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VERTEBRATE PESTS UNIT
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The breeding performance of Barn Owl populations in five regions of the United Kingdom – 2019 Data Set.

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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 (see Buckle et al., 2017).

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 The UK Barn Owl Population and recent breeding performance

For all bird species, estimating numbers of birds in a population is always problematic, because numbers will fluctuate from year to year as individuals breed, die and migrate, and it is usually impossible to count all individuals. Estimates of population size are commonly derived from surveys, and for barn owl, such surveys rely heavily on estimating numbers of breeding pairs over successive breeding seasons.

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). Although Toms (2014) subsequently considered this to be a little on the low side he gave no futher estimate of the (then) current size of the UK barn owl population.

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 Avian Population Estimates Panel (APEP) is a collaboration between the UK statutory conservation agencies and relevant non-governmental organisation, with the role of collating the best estimates of breeding and non-breeing bird populations. Their most recent Report (Woodward et al., 2020) provided a 2016 UK estimate of between 4,000 and 14,000 breeding pairs.

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 2013 and 2014, both nest occupancy and breeding productivity in many areas was especially high in 2014 (Shawyer, 2015[a]; Barn Owl Trust, 2017). 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, 2015b); 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, 2018b). The 2018 breeding season in the UK was generally poor when compared with 2017 (Shawyer, 2019), with below average nest occupancy and below average brood size (Barn Owl Trust, 2020). The reasons for these year to year fluctuations in breeding success are discussed in later sections of this report, and in annual reports from organisations such as the Barn Owl Trust (e.g. Barn Owl Trust, 2020).

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; Toms, 2014). 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, 2020).

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 BTO, both in their Nest Record Scheme (1939 to 2020), and in the BTO Barn Owl Monitoring Programme (BOMP – 2000 to 2009).

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

- In 2014 - 2,915 records submitted, a number only exceeded by blue tit and great tit
- In 2015 and 2016 - 1,792 and 2,331 records submitted respectively, numbers only exceeded by blue tit, great tit, swallow and tree sparrow
- In 2017, 2018 and 2019 - 3,053, 2,501 and 3,353 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 UK Centre for Ecology & Hydrology (UKCEH), 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, these reports do not provide contemporaneous 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 provide this information by monitoring various breeding parameters in a sample of barn owls from certain parts of the UK (Figure 1). The samples of barn owls studied for liver residues and those whose nest sites are monitored for BOMS are both sub-samples of the same, wider UK barn owl population, although clearly obtained in different ways.

To this end, and althought not directly required to do so by the Government Oversight Group,[1] 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, 2018 and 2019, together with similar available data provided by WCP from the same nest sites for 2011 to 2014.

This report comprises an analysis of the 2019 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). The report also provides comment on comparable information on barn owl breeding provided by the BTO's Bird Ringing Scheme and Nest Record Scheme. The close agreement between certain breeding parameters observed in the BOMS

[1] The Government Oversight Group for the UK Rodenticide Stewardship Regime is chaired by the UK regulatory body for biocides, the Health and Safety Executive. The group also includes representatives from the Department for Environment, Food and Rural Affairs, Natural England, Public Health England, Science and Advice for Scottish Agriculture and each of the Devolved Administrations.

dataset and similar data from the much larger BTO data, lead the authors of this report to conclude that the breeding data recorded within it are reasonably representative of the wider UK population, from which the UKCEH sample is itself taken.

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 recording of 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, and 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. Given a necessity to disturb the nests as little as possible during the study, as a condition of the license, no other information is available about possible reasons for nest abandonment prior to monitoring visits.

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

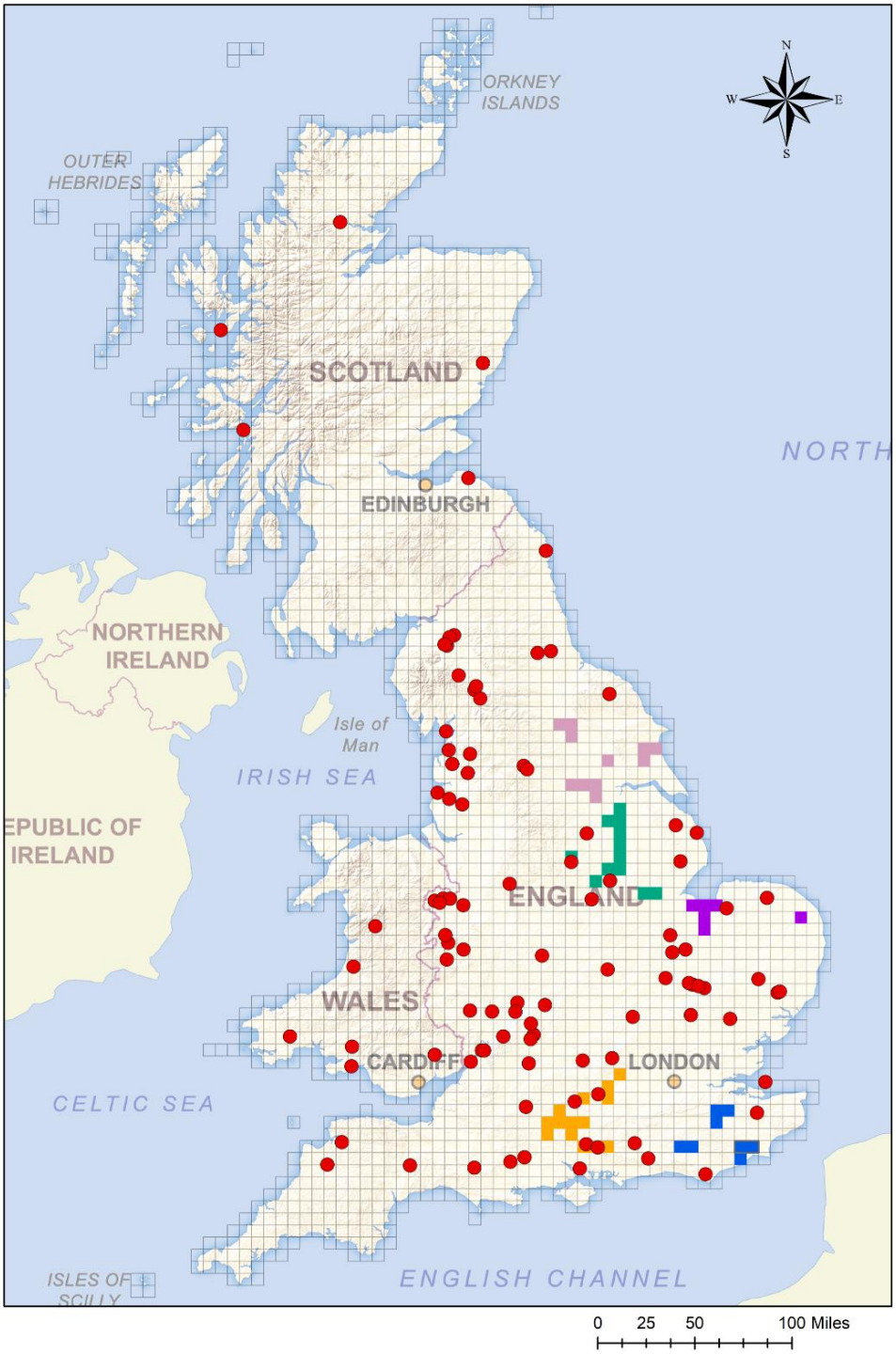
- Nest occupancy data
- Nest Productivity (mean number of chicks fledged) for successful nests
- Individual records of any chicks and eggs which show abnormal development

The survey area for the BOMS comprises the following five areas, surveying a total of approximately 120-130 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 provided, using the standardised methods of habitat recording 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 for BOMS in 2019. The location of the barn owls obtained by UKCEH for the CRRU liver residue analysis survey in the same year are also presented (red circles). [We gratefully acknowledge the kind co-operation of UKCEH for the provision of the latter information.]



[Region1 (N) = pink; Region 2 (E) = purple; Region 3 (C) = yellow; Region 4 (SE) = blue; Region 5 (Midlands) = green]

3. Results

3.1 The 2019 Data Set

Of the 120 barn owl nests monitored in 2019, a total of 154 young birds fledged from 58 nests. In addition there was evidence of 3 barn owl pairs that had produced eggs and then subsequently failed, and 1 pair where breeding had not been attempted (giving an overall nest occupancy of 51.6%). In addition, there were adult singletons present at a further 2 nests. The overall mean productivity for the successful nests was 2.66 fledged birds, with mean productivities for the five Regions ranging between 2.44 and 2.91 (Table 1).

Table 1 Barn owl nest occupancy in 2019, indicating the number of nests monitored and the number of young birds that fledged.

2019	Region 1 (N)	Region 2 (E)	Region 3 (C)	Region 4 (SE)	Region 5 (Midlands)	Total
Total number of nests monitored	20	24	24	23	29	120
Nest site occupancy by adult pairs	10	12	12	9	19	62
Nests that produced fledgling birds	9	11	11	9	18	58
Total number of birds fledged	22	27	32	22	51	154
Mean productivity per successful nest	**2.44**	**2.45**	**2.91**	**2.44**	**2.83**	**2.66**

Region 5 (Midlands) produced the largest number of fledglings, with 51 fledged chicks from 18 nest sites (Table 1). The other four regions produced between 22 and 32 fledged chicks from between 9 and 11 nest sites.

3.2 Comparison of the 2019 data with available data from 2011 to 2018

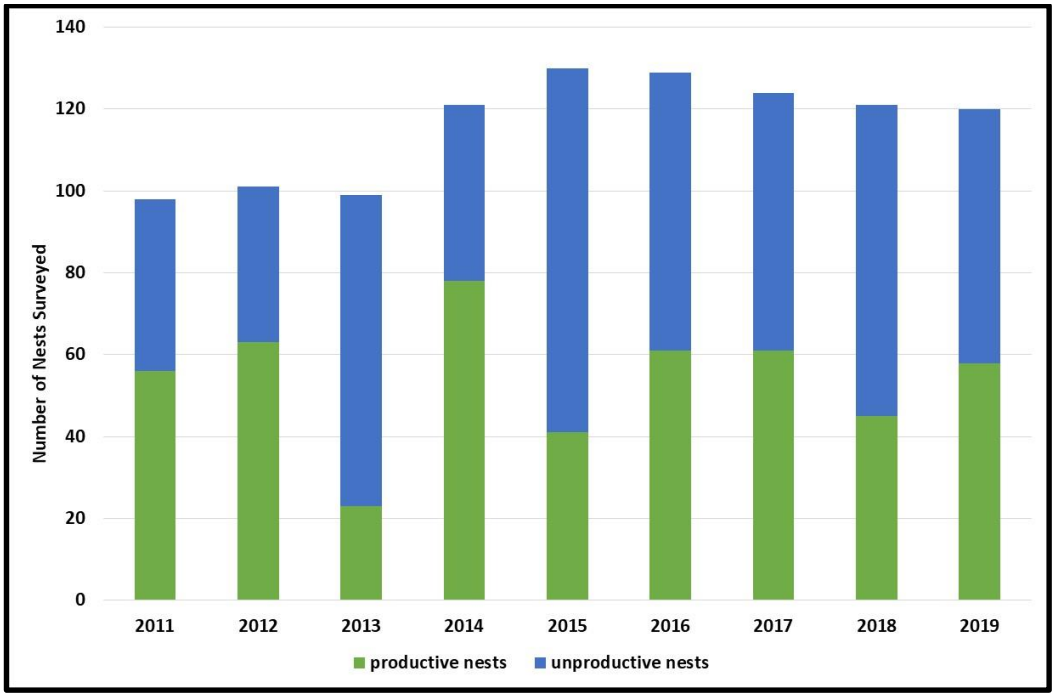
Of the 130 barn owl nest sites surveyed in 2015, 129 nest sites, 124 nest sites, 121 nest sites and 120 nest sites were monitored by WCP in 2016, 2017, 2018 and 2019 respectively; and between 98 and 121 sites were monitored by WCP each year between 2011 and 2014 (Table 2; Figure 2). The proportion of 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, 2017 and 2019, and between the 30th April and the 18th May in 2013, 2015, 2016 and 2018.

Table 2 Barn owl nest productivity between 2011 and 2019; 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**	**2019**
Total number of nests monitored	98	101	99	121	130	129	124	121	120
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)	20/04/19 (54)
Nests that produced fledgling birds	56	63	23	78	41	61	61	45	58
Total number of birds fledged	**186**	**153**	**83**	**336**	**103**	**154**	**153**	**122**	**154**
Nest surveyed that were productive	**57.1%**	**62.4%**	**23.2%**	**64.5%**	**31.5%**	**46.9%**	**46.9%**	**38.8%**	**48.3%**
Mean productivity per successful nest	3.32	2.43	3.61	4.31	2.51	2.52	2.51	2.71	2.66
Total number of Barn Owl chicks ringed*	***8,535***	***7,329***	***3051***	***14,501***	***4,969***	***7,630***	***10,963***	***6,648***	***10,107***
Total number of Barn Owl Nest Record Reports*	***1,975***	***2,330***	***894***	***2,915***	***1,792***	***2,331***	***3,053***	***2,501***	***3,353***

** Data from the BTO on total number of Barn Owl chicks ringed each year (Robinson et al., 2020).*

Figure 2. Barn owl nests surveyed between 2011 and 2019, indicating the proportion of productive nests that produced fledged young.

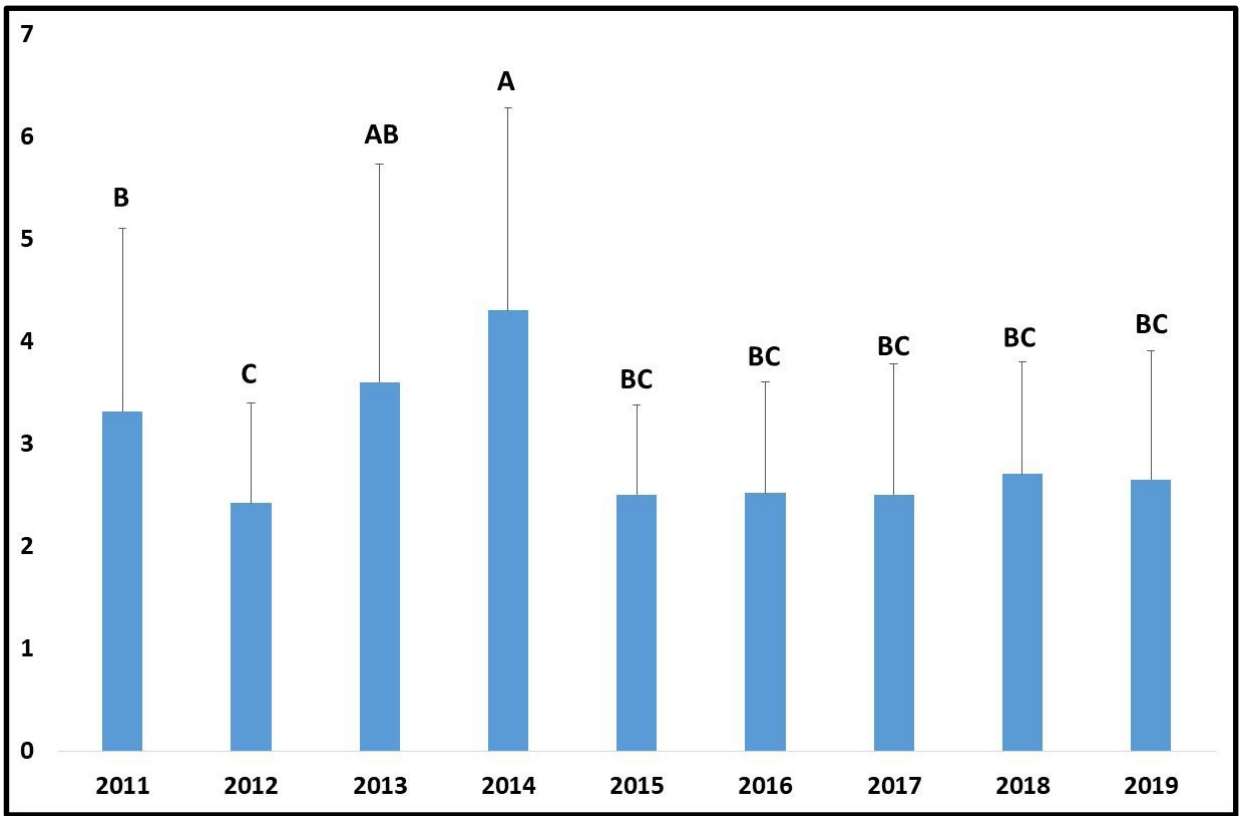


The numbers of birds fledged per successful nest site from each of the five regions between 2011 and 2019 (as summarised in Table 3) were compared using a General Linear Model, and were found to differ significantly between years ($F = 13.55$; $p < 0.001$), but not to differ significantly between regions ($F = 2.28$; $p = 0.060$). GLM Tukey Pairwise Comparisons of the nine 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, 2018 and 2019 data, and no significant difference between the 2012, 2015, 2016, 2017, 2018 and 2019 data (Figure 3).

Table 3. Mean barn owl nest productivity for each of the five Regions between 2011 and 2019 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**	**2019**	**Mean**
Region 1 (N)	3.00	2.33	3.00	3.33	2.60	2.57	2.00	2.00	2.44	**2.65**
Region 2 (E)	2.33	3.00	3.50	4.52	2.50	2.33	2.67	2.00	2.45	**3.12**
Region 3 (C)	3.33	2.17	2.00	4.93	2.38	2.27	2.62	2.64	2.91	**2.94**
Region 4 (SE)	3.60	2.42	no breeding recorded	3.27	2.58	2.44	3.00	2.91	2.44	**2.82**
Region 5 (Midlands)	4.00	2.21	4.00	5.06	2.57	2.83	2.13	2.88	2.83	**3.15**
Mean	**3.32**	**2.43**	**3.61**	**4.31**	**2.51**	**2.52**	**2.51**	**2.71**	**2.66**	

Figure 3. Mean number of fledgling barn owls produced per successful nests (with standard deviations) for all nests monitored between 2011 and 2019. Letters denote *post hoc* groups from a General Linear Model (using Tukey Pairwise Comparisons).



3.3 Correlation between the BOMS Data and BTO Data

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 2); and analysis of the nine years of available data indicates a very high correlation between the numbers of fledged barn owls reported in the BOMS and the total number of barn owl chicks ringed by the BTO (Pearson Correlation R=0.881; p=0.002).

3.4 Unusual Growth Caracteristics

Among the eggs and barn owls (both young and adult) studied during 2019, 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 (Colin Shawyer, personal communication.

3.5 Rodenticide Residues in UK Barn Owls

A long-term study has been conducted by the UK Centre for Ecology and Hydrology (UKCEH) 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, Shore et al., 2018, Shore et al., 2019).

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 2019, the year of collection of breeding data presented in this report, showed that of the 87% (n=100) of the 2019 birds with liver residue levels, 83 birds contained liver residues less than 100 ng/g wet wt. (Walker et al., 2020).

The geographical distribution of the birds sampled in 2019 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 of Barn Owl productivity.

3.6 Habitats at the sampled nest sites

The nature of the habitat surrounding monitored nests where foraging occurs is presented using the standardised methods developed by the BTO for their ringing and nest recording schemes; and was the method used for Project Barn Owl in the mid 1990s and for the Barn Owl Monitoring Programme, 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 respectively). All other nest sites were located on Farmland (letter code 'E'). Of these, the main subsidiary habitats were 'Grassland' for 74% of sites, and 'Tilled Land' for 26% of sites (Table 4). The full data set is presented in Annex 3.

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).

These habitats are considered to be typical of those preferred by breeding barn owls throughout the UK (Martin, 2008), although breeding pairs may occupy somewhat marginal habitats in the far north and west of the country.

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'.

4. Discussion

From 2011 to 2019 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. Across the five regions surveyed between 2011 and 2019, the annual mean nest productivity for the successful nests ranged between 2.4 and 4.3, with an overall mean nest productivity of 2.97 (n = 485). Analysis of the nine years of available data indicate a high correlation between the number of birds fledged in the current study and the total number of barn owl chicks ringed by the BTO across the UK each season, and if it is assumed that the numbers ringed by the BTO 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.

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, 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 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. Thus 2013 and 2014 were respectively the least and most productive barn owl breeding seasons of the present study. Successful nest occupancy was the main factor resulting in this contrast (with 23.2% and 64.5% repectively producing fledglings); as recorded nest productivity values were higher in 2013 and 2014 than in any other breeding season (3.61 and 4.31 respectively; Table 3). There are very few published studies that consider barn owl 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 there is every likelihood that many barn owls will simply go unrecorded, and surveys conducted in these years alone (rather than peak years like 2014), are likely to underestimate the population.

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.

The Barn Owl Trust (2020) reported 'a relatively good year in many areas for barn owls during the 2019 breeding season, with nest occupancy 21% higher than the all year average, although there were marked contrast across the country with -51% on Jersey and +101% in Gloucestershire (Barn Owl Trust, 2020).

In 2011, 2012, 2014, 2017 and 2019, 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.

The marked fluctuations in barn owl breeding productivity year on year are widely thought to be primarily the 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, 2020).

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 (Buckle et al., 2020). 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).

The samples of barn owls used in the BOMS and the UKCEH liver residue study (e.g. Shore et al., 2019) are necessarily selected using different sampling schemes. In the first, barn owl nesting sites are chosen as being typical of nest locations in the UK, and where nesting attempts have been recorded in the recent past. All nest studied are within five defined Regions (Figure 1), as this disposition permits intensive field study during a relatively short time window in the annual barn owl breeding cycle. In the second, carcases are discovered by members of the public and submitted to the Predatory Birds Monitoring Scheme (see https://pbms.ceh.ac.uk/). A sub-sample of livers is taken for residue extraction and analysis from among those submitted, having consideration for the condition of the carcase, the dates of submission of specimens, the estimated ages of submitted birds and the locations where they were found. Furthermore, no direct assessment of residue levels can be made of BOMS birds because they are inevitably alive when handled and ringed by the field researchers. However, it is the opinion of those who conduct and report the BOMS that, notwithstanding differences in sampling regime, the two samples are generally representative of the UK barn owl population as a whole and, therefore, the BOMS provides an assessment of the breeding performance of British barn owls in the presence of the rodenticide residues typically found in the UKCEH study.

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 2019 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). There is good evidence that barn owls 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.

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Annex 1 Barn owl breeding data for 2011 to 2019.

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**
2019	**Total number of nests**	20	24	24	23	29	120
	Nests that produced fledgling birds	9	11	11	9	18	58
	Total number of birds fledged	22	27	32	22	51	154
	Mean productivity per successful nest	**2.44**	**2.45**	**2.91**	**2.44**	**2.83**	**2.66**

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