analyses here (positive principal component weighting 0.13). Similar to our findings on low vegetation cover, Moles and Breen (1995) found that winter Song Thrushes were correlated with short scrub, but in contrast to our findings on hedge, their study found that winter abundance was negatively influenced by short narrow hedgerow. This difference in hedgerow may be related to differences in boundary structures between the two study areas, where hedged banks are common in Northern Ireland (Aalen *et. al.*, 1997) and hedgerow was poorly represented in our study sites.

Boundary management & gaps

We found that untrimmed boundaries with few gaps were positive predictors for Song Thrush winter density. Trimmed boundaries can restrict or prevent berry production (Murphy, 1997), where berries are known as an important food source during the winter (Davies & Snow, 1965). Therefore food source appears to be the key factor in explaining the importance of untrimmed boundaries for wintering Song Thrushes here. The positive influence by lower gap number is probably related to the fact that

untrimmed boundaries in this study tended to have fewer gaps in comparison to trimmed ones.

Breeding and wintering densities

Our study found that mean Song Thrush winter densities were significantly higher (almost double) than breeding densities. This distinct winter increase is undoubtedly related to the influx of migratory individuals from Britain and Northern Europe (Cramp, 1988; Thomson, 2002). We must remember that the densities calculated here are relative and are expected to be lower than absolute density calculations. This does appear to be the case, as Chapter 6 calculated Song Thrush breeding densities (per km²) across different farm enterprises as 17.1 – 18.9, which is higher than the average relative breeding density calculated by this study.

Looking at monthly trends (Figure 1) we see that fluctuations occur throughout but are especially marked during the breeding season, which generally extends from mid March to late June in Ireland (Chapter 2). During the breeding season these fluctuations are probably explained by changes in adult behaviour during different nest stages where for example lower activity, resulting in lower observations, would be expected during incubation. During the winter season monthly densities are more consistent with the obvious exception of November. It is reported that the main southerly movement of Song Thrushes from northern Europe occurs from

September to November (Cramp, 1988). Also, Thomson (2002) suggests that high Song Thrush numbers found in Britain during the autumn may be due to Scandinavian birds en route through the country. Therefore it seems plausible that a similar trend is happening in Ireland where the main movement of birds migrating to southern Europe passes through Ireland in November, as evident by the larger densities experienced then followed by a decline in December (see Figure 1). The next major peak in Song Thrush activity occurs in January and February (see Figure 1), which probably reflects the main passage of birds returning back to northern Europe. The lower densities recorded at this time, in comparison to the outward journey in November, is more than likely primarily due to mortality of birds. It is interesting to note the similarity in densities in March 2002 and March 2003, indicating that the increase in Song Thrush numbers during the winter period is indeed related to winter migration movements.

Conclusions

The importance of ditches as a foraging habitat in both breeding and winter seasons was emphasised by this study where the structural characteristics of width, length and vegetation proved to be key factors. The emphasis on tall ditch vegetation signifies the importance in maintaining such vegetation cover at ditches. It also suggests that in cases where ditch vegetation has to be trimmed or removed during ditch maintenance, some vegetation should be left, for example on one bank. While wet ditches were especially important during the breeding season, the possible

future change in Irish climate of drier summers (Sweeney & Fealy, 2002) will add to their value and importance for breeding Song Thrushes. We saw how Song Thrush habitat priority switched from tall dense vegetation during the breeding season to low thin vegetation in the winter season, indicating that Song Thrushes would benefit most in a landscape with a mixture of such vegetation types. Our findings on boundary management suggest that a rotational trimming system at farm level would benefit Song Thrushes the most by providing both nesting opportunities and winter food sources in any given year. This study also showed the main periods of Song Thrush migrant passage through Ireland during the winter, where this migratory influx almost doubles the total Song Thrush abundance from the resident or breeding abundance. The main period of migratory movement found by this study in November also indicates that boundary trimming should not be undertaken before December in order to maximize foraging opportunities for these passing migrants.

Currently in Ireland, watercourses (includes permanent wet ditches) and field boundaries are protected by Ireland's only agri-environment scheme, the Rural Environment Protection Scheme (REPS) (Department of Agriculture & Food, 2005). Even though this protection only applies to farms that join the scheme, the uptake is increasing, thereby increasing its potential impact on the Irish agricultural landscape. In relation to watercourse maintenance, the scheme recommends the removal of weeds from one bank only, which is in line with our findings on the

importance of ditch vegetation for Song Thrushes. However the scheme does not include dry ditches as part of its environmental prescriptions. In relation to field boundary maintenance, the scheme recommends that hedgerow maintenance should be carried out in late winter, which again is in line with our finding on the importance of untrimmed boundaries in winter especially before the major passage of migratory Song Thrushes in November. Therefore we can see that while REPS currently recognises some important habitat management strategies, it also ignores others. Of course, we must acknowledge that the habitat structure and management strategies suggested by our findings for the Song Thrush would also have benefits for other birds (*e.g.* ditches for snipe, reed bunting; see Lack, 1992) and wildlife (*e.g.* presence of field boundaries for dung beetles; Hutton & Giller, 2003).

While the current Song Thrush population is widespread and stable (Coombes, 2003) and appears to have a reasonably positive interaction with Irish farming (Chapters 3 & 6), the environmental consequences arising from current socio-economic changes in the Irish farming sector and changes in EU farm policies remain to be seen. There is a suggestion that farm policies post 2000 will create a wider division in Ireland between the more intensively productive farming areas and less intensive areas (Lafferty *et al.*, 1999). If this is the case, then it is highly likely that these intensive farming areas will also experience increased losses in habitat important to the Song Thrush (and other wildlife), including field boundaries. Therefore it is very important to monitor future habitat changes in the Irish farming

landscape. Our findings highlight several aspects in relation to habitat structure and management that should benefit breeding and wintering Song Thrushes, which should be considered in conservation strategies aimed at maintaining or restoring Song Thrush populations in areas of decline.

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Appendix 1: Summary of the habitat variables measured per field in this study.

Habitat variable	Definition	Units of measure
<i>Interior use</i>	Main agricultural use: arable, grassland	Categorical (1,2)
<i>Adjacent arable use</i>	Main adjacent agricultural use is arable farming: no, yes	Categorical (0,1)
<i>Adjacent mixed use</i>	Main adjacent agricultural use is mixed farming: no, yes	Categorical (0,1)
<i>Adjacent grass use</i>	Main adjacent agricultural use is grassland farming: no, yes	Categorical (0,1)
<i>Aspect</i>	Main aspect of field: north, northeast, east, southeast, south, southwest, west, northwest, inconclusive (<i>i.e.</i> more than one aspect)	Categorical (1-9)
<i>Coppice & scrub</i>	Length of coppice and/or scrub area adjacent to field boundary	Metres per hectare (m/Ha)
<i>Building & garden</i>	Length of building and/or garden area adjacent to field boundary	Metres per hectare (m/Ha)
<i>Road</i>	Length of road adjacent to field boundary	Metres per hectare (m/Ha)
<i>Dyke</i>	Length, height & width of dyke (<i>i.e.</i> stone and/or earthen embankment) boundary	Metres per hectare (m/Ha)
<i>Ditch</i>	Length & width of ditch (<i>i.e.</i> drain) boundary	Metres per hectare (m/Ha)
<i>Hedgerow</i>	Length, height & width of hedgerow (<i>i.e.</i> continuous woody linear feature with regular height and width; often found on dykes) boundary	Metres per hectare (m/Ha)
<i>River or stream</i>	Length of river or stream boundary	Metres per hectare (m/Ha)
<i>Grassy margin</i>	Length of grassy margin boundary	Metres per hectare (m/Ha)
<i>Townland boundary</i>	Length of townland boundary still intact (townland boundaries are very old and tend to have well established & high variety of plant, tree & hedgerow species)	Metres per hectare (m/Ha)

Appendix 1 (cont'd): Summary of the habitat variables measured per field in this study.

<i>Habitat variable</i>	Definition	Units of measure
<i>Boundary management</i>	Noticeable boundary management (<i>i.e.</i> trimming) during survey period: no, yes	Categorical (0,1)
<i>Tree height</i>	Tree height	Metres (m)
<i>Tree number</i>	Total number of trees in field	Count
<i>Tree number >50% ivy</i>	Total number of trees with greater than 50% ivy cover	Count
<i>Tree number < 50% ivy</i>	Total number of trees with less than 50% ivy cover	Count
<i>Mid-layer height of dyke & hedgerow</i>	Height of mid-layer vegetation of dykes and/or hedgerow. Includes shrubs, bushes, grasses and herbs	Centimeters (cm)
<i>Mid-layer height of ditch</i>	Height of mid-layer vegetation of ditches. Includes shrubs, bushes, grasses and herbs	Centimeters (cm)
<i>Overall % boundary with mid-layer</i>	Percentage of total field boundary with a mid-layer (as described above)	% (by eye)
<i>Overall % boundary with trees</i>	Percentage of total field boundary with trees	% (by eye)
<i>Overall % boundary with bush & shrub layer</i>	Percentage of total field boundary with a bush & shrub layer (excludes grasses and herbs)	% (by eye)
<i>Overall % boundary with field-layer</i>	Percentage of total field boundary with a field-layer. Includes herbs, mosses, lichens and liverworts.	% (by eye)
<i>Overall % boundary with bare earth</i>	Percentage of total field boundary with bare earth	% (by eye)
<i>Number of gaps (>1m)</i>	Total number of gaps greater than 1m in field boundary	Count
<i>Wet ditch</i>	Presence of wet ditch during survey; no, yes	Categorical (0,1)
<i>Dry ditch</i>	Presence of dry ditch during survey; no, yes	Categorical (0,1)
<i>Proportion of boundary with berry bearing species</i>	Proportion of total field boundary with species that produce berries (<i>e.g.</i> hawthorn <i>Crataegus monogyna</i>)	Proportion (by eye)

Chapter 6:

Changes in agriculture and its influence on breeding Song Thrush,
Turdus philomelos, populations in Ireland.



This has been submitted into Journal of Applied Ecology and is presented in the format of this journal.

Abstract

1. Changes in agricultural practices, driven by intensification, over the last 30 years have been implicated in Song Thrush, *Turdus philomelos*, population declines in Britain.
2. Population trends in Ireland are unclear due to the lack of long-term data. While the breeding population and distribution is thought to have declined and contracted, it is now currently widespread and stable.
3. Even though Ireland's landscape is dominated by agriculture, it has experienced a relatively lower degree of intensification than other European countries.
4. Using data from two Breeding Atlases for Ireland we related long term changes in Song Thrush breeding distribution (1968/1972 - 1988/1991) with changes in agriculture during the same period.
5. We also looked at changes in recent breeding distribution data (1998-2002) collected by a national monitoring scheme and calculated habitat specific densities which we used to assess breeding habitat use and preferences.
6. *Synthesis and applications.* Breeding distribution significantly contracted from 1968/1972 - 1988/1991, although the issue of lower survey effort for the latter period in Ireland has raised questions over the magnitude of contraction indicated. Changes in agriculture did not significantly differ between areas of breeding stability and decline during this period of contraction in breeding distribution. A non-significant increase of 4.6% in breeding distribution was noted during 1998 – 2002. While most of the current Song Thrush breeding population use farmland, it is

not the most preferred habitat. At the same time, no farmland habitat was avoided, further highlighting a positive relationship between breeding Song Thrushes and Irish farmland. We compare our findings on habitat specific densities, habitat use and habitat preference with similar studies in Britain, where Song Thrushes have undergone the sharpest decline in Western Europe. We consider some factors that may explain the positive interaction that exists between Irish agriculture and breeding Song Thrushes, although future environmental consequences of longer-term changes in Irish agriculture remain to be seen.

Key-words: Song Thrush, breeding distribution, habitat specific densities, habitat use, Jacobs' index

Introduction

Interactions between birds and agriculture have been widely studied in recent years (See Ormerod & Watkinson 2000) with declines recorded for many farmland bird populations across Western Europe over the last 30 years (Fuller *et al.* 1991; Tucker & Heath 1994). Such declines appear to be driven by landscape changes resulting from corresponding changes in agricultural practices (Fuller *et al.* 1991; Fuller *et al.* 1995; Pain *et al.* 1997; Tucker & Dixon 1997; Chamberlain *et al.* 2000; Gates & Donald 2000; Chamberlain 2002; Vickery *et al.* 2001; Benton *et al.* 2002; Newton 2004), which were instigated by the EU Common Agricultural Policy (CAP) (Donald *et al.* 2002). Such a link between landscape and agriculture is not surprising

given the dominance of agricultural land on most European landscapes (See Tucker & Dixon 1997). The Song Thrush has experienced population declines across Europe between 1970-1990 (Tucker & Heath 1994). While the population decline in the Netherlands has been slow and the population in France has fluctuated, the decline in Britain has been rapid (Tucker & Heath 1994). The long-term decline in Britain has been 52% (Eaton *et al.* 2004) with the largest (65%) on farmland (Thomson *et al.* 1997), although the present population appears to be recovering (Eaton *et al.* 2004; Newton 2004). Recent research in Britain has highlighted the important influences that agriculture has had on both stable and declining breeding Song Thrush populations there (Peach *et al.* 2004a and 2004b). The Song Thrush is currently classified as a species of conservation concern in Britain (Gibbons *et al.* 1996), but not in Ireland (Newton *et al.* 1999).

Due to the lack of long-term data, population trends for the Song Thrush population in Ireland are unclear with some indications of a decline (Tucker & Heath 1994) and contraction in breeding distribution (Sharrock 1976; Gibbons *et al.* 1993). Recent indications from the Countryside Bird Survey (CBS), a national bird-monitoring programme established in 1998, suggest that the Song Thrush population is currently widely distributed and stable in the Republic of Ireland (Coombes 2003).

The Republic of Ireland is amongst the highest agriculturally dominated landscapes in Europe (See Stanners & Bourdeau 1995; Tucker & Dixon 1997) but changes in agricultural practices and increases in agricultural intensification have occurred at a

slower rate and lower scale than other Western European countries (Cabot 1985; Lysaght 1989; Stanners & Bourdeau 1995; Aalen *et al.* 1997).

Prompted by the situation on British farmland and the unclear population trends in Ireland combined with lower rates of agricultural intensification, we investigated the interaction of Song Thrushes with Irish agriculture. Here we examine changes in Song Thrush breeding distribution in Ireland using data from both Breeding Atlases (Sharrock 1976; Gibbons *et al.* 1993) and data collected more recently by the CBS. We also assess corresponding changes in Irish agriculture, differences in agricultural variables between areas of Song Thrush stability and decline, and breeding habitat usage and preference. As well as providing us with information on interactions between Song Thrushes and Irish agriculture, and possible input into future conservation measures, the methodology applied in this study may also be applied to other bird species in Ireland, especially those of conservation concern.

Methods

Breeding bird data

Song Thrush data collected by both Breeding Atlases (Sharrock 1976; Gibbons *et al.* 1993) and the CBS were used for analysis. Breeding Atlas data were collected per 10-km squares across Ireland during 1968-1972 (Sharrock 1976) and in 2km² tetrads within each 10-km square during 1988-1991 (Gibbons *et al.* 1993). While

Sharrock (1976) recorded Song Thrush breeding status for each 10-km as probable, confirmed or possible, Gibbons *et al.* (1993) recorded Song Thrush status per square as either breeding (equivalent to probable and confirmed breeding categories of Sharrock's Atlas) or seen (equivalent to possible breeding category of Sharrock's Atlas). The CBS (See Coombes *et al.* 2002) in the Republic of Ireland is analogous to the Breeding Bird Survey (BBS) in the UK and is based on a stratified random sample of 1-km² squares that are located on the extreme southwest corner of each 10-km square. In every 1-km² square, two parallel 1-km transects, approximately 500m apart, are surveyed twice (*i.e.* early and late visits) for adult birds during the breeding season. These birds are assumed to be potential breeders, thereby representing the breeding population, and are recorded as either flying or in one of three distance bands (*i.e.* 0-25m, 25-100m or 100m-infinity) perpendicular to the transect line. In addition each 1-km transect is divided into 200m sections, giving a total of 10 survey sections, and the primary and secondary habitats are recorded per 200m section according to the BTO Habitat Coding Scheme, adopted from Crick (1992). The CBS began in 1998 and data collected for 1998 to 2003 were available for analysis from BirdWatch Ireland.

Long term breeding population data (Breeding Atlas data)

Assessing changes in breeding distribution

In the following analysis, we only used data from squares where Song Thrushes were present and either breeding or not breeding. The number of 10-km squares with and without breeding Song Thrushes was compared between Sharrock (1976)

(n=970) and Gibbons *et al.* (1993) (n=947) Breeding Atlases to assess overall changes in breeding distribution. We also assessed breeding changes in 10-km squares that were surveyed in both Breeding Atlas projects. This resulted in the assessment of 941 10-km squares where two major changes in breeding status were noted (a) ‘Areas of stability’ (*i.e.* birds breeding in both periods) and (b) ‘Areas of decline’ (*i.e.* birds breeding in 1968-1972 but not in 1988-1991). There was one square where breeding was not recorded in Sharrock (1976) but was recorded in Gibbons *et al.* (1993) and two cases where Song Thrushes were present but not breeding in both Breeding Atlases; these data were not considered in further analysis resulting in the subsequent analysis of 938 10-km squares.

Assessing changes in agriculture during the periods 1968-1972 and 1988-1991

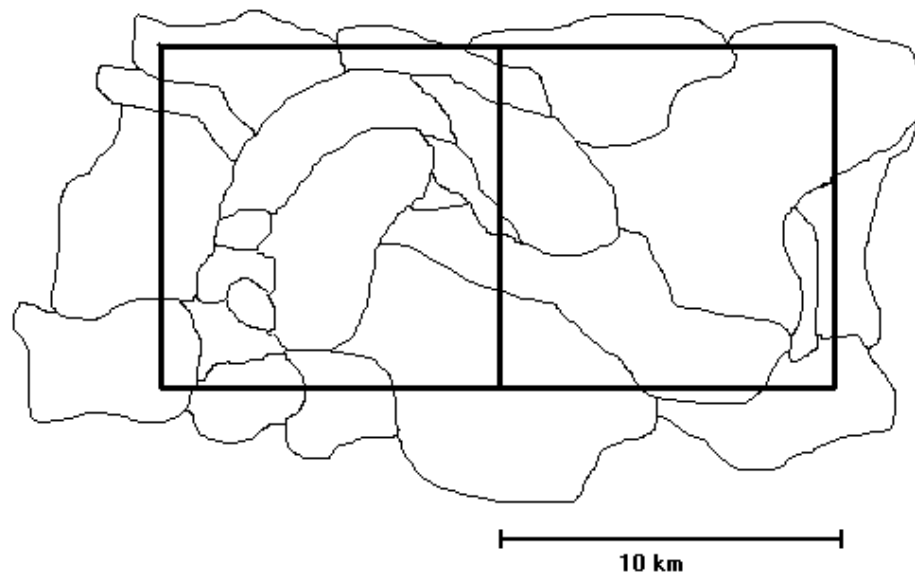
Agricultural data for the Republic of Ireland were obtained from the Census of Agriculture for 1970 and 1991, collected by the Central Statistics Office (CSO) every 5-10 years (pers. comm. Julie Maher). These years were chosen as they corresponded well with the timing of the Breeding Atlas bird data. This agricultural census is undertaken at District Electoral Divisions (DEDs) per county. There are approximately 3400 DEDs in the Republic, all irregularly shaped and sized (Lafferty *et al.* 1999). The agricultural variables that we included in the analysis were area farmed (in total hectares), number of cattle and sheep (both in total numbers) and area under arable (cereals and crops), hay & silage and pasture (all in total hectares). Unfortunately other agricultural variables such as fertilizer and

pesticide applications could not be used in our analysis, as these data are not available at DED level (pers. comm. Julie Maher). In assessing changes in agriculture, we used the 10-km squares from the bird data as our units of study. To achieve this, we had to firstly reconcile the agricultural data, at DED level, with the bird distribution data, at 10-km square level.

Reconciling agricultural data with Breeding Atlas bird data

Using GIS (ArcView 3.2), all 938 10-km breeding distribution squares were overlaid on a corresponding map of DEDs (Figure 1). For every square where breeding status had declined in the Republic of Ireland (*i.e.* 100 10-km squares), the corresponding DEDs were identified according to the following criteria: (i) at least 50% of each identified DED occurred within the 10-km square (since DEDs are irregular in size and shape) and (ii) the DEDs collectively covered at least 60% of the 10-km square. After these criteria were applied, a total of 71 10-km squares were available for further analysis. An equivalent number of 10-km squares (*i.e.* 71) where breeding status remained stable were randomly selected and the DEDs identified according to the same criteria. When DEDs were identified, the corresponding agricultural statistics were then collated and summed per 10-km square per year and area type (*i.e.* areas of stability and decline).

Figure 1: A representation of 10-km squares overlaid on DEDs. Note the irregular shape and size of DEDs.



Survey effort

Survey effort data for each 10-km square are available for Gibbons *et al.* (1993) but not for Sharrock (1976). However survey effort in Ireland is known to have been lower for Gibbons *et al.* (1993) than for Sharrock (1976) (See Gibbons *et al.* 1993). Seeing as changes in Song Thrush breeding population had occurred by Gibbons *et al.* (1993) Breeding Atlas survey, we tested for significant differences in survey effort between both area types that we reconciled with agricultural data to see if lower survey effort could be a contributing factor in the recording of lower breeding. In this case survey effort per 10-km square for each area type was assessed in two ways, firstly by looking at the total number of survey visits and secondly by looking at the total number of surveyed tetrads.

Recent breeding population data (CBS data)

Assessing changes in breeding distribution

For this analysis, we only considered 1-km² squares where all 200m sections were surveyed. Breeding Song Thrushes were deemed present in a 1-km² square if recorded in at least one 200m section during either visit. Changes in breeding distribution between 1998 and 2002 were compared by looking at the number of 1-km² squares with and without Song Thrushes. We also assessed breeding distribution changes in 1-km² squares surveyed in both years. A total of 197 1-km² squares were included in this assessment where four categories of change in

breeding distribution were noted (a) ‘Always occupied’ (*i.e.* birds present in both years), (b) ‘Always unoccupied’ (*i.e.* birds absent in both years), (c) ‘Newly occupied’ (*i.e.* birds absent in 1998 but present in 2002) and (d) ‘Newly unoccupied’ (*i.e.* birds present in 1998 but absent in 2002). In all cases, survey effort was accounted for by analysing 1-km² squares where all ten 200m sections were surveyed.

Assessing breeding habitat use and preferences

As part of the CBS, the primary and secondary habitats of each 200m-survey section of both 1-km transects in every 1-km² square were recorded. We investigated broad-scale habitat use by looking at the proportion of the breeding Song Thrush population occurring across different habitats (habitat level 1: woodland, scrubland, semi-natural grassland & marsh, heathland & bogs, farmland, human sites; see Crick 1992) with particular reference to farmland (habitat level 2: improved grassland, unimproved grassland, mixed land (*i.e.* grass & tilled), tilled land; see Crick 1992). To achieve this we calculated habitat specific densities from the CBS distance band bird data using DISTANCE (Version 4.1) since bird detectabilities differ with habitat types. We only used bird data from two distance bands, 0-25m and 25-100m, and in all cases fitted a half normal detection function (after Gregory & Baillie 1998, Newson *et. al.* 2005). Due to small dataset available per year we combined all years 1998-2003 (n=13 740) (with the exception of 2001 due to Foot and Mouth Disease fieldwork restrictions). To account for early and late visits without calculating actual means of bird counts from the two visits, we doubled

each transect length (after Gregory & Baillie 1998) per survey section where Song Thrushes were and were not recorded (*i.e.* 200m x 2=400m). Song Thrush densities were calculated with their equivalent 95% confidence intervals using a bootstrap resampling procedure of 400 iterations in DISTANCE (after Gregory & Baillie 1998; Newson *et al.* 2005).

We then multiplied these habitat specific densities by the area of land that each particular habitat encompassed in the Republic of Ireland giving Song Thrush population estimates per habitat. Habitat area within the Republic of Ireland was calculated by extracting the proportions of each habitat type from the CBS habitat data (1998-2003; n=13 303) and multiplying these proportions (which compare well with other studies; see Discussion) by the total land area of the Republic of Ireland (70 280 km²). From our estimates of Song Thrush population estimates per habitat, we were able to calculate the proportion of the Song Thrush breeding population that occupied each habitat.

Since habitat use does not always reflect habitat preference, we assessed habitat preference using Jacobs' Index (D) (Jacobs 1974):

$$D=(r-p)/[(r+p)-(2rp)]$$

r = the proportion of birds recorded in a habitat type (*i.e.* the proportion of Song Thrush breeding population occurring in each habitat); p = the proportion of habitat type available (*i.e.* the proportion of habitat as calculated from the CBS).

The index (D) ranges from +1 to -1, where the former represents a strong preference for a habitat type and the latter a strong avoidance of a habitat. As Gregory and Baillie (1998) point out, using the terms preference and avoidance for broad-scale habitats is inappropriate as habitat preference and avoidance will depend on other environmental factors coupled with species behaviour. However, in this study, we use these terms as a guide to the general positive (*i.e.* preferred) or negative (*i.e.* avoided) interactions between Song Thrushes and Irish habitat, especially Irish agriculture.

Statistical Analyses

Chi-squared tests were used to analyse breeding distribution with the application of Yates' correction where appropriate. Differences in agricultural variables between areas of decline and stability were compared both before (using 1970 agricultural statistics) and after (using 1991 agricultural statistics) the major changes in Song Thrush breeding status, using MANOVA, after the data were square root transformed. MANOVA was also used to compare the degree of change in these same agricultural variables between both areas, by calculating the differences for each variable from 1970 to 1991 after square root transforming the data. Survey effort in Gibbons *et al.* (1993) Breeding Atlas was tested by comparing the total number of visits and the total number of surveyed tetrads per 10-km square between areas where breeding had and had not declined, using Mann-Whitney U test. Analyses were undertaken using SPSS for Windows (Release 11.0.1.)

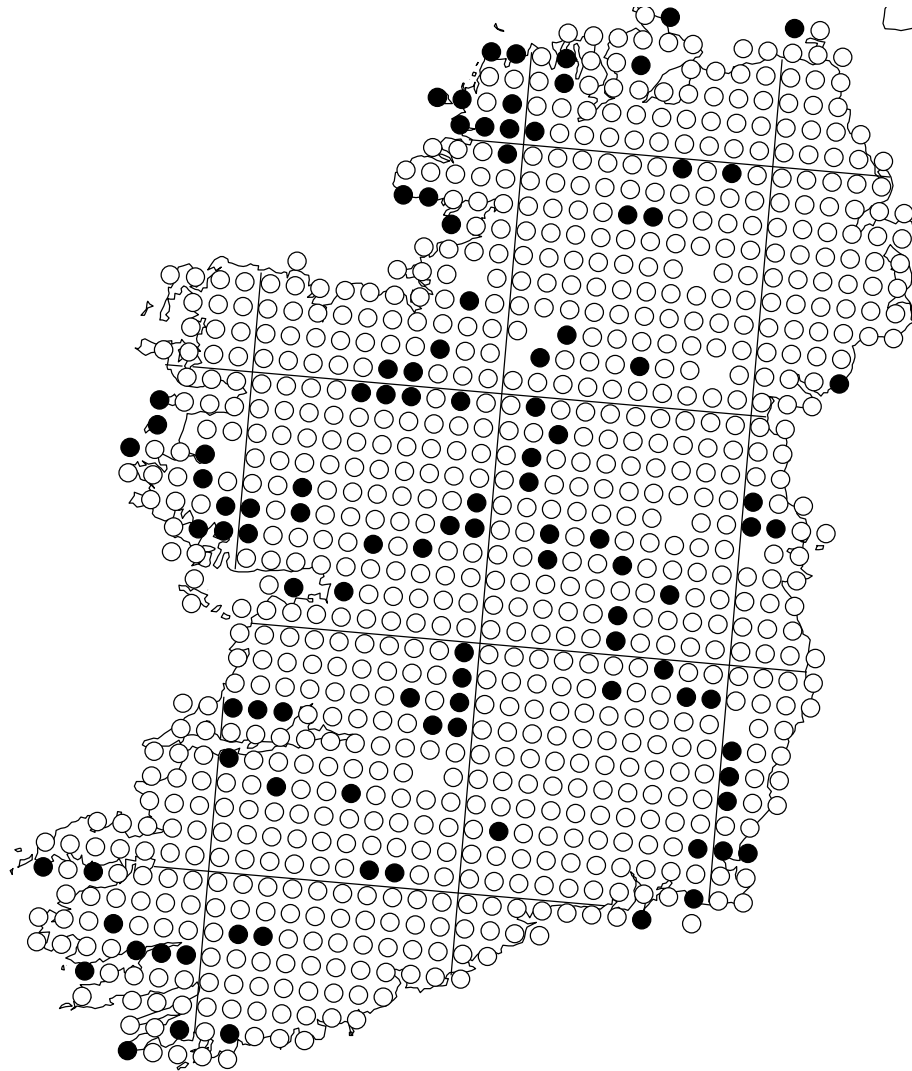
Results

Long term breeding population data (Breeding Atlas data)

Assessing changes in breeding distribution

In Sharrock (1976) only 0.3% of 10-km squares in Ireland were classified as areas containing no breeding Song Thrushes with the remaining 99.7% classified as containing breeding Song Thrushes. In contrast, Gibbons *et.al.* (1993) recorded 11.8% as areas without breeding Song Thrushes and 88.2% as areas with breeding Song Thrushes. These changes in breeding distribution with time are significant, with non-breeding areas significantly more associated with Gibbons *et. al.* (1993) Breeding Atlas and vice-versa ($\chi^2=110.7$; d.f.=1; $p<0.05$). Using data from 10-km squares surveyed for both Breeding Atlas projects (n=938), we found 11.3% experienced a decline in breeding population while 88.6% did not experience a decline but remained stable between both periods (Figure 2).

Figure 2: Areas of stability (open circle) and decline (filled circle) for Song Thrush breeding population distribution between both Breeding Atlases (1968/1972 – 1988/1991). Only areas surveyed in both periods were used to assess change in breeding status (n=938).



Assessing differences in agriculture between areas of breeding stability and decline

In the Republic of Ireland agriculture has changed since the 1970s and this is evident in both areas of Song Thrush breeding stability and decline, where trends in these changes are similar for both areas (Figure 3). In 1970, and before any major changes in breeding population, no significant differences were detected in agricultural variables between the areas where breeding population subsequently remained stable or declined (Hotelling's Trace=0.061; $F=1.36$; $p>0.20$). After changes had occurred in breeding population, differences in 1991 agricultural statistics between the two areas still remained statistically insignificant (Hotelling's Trace=0.080; $F=1.53$; $p>0.15$).

Degree of change in agricultural variables between both area types

Figure 4 illustrates trends in mean percentage change in agricultural variables, from 1970 to 1991, experienced by areas of both stability and decline. Again, no significant differences were found with the degree of agricultural change experienced in both areas of stability and decline (Hotelling's Trace=0.042; $F=0.935$; $p>0.40$)

Figure 3: Mean total hectares or numbers (\pm s.e.) of various agricultural variables in areas of stability (n=71) and decline (n=71) for Song Thrush breeding population distribution for 1970 and 1991.

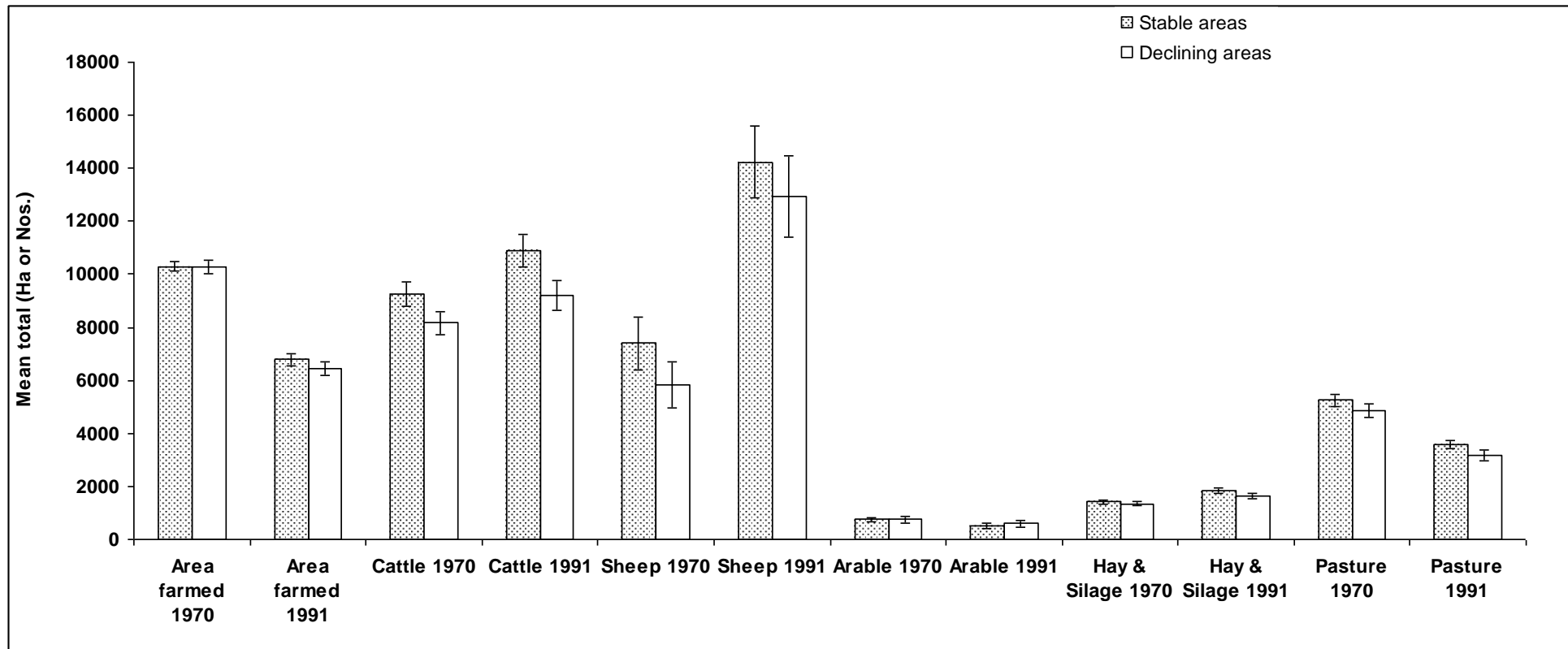
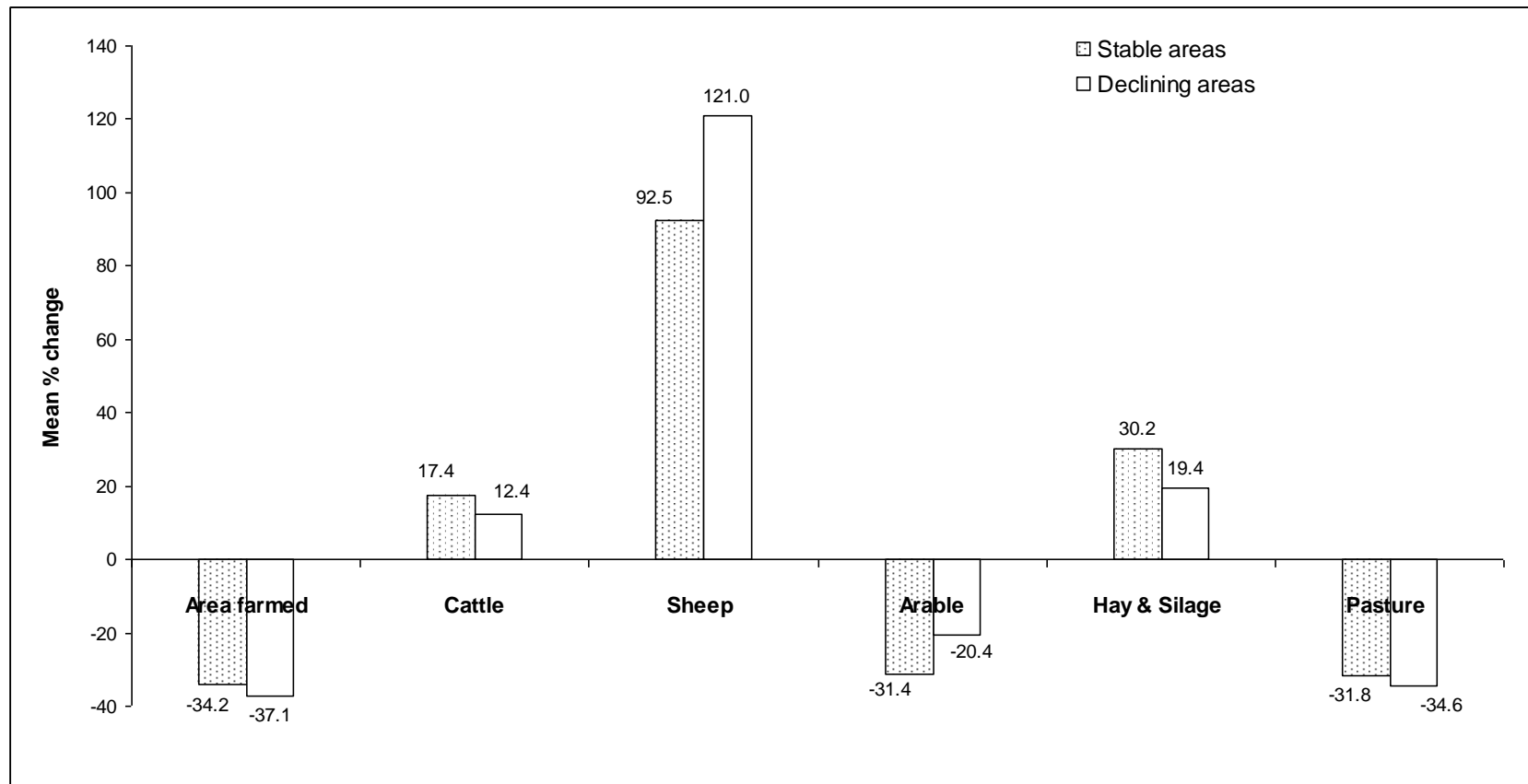


Figure 4: Mean percentage change of various agricultural variables from 1970 to 1991 in areas of stability (n=71) and decline (n=71) in Song Thrush breeding population distribution. Values are shown for each variable.



Survey effort

No significant difference was detected in the median number of visits ($W=4919.5$; $p>0.70$) between areas of stability and decline in Song Thrush breeding population. However, the number of tetrads surveyed per 10-km square was very close to being significantly higher in the stable areas ($W=5197.0$; $p=0.051$).

Recent breeding population data (CBS data)

Assessing changes in breeding distribution

In 1998, 80.3% ($n=239$) of 1km^2 squares were occupied by Song Thrushes, which increased to 84.3% for 2002 ($n=293$). There was no significant association between year and presence/absence ($\chi^2=1.173$; d.f.=1; $p>0.05$). Using data on 197 1km^2 squares surveyed in both years, 72.7% remained occupied, 10.7% remained unoccupied, 10.7% were newly occupied and 6.1% were newly unoccupied, suggesting an overall increase in breeding distribution of 4.6%.

Assessing breeding habitat use and preferences

Overall land coverage and bird population occurrence across different habitat types are shown in Figure 5, where farmland habitats have the most dominant impact on Song Thrush occurrence. When we applied Jacobs' index, the dominant impact of farmland on Song Thrushes was lessened with woodland, human sites and scrubland habitats being the more preferred (Figure 6 a). Within farmland habitat, tilled land was the least preferred habitat while mixed land was the most preferred followed by

unimproved and improved grassland (Figure 6 b). While the preference values for these farmland habitats are small, it is interesting to note that none of these farmland habitats were avoided (*i.e.* below 0).

Figure 5: Percentage frequency of broad-scale habitat type available within the Irish landscape and used by the Song Thrush population 1998-2003 according to habitat (n = 13,303) and bird (n = 13, 740) data collected by the CBS.

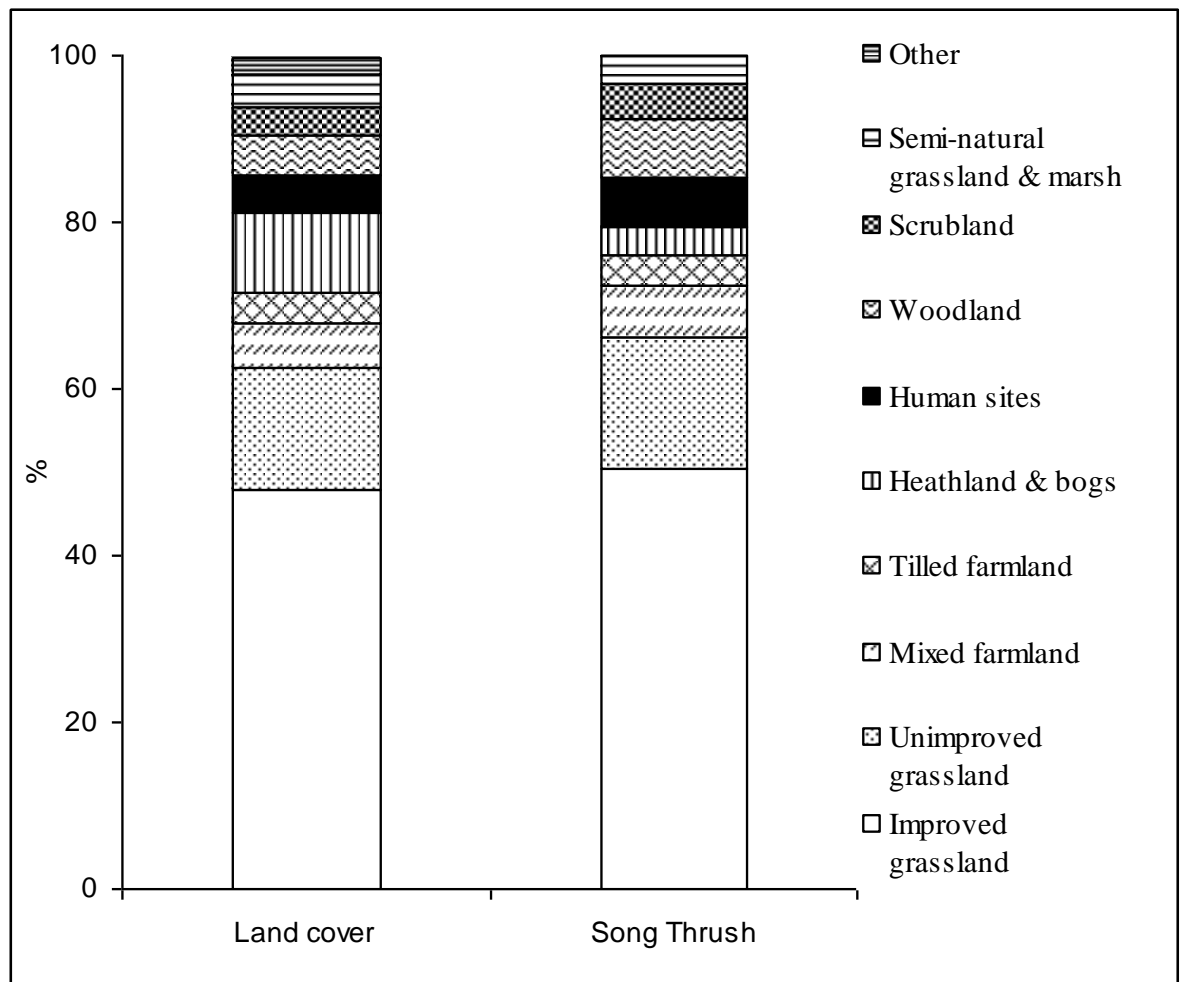


Figure 6 (a): Broad-scale habitat preferences (values shown) for Song Thrushes in Ireland, 1998-2003, according to Jacobs' index and calculated using CBS data

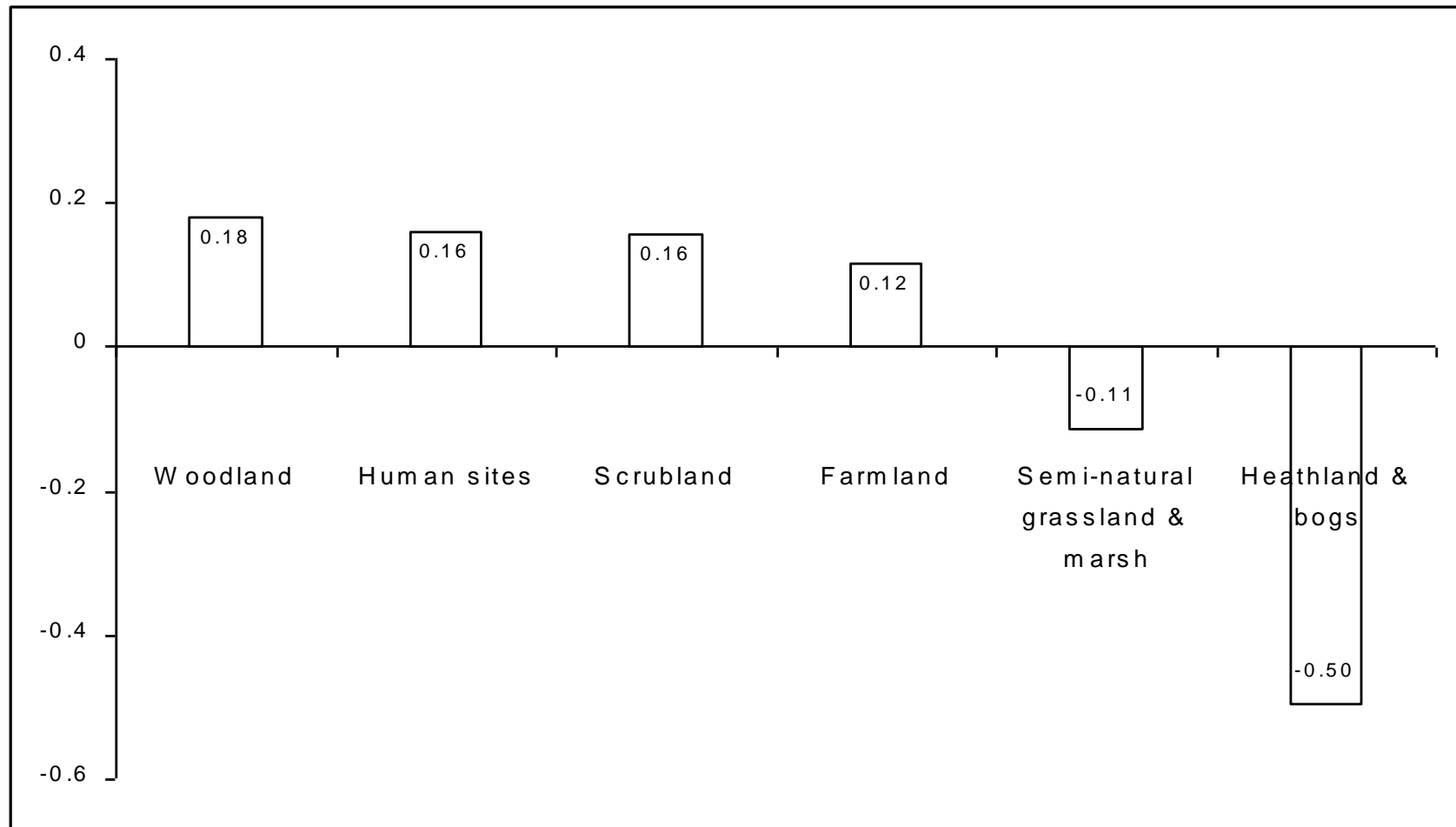
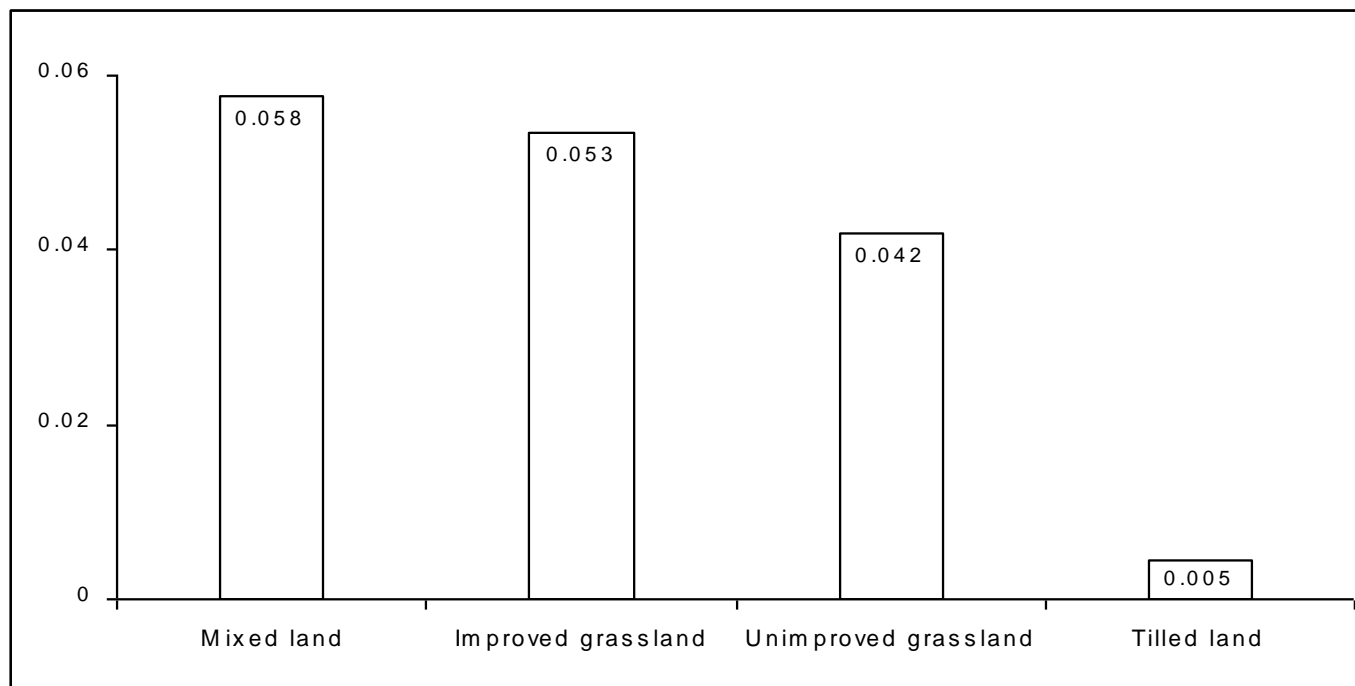


Figure 6 (b): Broad-scale farmland habitat preferences (values shown) for Song Thrushes in Ireland, 1998-2003, according to Jacobs' index and calculated using CBS data



Discussion

Changes in Breeding Atlas data of Song Thrushes in Ireland suggest a significant contraction in breeding distribution between the 1970's and 1990's. However survey effort in Ireland for Gibbons *et al.* (1993) Breeding Atlas was lower both in terms of coverage and finding breeding evidence. As Gibbons *et al.* (1993) acknowledged, this will complicate interpretation of change for breeding birds in Ireland, where areas may seemingly be in decline when they are not. Seeing as Song Thrushes were recorded in most 10-km squares across Ireland in Gibbons *et al.* (1993), this problem only exists for the apparent significant changes in breeding distribution and not overall distribution. The problem of survey effort is further highlighted by the fact that the number of surveyed tetrads was very close to being significantly higher in areas of apparent stability than decline. Given the loss of habitat during the period, as reflected by the loss of area farmed overall (Figure 4), we must acknowledge that some decline is likely but we cannot be certain as to the magnitude and must be very cautious about the degree of change suggested in the Breeding Atlases.

When we looked at overall agricultural differences and degree of agricultural change between areas of stability and decline, we found no significant differences either before or after the apparent decline in breeding population. These results could indicate that Irish agriculture has not impacted negatively on the Song Thrush

breeding population and that some other factor(s) may be driving the apparent significant decline instead.

However, this seems surprising given the widely accepted view that agriculture has impacted on farmland populations elsewhere (see Introduction), especially in light of the largest decline of Song Thrushes in Britain occurring on farmland (Thomson *et al.* 1997), and the fact that Ireland is amongst the highest agriculturally dominated landscapes in Europe (See Tucker & Dixon 1997). Of course not finding agricultural impacts on breeding Song Thrushes in Ireland, could simply be due to the low breeding survey effort experienced in Gibbons *et al.* (1993) leading to an over-exaggeration in the decline of the breeding population in the first place so that there were no significant differences in the breeding populations in areas of apparent stability and decline. However, we must also acknowledge that the limited number of agricultural variables available for analysis may underestimate potential impacts of Irish agriculture and Song Thrush breeding population. Although a recent survey (2001-2003) conducted on Song Thrush eggs and livers from southwest Ireland found little contamination by mercury and organochlorines (Chapter 4), both agrochemical-related contaminants. We also know that while agricultural intensification has continued in Ireland, a slow down has occurred during the 1990's in some aspects such as productivity and efficiency (O'Neill *et al.* 2001) and farm size increase (Lafferty *et al.* 1999). Potassium and phosphorus fertilizer consumption has declined from the mid-1980's to the mid-1990's while nitrogen increased in the same period (See Murphy *et al.* 1997). On the other hand,

percentage annual changes in livestock units have remained the same during the 1980's and 1990's (Lafferty *et al.* 1999).

Looking at the CBS data collected in 2002, we see that Song Thrushes occupied 86% of surveyed squares (Coombes 2002) which compares to 74% in the equivalent BBS survey in the UK for the same year (Raven *et al.* 2003). These differences not only highlight the differences that currently exist between the breeding populations of both countries, where the Republic of Ireland's population is more widespread, but also underlying differences in the respective landscapes. While overall changes in the CBS between 1998 and 2002 were not significantly different, changes found in squares surveyed in both periods suggested an increase of 4.6% in the distribution of the breeding population. This increase appears to have been confirmed by recent CBS population trend analysis, which has indicated a (non-significant) population increase in the Republic of Ireland from 1998-2003 (pers. comm. Olivia Crowe). Interestingly, the Song Thrush in the UK has experienced recent increases in its breeding population too (Raven *et al.* 2003; Eaton *et al.* 2004; Newton 2004).

Before we discuss our findings of habitat use and preference, we must assess how our calculations of the various broad-scale habitats within the Irish landscape (derived from CBS habitat data) compare with other Irish habitat studies. While comparison with other habitat studies can be difficult due to differences in habitat classification, especially with farmland, we were able to make some approximate comparisons. Smal (1995) found the following percentage habitat proportions in the

Irish landscape: peat & moorland (equivalent to heathland & bog in CBS) 15.8, built land (equivalent to human sites in CBS) 3.7, woodland 5.8 and scrub 2.5 (equivalent to scrubland in CBS). These compare to our respective percentage findings of 9.6, 4.3, 4.9 and 3.2 where heathland & bogs differ the most between both surveys. Farmland habitats are more difficult to assess but Smal (1995) found percentage grassland as 59.7 and arable as 7.5 compared to our findings of 62.5 and 3.8 respectively, although we also had 5.4% mixed land that we could not distinguish between grass and tillage. Within agriculture, the CSO (2003) calculated grassland (i.e. silage, hay, pasture & rough grazing) as 90.3% and arable as 9.7% in 2002, which compare to 87.1% and 5.2% respectively with our calculations, where again mixed land (7.5%) could not be differentiated into either category. Overall our calculated habitat proportions, as derived from the CBS habitat survey, appear to be quite similar with other Irish habitat statistics.

When we assessed habitat use, we found that the Song Thrush breeding population heavily used farmland habitats (more than 70%). However, when we assessed broad-scale habitat preference, the dominant impact of farmland decreased with woodland, human sites and scrubland dominating instead, although the interaction between farmland and Song Thrushes remained favourable. Within farmland habitat, mixed land had the most positive interaction with breeding Song Thrushes, being the most preferred habitat on Jacobs' index despite the little impact that this habitat type has on the Irish landscape. Improved grassland was the second most preferred farmland followed by unimproved grassland with tilled land as the least

preferred farmland habitat. While the preference index values for these farmland habitats are generally low, no farmland habitat was avoided, highlighting the generally positive interaction between breeding Song Thrushes and Irish agriculture. It also raises questions on the quality of the breeding distribution data collected by Gibbons *et al.* (1993), as recent agricultural intensification has obviously had little impact on breeding Song Thrushes as evident by their positive interaction with agriculture and slight increase in breeding population between 1998 and 2002. We also know that in Ireland, Song Thrush clutch size (significantly) and nest survival (non-significantly) are higher on farmland (4.5; 38%) than woodland (4.0; 19%) or garden & parkland (4.0; 16%) habitats (Chapter 3), again emphasizing the positive interaction between Irish farmland and breeding Song Thrushes.

Our farmland habitat preference findings are in contrast to a similar study by Gregory and Baillie (1998) who used BBS data collected in Britain in 1995. In general they found a negative interaction between breeding Song Thrushes and British farmland habitats, where all four farmland habitats were avoided (as calculated by Jacobs' index). While both studies have opposing indices, both show the same trend of tilled land having the most negative interaction on breeding Song Thrushes, a trend also found by other studies (*e.g.* Mason 1998 and 2000, Peach *et al.* 2004b). Interestingly, our calculated values of Jacob's index for the other broad-scale habitats show similar trends to that of Gregory & Baillie (1998) with woodland, human sites and scrubland showing their importance for breeding Song Thrushes and semi-natural grassland & marsh and heathland & bogs showing their

non-importance. However the differences in farmland habitats between both studies highlight that differences currently lie in the interactions between Irish and British agriculture and breeding Song Thrushes, where farmland habitats in Ireland have a more positive relationship with breeding Song Thrushes than in Britain.

Gregory and Baillie's study (1998) also highlight differences in overall habitat structure between the British and Irish landscapes and overall Song Thrush use across the different habitats (Table 1). Both studies found that farmland dominated their respective landscapes but the Irish landscape has approximately 1.5 times more farmland than the British landscape. While the proportion of mixed farmland habitat is slightly higher in Ireland, tillage is more dominant in the British environment (more than four times Ireland) while grassland is more dominant in Ireland (more than twice Britain). These differences are also reflected in Song Thrush habitat use (Table 2), where 76% of breeding Song Thrushes in Ireland use the four main farmland habitats compared to 36% in Britain. Again, it is no surprise that similar trends are found within farmland habitats as found for overall landscapes, with more Song Thrushes using grassland in Ireland than Britain and more using tillage in Britain than Ireland.

Song Thrush densities calculated for farmland habitats in this study (Table 3) are quite similar to other Irish farmland based studies, where Lysaght (1989) calculated densities in 1987 as 16 birds/km², Alex Copland & John O'Halloran (pers. comm.) found that densities ranged 14-19 birds/km² in 2003-2004, and in 1992 Moles &

Breen (1995) found densities in Northern Ireland to be approximately 21 birds/km². Britain and Ireland also differ in the estimated densities of breeding Song Thrushes (per km²) across different habitats where densities in Ireland are higher overall (Table 3), a trend noted for other bird species between Ireland and Britain (Lysaght 1989 and Holt 1996). While the island effect or ‘Insular Syndrome’ (Blondel 2000) may explain higher bird population densities in Ireland over Britain, we must also remember that an overall population decline of 52% is known to have occurred in Britain (Eaton *et al.* 2004) with a 65% decline on farmland (Thomson *et al.* 1997) and that the current reported densities in Britain are therefore representative of approximately 48% (or 35% for farmland) of the Song Thrush breeding densities before the major population decline in Britain. Thus the current densities calculated by this study for Song Thrushes in Ireland further support the view that a small decline in Song Thrush breeding population occurred in Ireland and not of the magnitude suggested by Gibbons *et al.* (1993).

Other studies in Britain have highlighted the importance of woodland edge, gardens, field boundaries and grassland for breeding Song Thrushes and the negative interaction with arable (Mason 1998; Mason 2000; Peach *et al.* 2004a and 2004b). This study also highlights the importance of woodland, human associated habitats (including gardens) and scrubland for breeding Song Thrushes here, despite the poor representation of these habitats within the Irish landscape. In fact our finding with woodland is consistent with Pithon *et al.* (2005) who found that Song Thrushes in Ireland were more abundant on farmland close to forest edges than that more remote

from forest edges during the summer season (*i.e.* breeding season). Ireland has been noted for its dense and complex network of field boundaries in comparison to Britain, especially lowland England (Lysaght 1989; Moles & Breen 1995; Aalen *et al.* 1997), where the lower level of agricultural intensification experienced here (Cabot 1985; Lysaght 1989; Stanners & Bourdeau 1995; Aalen *et al.* 1997) has resulted in lower field boundary loss, smaller fields and farm holdings than Britain (Webb 1988; Moles & Breen 1995; Stanners & Bourdeau 1995; Aalen *et al.* 1997). Therefore differences in agricultural intensification between Ireland and Britain may explain to some degree the differences that currently exist in the interaction of the breeding Song Thrush population and farmland habitats between both countries. In fact the influence of agricultural intensification on bird stability and decline has been highlighted by Fox (2004) who implicated that differences in agricultural intensification between Denmark and the UK explained the stability and/or increase of certain farmland bird species in Denmark that declined in the UK during the same time period.

Grassland dominates the Irish landscape with 80% of agriculture devoted to grass (*i.e.* pasture, silage and hay) (CSO 2003). Although the importance of grassland has been highlighted for breeding Song Thrushes in Britain, Peach *et al.* (2004b) also acknowledge that Song Thrush densities declined in grass-dominated areas (greater than 40% grass) of arable-dominated counties in eastern England. They feel that this represents a genuine avoidance, as the same decline was not found in the grass-dominated landscapes in western England. This highlights that grassland suitability

for breeding Song Thrushes can differ and Peach *et al.* (2004b) recognise that this merits further investigation. In this study we have shown a positive interaction between breeding Song Thrushes and Irish grass-dominated landscape, suggesting its suitability for the species, which may be similar to the suitability found in the pastoral areas of western England.

In conclusion, this study highlighted the positive interaction between breeding Song Thrushes and Irish agriculture, which is in stark contrast to the situation in Britain. This difference is probably explained by differences in agricultural intensification and overall habitat structure of the Irish landscape coupled with other factors not discussed here such as the milder and wetter climate. This study also emphasizes the unreliability in breeding population distribution data found for Ireland in Gibbons *et al.* (1993), where over exaggeration of contraction seems highly likely. Currently the Song Thrush breeding population in Ireland appears quite stable, with even some increase, and given its positive interaction with Irish agriculture, which still dominates the landscape, the immediate future looks good. However, long-term consequences for Irish agriculture, and subsequently the Irish landscape, by recent CAP reforms along with changes in the socio-economics of the Irish farming sector (Binfield *et al.* 2001; Commins 2001; Donnellan & Fingleton 2001; Leavy 2001) remain to be seen with a suggestion that farm policies post 2000 will create a wider divide in Ireland between the more intensively productive farming areas and less intensive areas (Lafferty *et al.* 1999).

Table 1: Percentage frequency of major broad-scale habitats in Ireland (this study) and Britain (Gregory and Baillie 1998) according to the CBS and BBS surveys respectively.

Habitat	Ireland	Britain
Farmland	71.8	46.4
<i>Improved grassland</i>	47.8	19.0
<i>Unimproved grassland</i>	14.7	7.2
<i>Tilled land</i>	3.8	16.8
<i>Mixed land</i>	5.4	3.4
Woodland	4.9	11.8
Human sites	4.3	10.2
Srubland	3.2	3.1
Semi-natural grassland & marsh	4.1	6.6

Table 2: Percentage frequency of the Song Thrush breeding population using major broad-scale habitats in Ireland (this study) and Britain (Gregory and Baillie 1998) according to the CBS and BBS respectively.

Habitat	Ireland	Britain
Farmland	76.1	35.8
<i>Improved grassland</i>	50.5	16.7
<i>Unimproved grassland</i>	15.8	5.6
<i>Tilled land</i>	3.8	11.4
<i>Mixed land</i>	6.0	2.1
Woodland	6.9	19.3
Human sites	5.9	23.7
Scrubland	4.3	4.9
Semi-natural grassland & marsh	3.3	3.4

Table 3: Broad-scale habitat specific density estimates for breeding Song Thrushes (per km²) in Ireland (1998-2003) and Britain according to CBS and BBS data respectively. Bootstrapped 95% confidence intervals are in parentheses.

Habitat	Ireland (This study)	Britain (Gregory & Baillie 1998)	Britain (Newson <i>et. al.</i> 2005)
Farmland:			
<i>Improved grassland</i>	17.9 (16.9-18.9)	4.7	4.9
<i>Unimproved grassland</i>	18.2 (16.7-20.2)	4.5	3.4
<i>Tilled land</i>	17.1 (14.0-21.1)	3.6	2.8
<i>Mixed land</i>	18.9 (16.1-22.4)	3.4	7.2
Woodland	23.9 (21.0-27.4)	6.1-10.6	5.9-11.9
Human sites	23.0 (19.1-26.7)	9.6-15.7	6.6-14.6
Scrubland	23.0 (18.9-27.2)	8.6	7.1
Semi-natural grassland & marsh	13.6 (11.0-16.6)	2.7	1.1-3.4

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Chapter 7: Concluding Remarks



Status of the Song Thrush in Ireland

At the onset of this study, there was a degree of uncertainty about the status of the Song Thrush here despite the fact that it is not classified as a species of conservation concern (Newton *et al.* 1999). Of course, the concern for Song Thrushes here was prompted by declines elsewhere in Europe during 1970-1990, especially Britain where the population suffered most on farmland (Tucker & Heath 1994, Thomson *et al.* 1997, Eaton *et al.* 2004). While long-term population trends are unclear in Ireland, due to the lack of long-term bird data, there were some suggestions that breeding population had declined and breeding distribution had contracted during 1970-1990 (Sharrock 1976, Gibbons *et al.* 1993, Tucker & Heath 1994). Since 1998, the Countryside Bird Survey (CBS) has suggested that the current breeding population is widely distributed and stable in the Republic of Ireland (Coombes 2003), but this only tells us about distribution and not abundance per se.

In this study, we saw that the amount of agricultural land in this country significantly decreased during 1970-1990 (Chapter 6), which undoubtedly involved habitat loss for Song Thrushes, suggesting that some population decline was inevitable during this period. This study also highlighted the problem of lower survey effort in Ireland for Gibbons *et al.* (1993) Breeding Atlas, thus implying that the magnitude of contraction (11.8%) in breeding population range suggested by Gibbons *et al.* (1993) is exaggerated to some unknown degree (Chapter 6).

Song Thrush breeding densities (per km²) calculated by this study for different broad-scale-habitat types are in stark contrast to those of Britain (Chapter 6). While the higher densities found here in comparison to Britain may be explained by insular syndrome, it must be remembered that the current British densities are the result of a large decline, and therefore insular syndrome is unlikely to completely account for these higher Irish densities. Taking these factors into account, it thus seems plausible that the densities calculated by this study for Ireland are not indicative of a population that has experienced a large decline since the 1970s. On the contrary, the densities calculated here suggest that Song Thrush population decline in Ireland has been small, which is in agreement with our findings of a smaller contraction in breeding population distribution than indicated by Gibbons *et al.* (1993) Breeding Atlas and the current suggestion of a widespread and stable breeding population by the CBS since 1998 (Chapter 6, Coombes 2003).

Breeding characteristics: influence of latitude, longitude and insular syndrome

This study not only reported the basic breeding variables for Song Thrushes here (clutch size, daily survival rates *etc.*), but also allowed us to examine possible influences by latitude, longitude and ‘insular syndrome’ (Chapter 2). We showed that clutch sizes here exhibit both latitudinal and longitudinal effects (larger in northern latitudes; larger in eastern Europe respectively) as described by Lack (1947) (Chapter 2). We also found that Song Thrush breeding characteristics here conform to some, but not all, ‘insular syndrome’ traits (Blondel 2000) as found with other Irish passerine studies (Smiddy *et al.* 1995, Smiddy & O’Halloran 1998,

Fennessy 2001, Cummins & O'Halloran 2003) (Chapter 2). One of these conformities includes the relatively high breeding population densities found here (Chapter 6), as already discussed above, and follow a similar trend for other passerine species in Ireland in comparison to the same species in Britain (*e.g.* Lysaght 1989, Holt 1996, Fennessy 2001). The higher breeding densities found here may also have an implication on territory size, where Song Thrush territories here are likely to be smaller than those in Britain, as found by Fennessy (2001) for Robins (*Erithacus rubecula* L.) in Ireland.

Habitat

Before this study, very little data on the relationship between Song Thrushes and Irish habitat were available (*e.g.* Moles & Breen 1995) and no Song Thrush habitat-specific Irish studies were known. However, the importance of farmland, field boundaries, woodland, scrub, dense vegetation and human habitats for Song Thrushes, especially breeding Song Thrushes, was known from British based studies (*e.g.* Gregory & Baillie 1998, Mason 1998, Gruar *et al.* 2003, Murray 2004, Peach *et al.* 2004). This study highlighted the importance of several habitat characteristics for Song Thrush populations here (Chapters 3, 5, 6), which may be beneficial in drawing up conservation measures elsewhere, especially in areas of decline.

The presence of dense vegetation proved to be especially important for breeding Song Thrushes here in respect of nesting requirements, breeding output and daily nest failure rates (Chapter 3). In addition, dense vegetation was an importance

predictor for the presence of breeding Song Thrushes on Irish farmland boundaries (Chapter 5). Ditches with tall vegetation, especially wet ones, were also found to have an important influence on the presence of Song Thrushes during the breeding season here (Chapter 5). During the winter, ditches, whether wet or dry, continued to be important for Song Thrushes along with low thin vegetation and berry bearing species (Chapter 5).

Even though farmland is the most heavily used (broad-scale) habitat by breeding Song Thrushes here, woodland, human sites and scrubland are more preferred (respectively) while semi-natural grassland & marsh and heathland & bogs are avoided (Chapter 6). This study also highlights that no Irish farmland habitat is avoided by breeding Song Thrushes, in stark contrast to Britain where all are avoided, with mixed farmland being the most preferred farmland habitat here followed by improved grassland, unimproved grassland and tilled land respectively (Chapter 6). The least preference for tilled land here follows similar trends of avoidance for breeding Song Thrushes in Britain (Gregory & Baillie 1998, Mason 1998, Murray 2004, Peach *et al.* 2004). We also see that Ireland has a higher proportion of grassland in its landscape in comparison to Britain (Chapter 6), which may provide more foraging opportunities for Song Thrushes in Ireland, as grassland is known to be an important foraging habitat for both breeding and wintering Song Thrushes (Peach *et al.* 2002, Peach *et al.* 2004).

Contaminants

Pesticides remain possible candidates in the decline of the Song Thrush in Britain (Robinson *et al.* 2004). This study found mercury and organochlorine contamination in Song Thrush eggs and livers, but the levels and frequency of contamination found were low and believed to be of no apparent biological or ecological concern (Chapter 3). Nevertheless, the data do provide a baseline for mercury and organochlorine contamination levels in the Irish terrestrial environment, which can be used in future monitoring studies (Chapter 4).

Predation

Even though Ireland has a lower diversity of predator species in comparison to Britain or mainland Europe, predation levels found in this study were broadly similar to other studies (Chapter 2). We know that some Irish bird populations are known to have relatively higher densities in comparison to other countries (Chapter 6, Lysaght 1989, Holt 1996, Fennessy 2001) and it may be the case that predator populations are also in relatively high numbers, thereby accounting for the similar predation levels with other studies. Unfortunately predator identity was beyond the scope of this study, but we were able to show that avian predation of Song Thrush nests is more prominent than mammalian predation.

Agricultural intensification in Ireland: relatively lower rate & scale

This study showed that a suite of agricultural variables (area farmed, livestock numbers and area under crop type) significantly changed in Ireland during 1970-

1990, with particular intensification in livestock numbers and area under hay & silage (Chapter 6). Yet these same variables did not significantly differ between areas of apparent stability and decline in Song Thrush breeding range (according to Breeding Atlas data) (Chapter 6). It is worth noting that univariate analyses of the same agricultural data showed that cattle numbers between areas of Song Thrush breeding stability and decline approached significance (areas of stability having higher numbers), suggesting that a positive influence of cattle grazing on breeding Song Thrushes may operate at a lower scale. This study also shows that the current breeding population in Ireland has a reasonably positive relationship with Irish agriculture, as evident by its preference for all farmland habitats here (Chapter 6) and having (significantly) higher clutch sizes and (non significantly) higher nest success rate on farmland than either garden & parkland or woodland (Chapter 3). In addition, these signs of a positive relationship between Irish agriculture and breeding Song Thrushes are occurring at a time when Irish agriculture is at its most intensified state. Therefore it would appear that the relatively lower rate and scale of agricultural intensification in this country since the 1970s, in comparison to other western European countries (Cabot 1985, Lysaght 1989, Stanners & Bourdeau 1995, Aalen *et al.* 1997), has had a positive effect on Song Thrush populations in Ireland.

Irish climate

Faster drying soils have been highlighted as an important limiting factor in the availability of key prey (*i.e.* earthworms) for breeding Song Thrushes in an English

based study with particular implications on nesting attempts in a declining population (Gruar *et al.* 2003, Peach *et al.* 2004). In comparison to England, the Irish climate is milder and wetter with up to 20% higher annual rainfall here than in the open lowlands of England (Keane 1986, Bowen 1973, Chandler & Gregory 1976, Hulme & Barrow 1997). Apart from suggesting that the Irish climate provides better foraging opportunities for Song Thrushes here, it may also have positive implications on over winter survival for Song Thrushes here, since winter frosts are known to negatively affect Song Thrush survival (Baillie 1990, Thomson *et al.* 1997, Robinson *et al.* 2004). Of course this in turn may have further implications on breeding productivity, where fewer resident individuals, that belong to a species limited by over-winter survival such as the Song Thrush, surviving the winter in a ‘seasonal’ environment may have greater resources available during the following breeding season resulting in higher breeding productivity (O’Connor 1986). If we use Britain as an example of a ‘seasonal’ environment and Ireland as an example of an ‘aseasonal’ environment, then we would expect lower breeding productivity in Ireland, which is what this study found (Chapter 2). Thus it appears that the Irish climate is beneficial to Song Thrush populations here and combined with the relatively lower degree of agricultural intensification, allows for good foraging and nesting opportunities to exist for Song Thrushes in the Irish landscape.

In conclusion

This is the first detailed study of the ecology of the Song Thrush in Ireland. The findings from this study provide many answers to the gaps that previously existed in

our knowledge and understanding of Song Thrush interactions with the Irish environment. Knowing that the current population in Ireland is widespread and stable, gives added importance to these findings, as their insight into the relationship between Song Thrushes and the Irish environment can be applied to conservation measures elsewhere that aim to maintain or restore declining populations. While this study answers many questions on the ecological interaction of Song Thrushes with the Irish landscape, it also leaves others unanswered that should be directed into future research including, territory sizes, overwinter survival, diet, dispersal, migration and predator identity. While the current Song Thrush population in Ireland is healthy in respect of stability, distribution and abundance, we must await the outcome of current agricultural reforms in conjunction with changes in the socio-economics of the Irish farming sector (Lafferty *et al.* 1999, Binfield *et al.* 2001, Commins 2001, Donnellan & Fingleton 2001, Leavy 2001) to assess any potential long-term changes in Irish farming and consequently the Irish landscape. The same can be said for possible changes in our landscape due to climate change, with indications of drier summers and wetter winters (Sweeney & Fealy 2002), where the former would have implications on foraging opportunities for breeding Song Thrushes and other insectivores. Monitoring such changes is vital, not just for the Song Thrush but for Irish wildlife as a whole.

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