CONFIDENTIAL

REPORT SERIES:
VPU/19/011

VERTEBRATE PESTS UNIT
UNIVERSITY OF READING

The breeding performance of Barn Owl populations in five regions of the United Kingdom – 2018 Data Set.

Test Facility
The Vertebrate Pests Unit
School of Biological Sciences
The University of Reading
Whiteknights
Reading RG6 6AJ, UK

Sponsor
Campaign for Responsible Rodenticide UK
Crown House
85-89 St George's Road,
Leeds LS1 3BR, UK

Authors:

Dr C.V. Prescott

Dr A.P. Buckle

Mr C.R. Shawyer

Date: 10th October 2019

DISTRIBUTION:

University of Reading

Professor Robert Jackson – Head of School
Dr C.V. Prescott – Associate Professor; Director, Vertebrate Pests Unit

1. Introduction

1.1 General

The Barn Owl Monitoring Scheme (BOMS) is one of the surveillance projects being carried out, within the UK Rodenticide Stewardship Regime, by the Campaign for Responsible Rodenticide Use (CRRU) UK.

The barn owl (*Tyto alba*) is a charismatic and iconic species of Britain's agricultural landscape that typically hunts rough grassland on open farmland, where meadows, field margins and woodland edge habitats provide high densities of their small mammal prey (Shawyer 1987, Toms, 2014). The most frequently taken prey items in mainland Britain are field vole (*Microtus agrestis*) and wood mouse (*Apodemus sylvaticus*), whilst bank vole (*Myodes glareolus*), common shrew (*Sorex araneus*) and pygmy shrew (*Sorex minutus*) assume secondary importance in the diet. Both UK commensal species, Norway rat (*Rattus norvegicus*) and house mouse (*Mus musculus*), are also taken (Love et al., 2000; Martin, 2008) but usually contribute less than 1% of the diet of barn owls (Love et al., 2000).

1.2 A Fluctuating UK Barn Owl population

In the 18th century, barn owls were regarded as the most common species of owl over much of the country; where traditional low intensity agricultural practice, together with high reliance on livestock, provided prey-rich habitat for barn owls (Shawyer, 1987). However, a decline in the numbers of this bird was evident by the early 1900's following advances in agricultural practice (Blaker, 1933; Shawyer, 1987, Toms, 2014).

The most recent organised national survey of the barn owl breeding population conducted across the UK was undertaken between 1995 and 1997, and provided a national estimate of c. 4,000 breeding pairs, using a standardised survey design (Toms et al., 2001). Over subsequent years, considerable conservation effort has been targeted at Britain's barn owl population, and expert groups and organisations have reported UK population estimates of c. 9,000 breeding pairs in 2011 (Shawyer, 2015[a]) and 2014 (Shawyer, 2014). The breeding population is currently estimated at between 9,000 and 12,000 pairs and considered close to the upper end of this range (Shawyer, 2019).

The increase in the barn owl population over the last 21 years has been acknowledged by 'The state of the UK's birds 2016' Report, by downgrading it from the 'Amber List' in 2015 to the 'Green List' in 2016 (Eaton et al., 2015). This Report considers the status of UK breeding and non-breeding birds in the UK, taking into consideration the results from annual, periodic and one-off surveys and monitoring studies, such as those conducted by the BTO, which have reported a 217% increase in population size between 1995 and 2015 (Hayhow et al., 2017).

Two extreme years for barn owls were the breeding seasons of 2013 and 2014. The month of March 2013 was the coldest reported since 1962 and, during that month, numbers of dead barn owls reported to the BTO's ringing scheme were about three times above normal. With nest occupancy estimated to be below 72% of the 'all-years' average, 2013 was considered to be one of the worst barn owl breeding seasons since 1958 (Shawyer, 2015[b]).

The mild winter of 2013-14 was followed by an early spring and one of the warmest summers on record. Subsequently, 2014 became a peak year for small mammals, and in spite of the low

breeding productivity during the summer of 2013 and higher than average barn owl mortality in the winter of 2013and 2014, both nest occupancy and breeding productivity in many areas was especially high in 2014 (Shawyer, 2015[a]; Barn Owl Trust, 2016). The estimated 9,000 pairs that attempted to breed in 2014, with most traditionally-used nests sites occupied by breeding birds, provided a reliable UK population estimate for the species at that time (Shawyer, 2014).

With such marked annual fluctuations in the barn owl breeding population, nest occupancy and productivity data in any one year are unlikely to provide an accurate reflection of the actual barn owl breeding population. The most recent surveys now use a standardised methodology that is conducted over several consecutive years, using the most productive years to estimate population size.

Overall, 2015 was a poor breeding season for barn owls in the UK, although not as bad as that of 2013 (Shawyer, 2015[b]); while 2016 and 2017 were a better breeding seasons, primarily as a result of repeat and second nesting attempts, following in both years a highly productive June and July (Shawyer, 2017; Shawyer, 2018[b]).

Examination of the breeding range of the barn owl shows that, in the UK, the species is at the northernmost limit of its geographical distribution (Hagemeijer and Blair, 1997). Indeed, even within the UK, differences have been reported in their abundance from the lowland south to the highlands of the north (Balmer et al., 2013). It is therefore unsurprising that, together with prey abundance, weather conditions, in particular climatic extremes, can exert a significant effect on the breeding performance of barn owls in the UK (Shawyer, 1987; Toms, 2014, Barn Owl Trust, 2019).

1.3 The Barn Owl as a sentinel species

Like many other species of vertebrate wildlife in the UK, the barn owl is exposed to second-generation anticoagulant rodenticides (SGARs) (Shore et al., 2014). The barn owl has been identified by the Health and Safety Executive (HSE) as a sentinel species for other species that are generalist predators of small mammals in rural areas and that are also exposed to SGARs (HSE, 2017). The barn owl is an ideal species for monitoring breeding performance, being one of the most frequently monitored species by the British Trust for Ornithology's Barn Owl Monitoring Programme (BOMP – 2000 to 2009) and Nest Record Scheme.

The number of Nest Record reports for barn owl submitted to the BTO were:

- In 2014, 2,766 records submitted, a number only exceeded by blue tit and great tit
- In 2015 and 2016, 1,791 and 2,332 records submitted respectively, numbers only exceeded by blue tit, great tit, swallow and tree sparrow
- In 2017 and 2018, 3,027 and 2,402 records submitted respectively, numbers only exceeded by blue tit and great tit

Since the mid 1990's, and following major improvements in habitat quality, barn owl nest site availability would appear to have become the main limiting factor for the species and their willingness to occupy artificial nest sites has increased the number of birds monitored by the Nest Record Scheme (Shawyer, pers. comm.). In addition, these artificial nest sites appear to be having a positive effect on the national population and by 2006 were believed to be contributing more than 70% of all known breeding sites for this species in the UK (Shawyer 2006).

1.4 Objectives of the study

One of the important CRRU monitoring projects for rodenticide stewardship, conducted by the Centre for Ecology & Hydrology (CEH), is the monitoring of SGAR residues in the livers of 100 barn owls each year, in an attempt to quantify exposure in free-living birds (Shore et al., 2016, 2017, 2018). However, reports of these data do not provide contextual information on the status and breeding success of the UK barn owl population that carries them. Therefore, it is the purpose of the CRRU UK Barn Owl Monitoring Study (BOMS) to bridge this gap by monitoring various breeding parameters in a representative sample of barn owl populations across the UK. To this end, CRRU commissioned the Wildlife Conservation Partnership (WCP) to conduct this work. The output from the WCP is an "Annual Data Set", giving barn owl nest monitoring data for the preceding season.

The BOMS provides annual data on key breeding parameters for selected barn owl populations. CRRU has received and analysed the annual BOMS data sets for 2015, 2016, 2017 and 2018, together with similar available data provided by WCP from the same nest sites, from 2011 to 2014. This report comprises an analysis of the 2018 breeding data and a comparison with equivalent data from seven previous breeding seasons. In addition, the BOMS field operators monitor fledgling and adult birds for any unusual growth characteristics that could potentially be attributed to anticoagulant residues (Shawyer, 1985).

2. Methodology Overview

The main aim of the BOMS is to examine a substantial core sample of barn owl nests and broods across five regions of the UK, in order to investigate various breeding performance parameters year on year. The same set of core sites is being monitored annually throughout the course of this project, which was initially of three years duration. The examination of breeding adults, eggs and chicks undertaken during nest monitoring, will also provide information on possible sub-lethal effects of low-level SGAR liver residue levels on chick development and barn owl breeding that might be visible on external examination (e.g. see Toms, 2014; pg 236 and Naim et al., 2010).

Data collection at each nest site was based largely on methods successfully developed and validated for the BTO's 10-year Barn Owl Monitoring Programme (Crick et al., 2001). The field research for the BTO project involved inspection of nests by Wildlife Conservation Partnership (WCP), BTO and Barn Owl Conservation Network (BOCN) nest recorders, under Natural England Disturbance Licences, primarily to determine nest occupancy levels, clutch size and brood size. For the purpose of the BTO project and that of the BOMS, brood size at ringing is considered equivalent to fledging success.

For the BOMS, brood size was recorded at successful nests and where nests were not visited at the egg stage, clutch size was estimated from the number of chicks and the age intervals between them. Chick ages were determined by wing development, either by wing cord for chicks under 13 days of age or the length of the developing 7th primary feather for older chicks (Shawyer, 1998). The hatch date was derived from the age of the oldest chick and the first successful egg date determined by adding the 30-day incubation period.

The biometric measurements of young birds caught at the nest included sexing, measurement of wing development (to age and determine first egg date) and body weight (to establish body condition and growth patterns). Adult birds were treated in a similar way but were aged from their wing moult pattern, from the length of moulted primary and secondary wing feathers found at nests (Shawyer, 1998), or for those owls which were already ringed as chicks, the year in which ringing had occurred. Both young and new adult birds were ringed.

All birds handled, and eggs found in the nest, were screened for any unusual development characteristics and physiological deformities that were externally visible. The main factors screened were, for eggs; size, structural integrity and the smoothness of the shell surface; and for the barn owls, feather structure and the occurrence of unusual growths; although it is acknowledged that any of these abnormalities are rarely observed in this species.

Each nest under observation was visited on at least one occasion, and in order to collect the necessary nest data for BOMS, the visit was optimally timed to occur when chicks were between 3 and 9 weeks of age. In this study no attempt was made to record second broods, which can occasionally occur, typically in years when field vole abundance is particularly high in late winter and early spring and when first clutches are laid earlier than usual (Jackson, 2017).

For nests that were unsuccessful at producing fledged birds, it was usually possible to distinguish between nest sites where a barn owl breeding attempt had failed (presence of deserted eggs or dead young), and nest sites that had not been used by barn owls in that season.

Key Performance Indicators for each of the proposed survey areas of the BOMS are:

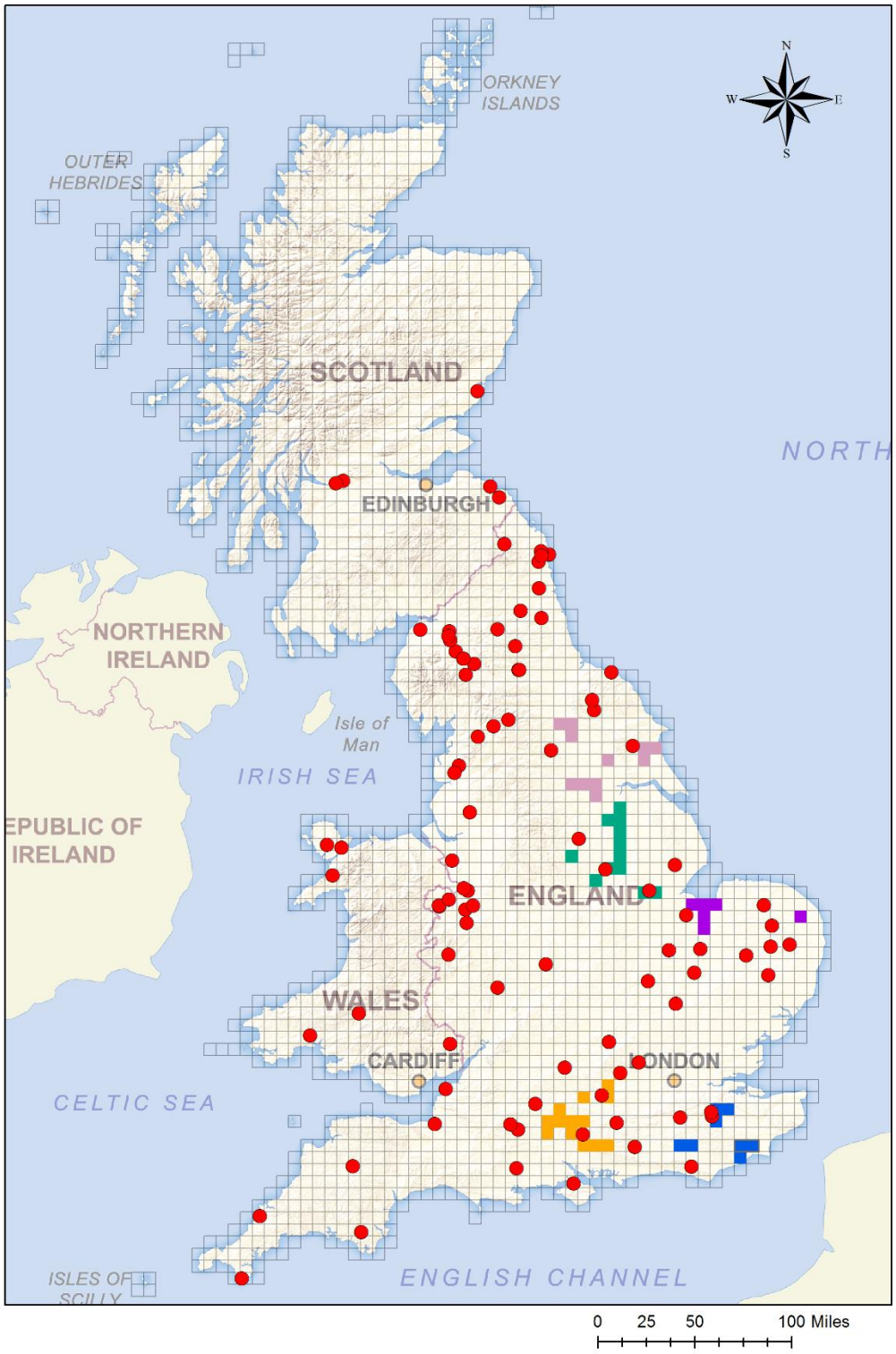
- Nest occupancy data
- Nest Productivity (mean number of chicks fledged) for successful nests
- Individual records of any chicks and eggs which show abnormal development

The survey area for the BOMS comprises the following five areas, surveying a total of approximately 130 nests (Figure 1):

Region 1 – (N) SE Yorkshire, Mid/West Yorkshire and SW Yorkshire (25 nests)
Region 2 – (E) East and West Norfolk (25 nests)
Region 3 – (C) Berkshire, South Hampshire, North Hampshire, South Wiltshire and North Wiltshire
(25 nests)
Region 4 – (SE) Kent (25 nests)
Region 5 – (Midlands) Nottinghamshire, South Lincolnshire and Cambridgeshire (30 nests).

Details of the habitat surrounding monitored nests where foraging occurs is given for the first time in this report. Habitat recording followed the standardised methods developed by the British Trust for Ornithology (BTO) for their ringing and nest recording schemes.

Figure 1. A map of England showing the locations of the 10 kilometre squares in each of the five Regions containing the barn owl nest sites surveyed in 2018. The location of the barn owls obtained by CEH for the CRRU liver residue analysis survey in the same year are also presented (red circles). [We gratefully acknowledge the kind co-operation of CEH for the provision of the latter information.]



[Region1 (N) = pink; Region 2 (E) = purple; Region 3 (C) = yellow;

3. Results

3.1 The 2018 Data Set

Of the 130 barn owl nests monitored in 2018, a total of 122 young birds fledged from 45 nests. In addition there was evidence of 11 barn owl pairs that had produced eggs and then subsequently failed, and 3 pairs where breeding had not been attempted (giving an overall nest occupancy of 45.4%). In addition, there were adult singletons present at a further 10 nests. The overall mean productivity for the successful nests was 2.71 fledged birds, with mean productivities for the five Regions ranging between 2.00 and 2.91 (Table 1).

Table 1 Barn owl nest occupancy in 2018, indicating the number of nests monitored and the number of young birds that fledged.

2018	Region 1 (N)	Region 2 (E)	Region 3 (C)	Region 4 (SE)	Region 5 (Midlands)	Total
Total number of nests monitored	22	23	24	22	30	121
Nest site occupancy by adult pairs	5	1	13	12	17	48
Nests that produced fledgling birds	5	1	11	11	17	45
Total number of birds fledged	10	2	29	32	49	122
Mean productivity per successful nest	**2.00**	**2.00**	**2.64**	**2.91**	**2.88**	**2.71**

Region 5 (Midlands), Region 4 (SE) and Region 3 (C) produced the largest number of fledglings, with 49, 32 and 29 fledged chicks from 17, 11 and 11 nest sites respectively (Table 1).

3.2 Comparison of the 2018 data with available data from 2011 to 2017

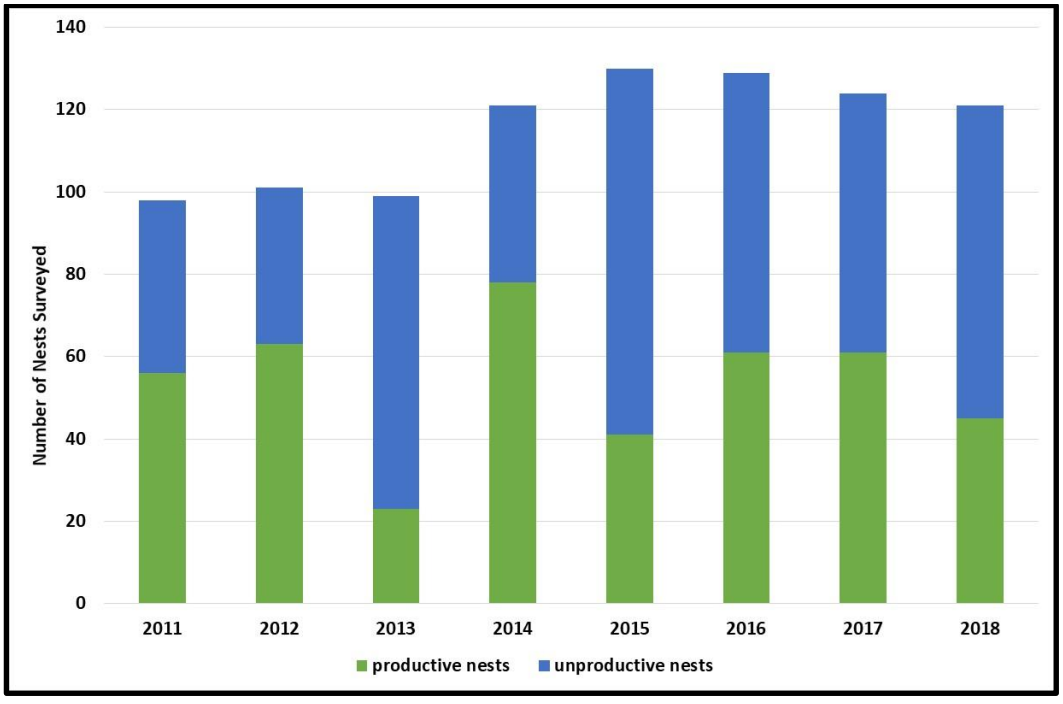
Of the 130 barn owl nest sites surveyed in 2015, 129 nest sites, 124 nest sites and 121 nest sites were monitored by WCP in 2016, 2017 and 2018 respectively; and between 98 and 121 sites were monitored by WCP each year between 2011 and 2014 (Table 2; Figure 2). The proportion of nests that were productive and produced fledged young was highest in 2014 (where 64.5% of nests produced a total of 336 fledged birds) and lowest in 2013 (where 23.2% of nests produced a total of 83 fledged birds), which corresponds well with the barn owl productivity assessments of the BOCN (Shawyer, 2015[a]; Shawyer, 2015[b]) and the Barn Owl Trust (2019). The average date for the first successful egg to be laid across the five regions ranged between the 10th and 23rd April in 2011, 2012, 2014 and 2017, and between the 30th April and the 18th May in 2013, 2015, 2016 and 2018.

Table 2 Barn owl nest productivity between 2011 and 2018; indicating total numbers of nests monitored, average date of first egg laid, numbers of nests that produced fledged birds, numbers of fledged birds produced, and the mean productivity per successful nest.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Total number of nests monitored	98	101	99	121	130	129	124	121
Average date of first egg (number of nests)	23/04/11 (46)	10/04/12 (53)	18/05/13 (22)	14/04/14 (64)	12/05/15 (43)	02/05/16 (59)	15/04/17 (57)	30/04/18 (40)
Nests that produced fledgling birds	56	63	23	78	41	61	61	45
Total number of birds fledged	**186**	**153**	**83**	**336**	**103**	**154**	**153**	**122**
Nest surveyed that were productive	**57.1%**	**62.4%**	**23.2%**	**64.5%**	**31.5%**	**46.9%**	**46.9%**	**38.8%**
Mean productivity per successful nest	3.32	2.43	3.61	4.31	2.51	2.52	2.51	2.71
Total number of Barn Owl chicks ringed*	***8533***	***7327***	***3051***	***14504***	***4968***	***7630***	***10993***	***6684***
Total number of Barn Owl Nest Record Reports*	***1972***	***2333***	***894***	***2849***	***1791***	***2332***	***3027***	***2402***

** Data from the BTO on total number of Barn Owl chicks ringed each year.*

Figure 2. Barn owl nests surveyed each year, indicating the proportion of productive nests that produced fledged young.



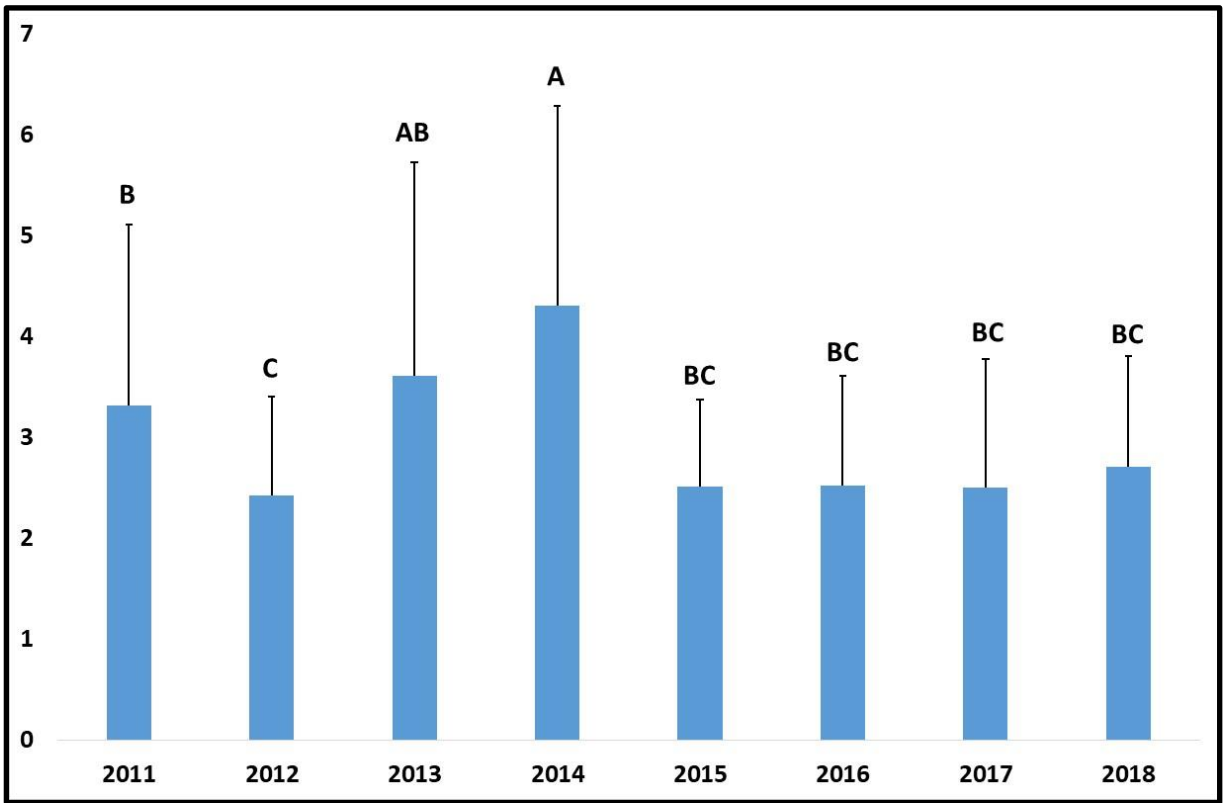
The numbers of birds fledged per successful nest site from each of the five regions between 2011 and 2018 (as summarised in Table 3) were compared using a General Linear Model, and were found to differ significantly between years ($F = 14.47$; $p < 0.001$), but not to differ significantly

between regions (F = 2.12; p = 0.077). GLM Tukey Pairwise Comparisons of the eight years of barn owl productivity data indicate no significant difference between the 2014 and 2013 data, no significant difference between the 2011, 2013, 2015, 2016, 2017 and 2018 data, and no significant difference between the 2012, 2015, 2016, 2017 and 2018 data (Figure 3).

Table 3. Mean barn owl nest productivity for each of the five Regions between 2011 and 2018 for the nests that successfully produced fledged birds (summary data derived from Annex 1). Some nests were not visited in Region 4 (the 'South-East') in 2013 and those that were visited (16/25) produced no chicks.

	Year								
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Mean**
Region 1 (N)	3.00	2.33	3.00	3.33	2.60	2.57	2.00	2.00	**2.69**
Region 2 (E)	2.33	3.00	3.50	4.52	2.50	2.33	2.67	2.00	**3.21**
Region 3 (C)	3.33	2.17	2.00	4.93	2.38	2.27	2.62	2.64	**2.94**
Region 4 (SE)	3.60	2.42	no breeding recorded	3.27	2.58	2.44	3.00	2.91	**2.86**
Region 5 (Midlands)	4.00	2.21	4.00	5.06	2.57	2.83	2.13	2.88	**3.20**
Mean	**3.32**	**2.43**	**3.61**	**4.31**	**2.51**	**2.52**	**2.51**	**2.71**	

Figure 3. Mean number of fledgling barn owls produced per successful nests (with standard deviations) for all nests monitored between 2011 and 2018. Letters denote post hoc groups from a General Linear Model (using Tukey Pairwise Comparisons).



3.3 Unusual Growth Characteristics

Among the eggs and barn owls (both young and adult) studied during 2018, none was found to have any unusual growth characteristics or physical deformities (such as abnormal feather development or pattern of moult), that might suggest any sub-lethal effects of exposure to anticoagulant rodenticides.

3.4 Rodenticide Residues in UK Barn Owls

A long-term study has been conducted by the Centre for Ecology and Hydrology (CEH) to investigate the exposure of UK barn owls to anticoagulants. The study reported that the number of UK barn owl individuals found to carry residues of one or more SGAR's ranges from 94% [of 100 birds analysed in 2015] to 78% [of 100 birds analysed in 2016] (Shore et al., 2017).

Generally, the residue levels in the birds were found to be low, and are considered unlikely to be a major cause of mortality, their deaths having been caused by a range of other factors such as collisions with road traffic, starvation and disease (Shawyer, 1987; Toms, 2014; Smith and Shore, 2015). The barn owl liver residue results obtained for 2018, the year of collection of breeding data presented in this report, showed that of the 87% (n=99) of the 2018 birds with

liver residue levels, 86 birds contained liver residues less than 100 ng/g wet wt. (Shore et al., 2019).

The geographical distribution of the birds sampled in 2018 is shown in Figure 1; and it can be seen that in eastern and central-southern England there is some good concurrence in the locations of those birds collected for liver analysis and the locations of the nests studied in the present investigation of barn owl breeding performance. The present study can therefore be considered as a monitoring procedure, providing information about barn owl breeding performance in the presence of the SGAR residues detected by the CEH investigation, in at least those parts of the country.

3.5 Habitats at the sampled nest sites

The nature of the habitat surrounding monitored nests where foraging occurs is given for the first time in this report. Habitat recording followed the standardised methods developed by the British Trust for Ornithology (BTO) for their ringing and nest recording schemes and in particular for Project Barn Owl in the mid 1990s and the Barn Owl Monitoring Programme (BOMP), 2000-2009 (see Toms et al., 2001 and BTO, 2019)

The habitat codes are presented in Annex 2 with brief descriptions of their meaning. The main habitat (letter code) is followed by three/four subsidiary habitat types (numeric codes), which describe the key habitat features of the main habitat type.

Differences in habitat are likely to influence prey type and abundance, and are known to affect nest occupancy and breeding success in barn owls.

One nest site located in Region 4 (SE) was located in Semi-natural Grassland (letter code 'C'), in an isolated group of trees located within a water meadow / grazing marsh (numberic codes 6 and 5 resperctively). All other nest sites were located on Farmland (letter code 'E'). Of these, the main subsidiary habitat was 'Grassland' for 74% of sites, and 'Tilled Land' for 26% of sites (Table 4). The full data set is presented in Annex 3.

Table 4. For all Nest sites located on Farmland (Letter code E), the main subsidiary habitat, recorded as either Grassland (numeric code 1, 2 or 3) or Tilled Land (numeric code 4), are presented below for the five separate regions of the study, and for all nest sites combined.

Region:	**1 (N)**		**2 (E)**		**3 (C)**		**4 (SE)**		**5 (Midlands)**		**All**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Grass	20	**80**	11	**44**	19	**76**	24	**100**	22	**73**	96	**74**
Tilled	5	**20**	14	**56**	6	**24**	0	**0**	8	**27**	33	**26**

Grassland was recorded either as 'apparently imporoved', 'apparently unimproved' or 'mixed alongside tilled land'.

Four nest sites in Region 2 (E) and one nest site in Region 3 (C), were located in active Farmyards. Another twelve nests sites were located within isolated groups of trees; and all other nest sites were located along field boundaries such as hedgerows and ditches (see Annex 2 and Annex 3).

4. Discussion

From 2011 to 2018 between 98 and 130 barn owl nest sites were surveyed each year across five regions of the UK, and during this time, between 23 and 78 of these nest sites were successful, producing between 83 and 336 fledgling birds each year. The number of fledged birds produced from each successful nest has been used to assess nest productivity as a measure of barn owl breeding success. Across the five regions surveyed between 2011 and 2018, the annual mean nest productivity for the successful nests ranged between 2.4 and 4.3, with an overall mean nest productivity of 3.01 (n = 428). Nest productivity was used in this study as a measure of barn owl breeding success to enable broad comparisons to be made with some other studies that generate data of this type (see Henderson et al., 1993; Toms et al., 2001; Shawyer, 2010).

An advantage of the present study is that nest occupancy is being assessed in 130 specific barn owl nest sites on an annual basis, so that for any particular year, the proportion of nest sites that successfully produce fledged birds can be used as another measure of barn owl breeding success alongside the nest productivity data. However, there appear to be very few published studies that present monitoring data year on year for barn owl nests sites, irrespective of their occupancy and productivity. The analysis in the present study is therefore able to consider the nest productivity data in the light of the nest occupancy data.

It is important to recognise that barn owl nest occupancy and breeding success can vary considerably from year to year for a very wide variety of reasons, including population numbers, prey availability and weather conditions (Toms, 2014). For this reason, both the 1982-1985 Barn Owl Survey of Britain and Ireland (Shawyer 1987) and the 1995-97 BTO/Hawk and Owl Trust 'Project Barn Owl' survey (Toms et al., 2001) provided annual UK population estimates over their three or four year study periods, thus embracing the more complete 3-4 year cycle of field vole abundance.

For example, in years when vole numbers are particularly low (such as 2013), many barn owls will remain at or near their winter roosts and will make little attempt to occupy their breeding sites. In such years many barn owls will simply go unrecorded. Where population estimates are based on these years alone, rather than peak years like 2014, they are likely to prove inaccurate.

The average date for the first egg laid in the nests monitored across the five regions was the 18th May and the 14th April in 2013 and 2014 respectively (Table 3), indicating that the few barn owls which were able to breed in 2013 had delayed their breeding activity on average by 34 days when compared with 2014. This, in combination with the high mean 2013 nest productivity would suggest that food availability was a limiting factor for the barn owls at the onset of breeding, but not as the season progressed.

Shawyer (2019) reported a poor barn owl breeding season in 2018, with many nests failing both with eggs and small chicks, particulalrly for pairs that laid in early to mid April; and adverse cold and snowy weather conditions (referred to in the media as the 'Beast from the East') were proposed as the main cause of these early nest failures. However, the severe weather of March transformed to the hottest April on record, with drought conditions persisting throughout the summer.; and barn owls that did produce clutches in June and July, produced brood sizes that were close to the 10-year average (Shawyer, 2019).

The number of fledged barn owls that have been recorded in this survey represents between 1.4% and 2.7% of the total number of barn owl chicks ringed by the BTO in Britain and Ireland each year

(Table 3). Analysis of the eight years of available data indicates a very high correlation between the two data sets (Pearson Correlation R=0.908; p=0.002). Assuming that numbers of barn owl chicks ringed across the UK each season is a reflection of the national productivity of the species, the BOMS survey would appear to provide a useful and reliable indication of barn owl productivity across the UK.

In 2011, 2012, 2014 and 2017, when the average date for the first egg laid in the nests monitored across the five regions was between the 10th and 23rd April, the number of birds fledged each year ranged from 153 to 336. In contrast, for 2013, 2015, 2016 and 2018, the average date for the first egg laid in the nests monitored across the five regions was between the 30th April and the 18th May, and the number of birds fledged each year ranged from 83 to 154 (Table 3). The ability of the birds to lay eggs early in the season would appear to be an important factor influencing the total number of fledged birds produced each year.

Between 1982 and 1986, Shawyer (1987) estimated barn owl mean productivities of 3.35 (n=155) for England and Wales, and 2.84 (n=135) for Scotland, and presented annual productivity values for the British Isles ranging from 2.77 to 3.36, with a mean value of 3.00 (n=290).

In a BTO Research Report (Henderson et al., 1993), barn owl annual mean productivity was presented for six specified regions of England and Wales between 1988 and 1990, and ranged between 2.6 and 4.2 (n=246). Similarly an internal report to the Environment Agency (Shawyer, 2010) reported annual mean productivity between 2000 and 2009 ranging between 2.6 and 3.5 (n=581). These values are comparable with earlier data presented by Shawyer (1987) and with the data presented in this Report.

According to Shawyer, Toms and the Barn Owl Trust, the marked fluctuations in barn owl breeding productivity year on year are primarily a result of annual changes in small mammal abundance and extreme weather events at critical times during the barn owl's annual cycle (see Shawyer, 1987; Shawyer, 1998; Toms 2014; Barn Owl Trust, 2019).

Barn owl exposure to SGAR's in the UK would be expected to be greatest across agricultural areas, because of the association between modern agricultural practice and Norway rat infestations, particularly around livestock-rearing and grain storage facilities. In addition, the high incidence of physiological resistance to anticoagulant rodenticides in Southern England might be expected to cause an increase in the use of anticoagulant rodenticides in this area, as the effectiveness of these rodenticides is reduced. Such areas would include ~~Region 5 (Midlands NO),~~ Region 4 (SE) and Region 3 (C). Furthermore, the use of SGARs in these Regions would be expected to be relatively consistent from year to year, to address the consistent problem of resistant Norway rats in this area (Buckle and Prescott, 2012).

No information is directly provided by this study on any putative relationship between barn owl nest productivity and exposure of barn owls to anticoagulant rodenticides. The number of breeding pairs of barn owl in any given year is determined by factors which include the level of overwintering mortality of breeding adults, the survival of first year birds and the successful recruitment of these birds into the breeding population. Data presented from various reported studies in Britain between 1987 and 2018 indicate that the productivity of barn owls has not changed markedly over this 31-year period. Breeding success is influenced by prey availability and survival, which in turn is shaped by numerous other factors such as climate, habitat quality and population density (Toms, 2014). Barn owls clearly are widely exposed to SGARs, but the impact of this exposure on the productivity of the UK population, if any, is difficult to quantify

directly. The study will continue in the forthcoming years to assemble more information on this important aspect of the biology of UK barn owls, the chosen sentinel species for SGAR contamination.

Acknowledgements:
WCP would like to thank Matthew Stevens, Hawk Conservancy Trust for his nest monitoring support in Region 3.

References

Balmer, D., Gillings, S., Caffrey, B., Swann, B., Downie, I. and Fuller, R. (2013) Bird Atlas 2007-2011. The breeding and wintering birds of Britain and Ireland. BTO Books, Thetford, UK. 720 pp.

Barn Owl Trust (2019). State of the UK Barn Owl population – 2018. https://www.barnowltrust.org.uk/wp/wp-content/uploads/State-of-the-UK-Barn-Owl-Population–2018.pdf; accessed 15/09/2019.

Blaker, G. B. (1933). *The Barn Owl in England and Wales*. RSPB, London.

BTO (2019). Barn Owl Monitoring Programme (BOMP). Methodology. The British Trust for Ornithology, Thetford, UK. https://www.bto.org/our-science/projects/bomp/bomp-methodology

Buckle, A.P. and Prescott, C.V. (2012) The Current Status of Anticoagulant Resistance in Rats and Mice in the UK. Report from the Rodenticide Resistance Action Group of the United Kingdom to the Health and Safety Executive. 17th May 2012. 37 pp.

Crick, H. Q. P, Shawyer, C. R., Siriwardena, G. M., Balmer, D. E. and Toms, M. P. (2001). The BTO Barn Owl Monitoring Programme: 1st Report: Pilot Year 2000. BTO Research Report No. 258. BTO, Thetford.

Eaton, M., Aebischer, N., Brown,A., Hearn, R., Lock, L., Musgrove, A., Noble, D., Stroud, D and Gregory, R. (2015). Birds of Conservation Concern 4: the population status of birds of the UK, Channel Islands and Isle of Man. *British Birds: 108; 708-746.*

Gibbons, D.W., Ried, J.B. & Chapman, R.A. (1993). The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991. T & A D Poyser, London.

Hagemeijer, W.J.M. and Blair, M.J. (1997). The EBCC Atlas of European Breeding Birds: the Distribution and Abundance. T. & A.D. Poyer Ltd., London, UK. 903 pp.

Hayhow DB, Bond AL, Douse A, Eaton MA, Frost T, Grice PV, Hall C, Harris SJ, Havery S, Hearn RD, Noble DG, Oppel S, Williams J, Win I and Wotton S (2017). The state of the UK's birds 2016. The RSPB, BTO, WWT, DAERA, JNCC, NE, NRW and SNH, Sandy, Bedfordshire. https://www.bto.org/sites/default/files/publications/state-of-uk-birds-2016.pdf

Health and Safety Executive (2017). An information paper by the Rodenticides Stewardship Regime Government Oversight Group. First Report on the Rodenticides Stewardship Regime. Assessment of Implementation – February 2017 Rodenticides Stewardship Government Oversight Group. Health and Safety Executive, UK. 13 pp.

Henderson, I.G., McCulloch, M.N. and Crick, H.Q,P. (1993). Barn owl productivity and survival in relation to the use of second-generation rodenticides in 1998 – 1990. BTO Research report No. 106, BTO, Thetford. ISBN 0-903793-30-X.

Jackson, P. & Cresswell, W. (2017) Factors determining the frequency and productivity of double brooding of Barn Owls *Tyto alba*. Bird Study.

Love, A.R., Webbon, C.E., Glue, D. and Harris, S. (2000). Changes in the food of British Barn Owls (*Tyto alba*) between 1974 and 1997, Mammal Review 30: 107-129.

Martin, J. (2008). Barn Owls in Britain. Whittet Books, ISBN-13 978-1-873580-752.

Naim, M., Noor H. M., Kasim, A. and Abu, J. Growth Performance of Nesting Barn Owls *Tyto alba javanica* in Rat Baiting Area in Malaysia. Department of Plant Protection and Animal Science, Faculty of Agriculture and Department of Veterinary Clinical Studies, Faculty of Veterinary Medicine: Putra University Malaysia.

Sharrock, J.T.R. (1976). The Atlas of Breeding Birds in Britain and Ireland. Poyser, Berkhamsted.

Shawyer, C. R. (1985). Rodenticides: A Review and Assessment of their Potential Hazard to Non-target Wildlife with Special Reference to the Barn Owl *Tyto alba*. The Hawk Trust, London.

Shawyer, C. R. (1987). The Barn Owl in The British Isles: Its Past, Present and Future. The Hawk Trust, London. ISBN 0-9503187-2-8.

Shawyer, C. R. (1994). The Barn Owl. Hamlyn Ltd, London. 128 pp. ISBN 0 600 57949 2.

Shawyer, C. R. (1998). The Barn Owl. Arlequin Press, Chelmsford. 213 pp. ISBN 1900159 70 8

Shawyer, C.R. (2006). What makes owls tick? Adopt a Box News. No. 28: 45. The Hawk and Owl Trust, Taunton.

Shawyer, C.R. (2009). *Barn Owl Conservation Network Symposium*. BOCN, Lambourn.

Shawyer, C. R. (2014). The British Barn Owl Population. Adopt a Box News. No. 44: 4-5. The Hawk and Owl Trust, Taunton.

Shawyer, C.R. (2015[a]). Barn Owls in 2014. https://www.bto.org/volunteer-surveys/nrs/about/barn-owls-2015; dated 24/02/2015; accessed 21/03/2016

Shawyer, C.R. (2015[b]). Barn Owls in 2015. https://www.bto.org/news-events/news/2015-11/colin-shawyers-thoughts-2015-season; dated 03/11/2015; accessed 21/03/2017

Shawyer, C.R. (2017). Barn Owls in 2016. https://www.bto.org/news-events/news/2017-01/barn-owls-2016-colin-shawyers-report; dated 06/01/2017; accessed 08/08/2017

Shawyer, C.R. (2018[a]). Barn Owls in 2017. https://www.bto.org/news-events/news/2017-05/barn-owls-2017-update-colin-shawyer; dated 31/08/2018; accessed 03/09/2018

Shawyer, C.R. (2018[b]). Barn Owls in 2018. https://www.bto.org/news-events/news/2018-04/barn-owls-2018-update-colin-shawyer; dated 31/08/2018; accessed 03/09/2018

Shawyer, C.R. (2019). Barn Owls in 2019. https://www.bto.org/news-events/news/2018-04/barn-owls-2018-update-colin-shawyer; dated January 2019; accessed 03/09/2019

Shore, R.F., Henrys, P.A. & Walker, L.A. (2014). Power analysis of liver second generation anticoagulant rodenticide (SGAR) residue data in barn owls from Britain: a Predatory Bird Monitoring Scheme (PBMS) report. CEH contract report to the Health & Safety Executive. 45pp. https://wiki.ceh.ac.uk/x/DAIDC, accessed 21/04/17

Shore, R.F, Walker, L.A., Potter E.D. and Pereira, G. (2016). Second generation anticoagulant rodenticide residues in barn owls 2015. CEH contract report to the Campaign for Responsible Rodenticide Use (CRRU) UK, 17 pp.
https://pbms.ceh.ac.uk/sites/default/files/stewardship-2015-owls_0.pdf

Shore, R.F., Walker, L.A.., Potter E.D., Pereira, M.G., Sleep, D., Thompson, N.J. 2017. Second generation anticoagulant rodenticide residues in barn owls 2016. CEH contract report to the Campaign for Responsible Rodenticide Use (CRRU) UK, 21 pp.
https://pbms.ceh.ac.uk/sites/default/files/stewardship-2016-owls_FINAL.pdf

Shore, R.F., Walker, L.A.., Potter E.D., Pereira, M.G., Sleep, D., Thompson, N.J. and Hunt, A.G. (2018). Second generation anticoagulant rodenticide residues in barn owls 2017. CEH contract report to the Campaign for Responsible Rodenticide Use (CRRU) UK, 22 pp.
https://pbms.ceh.ac.uk/sites/default/files/stewardship-2017-owls_FINAL.pdf

Shore, R.F., Walker, L.A., Potter, E.D., Chaplow, J.S., Pereira, M.G., Sleep, D., Hunt, A. 2019. Second generation anticoagulant rodenticide residues in barn owls 2018. CEH contract report to the Campaign for Responsible Rodenticide Use (CRRU) UK, 23 pp. https://pbms.ceh.ac.uk/sites/default/files/stewardship-2018-owls_FINAL.pdf

Smith, R. H. and Shore, R. F. (2015). Environmental impacts of rodenticides. Chapter 16. In: Rodent Pests and their Control. A. P. Buckle and R. H. Smith eds. CAB International. Wallingford, UK. Pp 330-345.

Toms, M.P., Crick, H.Q.P. and Shawyer, C.R. (2001). The status of breeding Barn Owls *Tyto alba* in the United Kingdom 1995-97. Bird Study, 48: 23-37.

Toms, M., (2014). Owls. The New Naturalist Library No 125. Harper Collins. ISBN 978-0-00-742555-6.

Annex 1 Barn owl breeding data for 2011 to 2018.

Year	Parameter	Region 1 (N)	Region 2 (E)	Region 3 (C)	Region 4 (SE)	Region 5 (Midlands)	All Regions
2011	**Total number of nests**	16	20	16	22	24	98
	Nests that produced fledgling birds	6	12	12	10	16	56
	Total number of birds fledged	18	28	40	36	64	186
	Mean productivity per successful nest	**3.00**	**2.33**	**3.33**	**3.60**	**4.00**	**3.32**
2012	**Total number of nests**	16	19	17	21	28	101
	Nests that produced fledgling birds	6	14	12	12	19	63
	Total number of birds fledged	14	42	26	29	42	153
	Mean productivity per successful nest	**2.33**	**3.00**	**2.17**	**2.42**	**2.21**	**2.43**
2013	**Total number of nests**	14	20	18	16	30	98
	Nests that produced fledgling birds	2	10	1	0	10	23
	Total number of birds fledged	6	35	2	0	40	83
	Mean productivity per successful nest	**3.00**	**3.50**	**2.00**	**-**	**4.00**	**3.61**
2014	**Total number of nests**	25	25	22	21	28	121
	Nests that produced fledgling birds	15	21	14	11	17	78
	Total number of birds fledged	50	95	69	36	86	336
	Mean productivity per successful nest	**3.33**	**4.52**	**4.93**	**3.27**	**5.06**	**4.31**
2015	**Total number of nests**	25	25	25	25	30	130
	Nests that produced fledgling birds	5	4	13	12	7	41
	Total number of birds fledged	13	10	31	31	18	103
	Mean productivity per successful nest	**2.60**	**2.50**	**2.38**	**2.58**	**2.57**	**2.51**
2016	**Total number of nests**	25	25	25	25	30	130
	Nests that produced fledgling birds	7	9	11	16	18	61
	Total number of birds fledged	18	21	25	39	51	154
	Mean productivity per successful nest	**2.57**	**2.33**	**2.27**	**2.44**	**2.83**	**2.52**

Annex 1 Continued

Year	Parameter	Region 1 (N)	Region 2 (E)	Region 3 (C)	Region 4 (SE)	Region 5 (Midlands)	All Regions
2017	**Total number of nests**	25	25	25	25	30	130
	Nests that produced fledgling birds	8	9	13	15	16	61
	Total number of birds fledged	16	24	34	45	34	153
	Mean productivity per successful nest	**2.00**	**2.67**	**2.62**	**3.00**	**2.13**	**2.51**
2018	**Total number of nests**	22	23	24	22	30	121
	Nests that produced fledgling birds	5	1	11	11	17	45
	Total number of birds fledged	10	2	29	32	49	122
	Mean productivity per successful nest	**2.00**	**2.00**	**2.64**	**2.91**	**2.88**	**2.71**

Annex 2 Nest Record Scheme – Relevent Habitat Codes with Descriptions

<table>
<tr><th></th><th>COLUMN A</th><th>COLUMN B</th><th>COLUMN C</th></tr>
<tr><td>A. Woodland</td><td></td><td></td><td></td></tr>
<tr><td>B. Scrubland</td><td></td><td></td><td></td></tr>
<tr><td>C. Semi-natural Grasssland and Marsh</td><td>1 Chalk downland
2 Grass moor (unenclosed)
3 Grass moor mixed with heather (unenclosed)
4 Machair
5 Other dry grassland
6 Water-meadow/ grazing marsh
7 Reed swamp
8 Other open marsh
9 Saltmarsh</td><td>1 Hedgerow with trees
2 Hedgerow without trees
3 Tree-line without hedge
4 Other field boundary (wall, ditch, etc.)
5 Isolated group of 1-10 trees
6 No field boundary
7 Montane
8 High-medium disturbance from people
9 Low disturbance</td><td>1 Ungrazed
2 Cattle
3 Sheep
4 Horses
5 Rabbits
6 Deer
7 Other grazers
8 Extensive bracken
9 Hay</td></tr>
<tr><td>D. Heathland and Bogs</td><td></td><td></td><td></td></tr>
<tr><td>E. Farmland</td><td>1 Apparently improved grassland
2 Apparently unimproved grassland
3 Mixed grass/ tilled land
4 Tilled land
5 Orchard
6 Other Farming</td><td>1 Hedgerow with trees
2 Hedgerow without trees
3 Tree-line without hedge
4 Other field boundary (wall, ditch, etc.)
5 Isolated group of 1-10 trees
6 Farmyard (active)</td><td>1 Ungrazed
2 Cattle
3 Sheep
4 Horses
5 Other stock
6 Bare earth
7 Autumn cereal
8 Spring cereal
9 Root crops
10 Other crops</td></tr>
<tr><td>F. Human Sites</td><td></td><td></td><td></td></tr>
<tr><td>G. Water Bodies</td><td></td><td></td><td></td></tr>
<tr><td>H. Coastal</td><td></td><td></td><td></td></tr>
<tr><td>I. Inland Rock</td><td></td><td></td><td></td></tr>
<tr><td>J. Miscellaneous</td><td></td><td></td><td></td></tr>
</table>

Annex 3. Of the 129 nest sites were located on Farmland (Letter code E) and the one nest site located on Semi-natural Grassland and March (Letter Code C), the main subsidiary habitats as coded in Annex 2 (Column A [CA] and Column B [CB]) are tabulated below for each of the five regions of the study.

Regions:	1 (N)			2 (E)			3 (C)			4 (SE)			5 (Midlands)		
Box No.	L	CA	CB	L	CA	CB	L	CA	CB	L	CA	CB	L	CA	CB
1	E	3	4	E	4	4	E	1	1	E	3	4	E	4	4
2	E	4	1	E	4	4	E	1	4	E	3	4	E	4	4
3	E	1	4	E	4	4	E	3	1	E	1	4	E	4	1
4	E	4	5	E	3	4	E	1	4	E	1	4	E	4	4
5	E	4	4	E	4	6	E	3	4	E	1	4	E	3	4
6	E	2	2	E	4	6	E	1	1	E	1	4	E	3	2
7	E	3	1	E	4	3	E	1	1	E	1	4	E	3	4
8	E	3	1	E	3	4	E	1	1	E	3	4	E	3	4
9	E	1	5	E	4	4	E	1	1	E	1	1	E	1	4
10	E	3	1	E	3	5	E	3	1	E	1	3	E	3	4
11	E	4	4	E	3	4	E	4	4	E	1	1	E	4	4
12	E	3	4	E	4	3	E	4	4	E	1	5	E	4	1
13	E	1	4	E	3	3	E	4	4	E	3	1	E	3	5
14	E	1	4	E	4	4	E	4	4	E	1	4	E	4	4
15	E	3	4	E	4	4	E	3	4	C	6	5	E	2	4
16	E	3	4	E	3	4	E	3	3	E	1	1	E	3	5
17	E	3	4	E	4	4	E	3	4	E	3	1	E	3	4
18	E	3	4	E	4	6	E	3	3	E	1	4	E	3	4
19	E	3	4	E	4	5	E	4	6	E	1	1	E	3	4
20	E	3	4	E	3	5	E	3	2	E	3	1	E	3	4
21	E	1	4	E	4	4	E	3	2	E	3	1	E	3	1
22	E	3	4	E	3	4	E	3	1	E	1	5	E	3	1
23	E	1	1	E	2	6	E	3	1	E	1	4	E	3	5
24	E	4	4	E	1	6	E	3	4	E	3	4	E	3	4
25	E	3	4	E	1	5	E	4	1	E	3	5	E	3	1
26													E	1	4
27													E	3	4
28													E	3	4
29													E	3	4
30													E	4	4