BTO RESEARCH REPORT 733

Incidence of road mortality in ringed raptors and owls: a spatial analysis

Hugh J Hanmer & Robert A Robinson

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BTO, The Nunnery, Thetford, Norfolk IP24 2PU
Tel: +44 (0)1842 750050 Email: info@bto.org
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EXECUTIVE SUMMARY

1. Roads represent a significant threat to wildlife through both behavioural effects and the increased direct risk of mortality from collisions with vehicles. The effects of roads may be further increased in countries with dense road networks such as the UK. Some wildlife taxa such as raptors (typical birds of prey and owls) may be especially vulnerable and are often reported as road casualties. However, the true scale and importance of road casualties and other human caused (anthropogenic) mortality on raptors is poorly understood, primarily due to a lack of systematic data gathering and general under reporting. Here we use the existing BTO ring recovery dataset to explore the location and, where reported, circumstances of mortality for ringed raptors in the UK between 2002 and 2019. Within this we consider variations in recoveries and specifically road casualties in relation to species, location, age, season and the presence of roads.

2. We found that Barn Owl (*Tyto alba*) was by far both the commonest ringed and recovered raptor species making up approximately half of all ringing records and two-thirds of recoveries, followed by Kestrel (*Falco tinnunculus*), Tawny Owl (*Strix aluco*), Sparrowhawk (*Accipiter nisus*), Buzzard (*Buteo buteo*) and Red Kite (*Milvus milvus*), with all other species having fewer than 500 recovery records during the target period (2002–2019). The finding circumstances of most recoveries were not reported but, of those that were, human-related causes accounted for the overall majority; road casualties were the commonest recorded finding circumstance across eight species, including Barn Owl. Most recoveries across all considered species, apart from Hobby (*Falco subbuteo*), Long-eared Owl (*Asio otus*) and Sparrowhawk, were of young birds in their first summer or winter following hatching.

3. Across the UK, counties with high numbers of birds ringed typically also had a high number of individuals found dead, including road casualty recoveries, indicating most recoveries occurred in the same area they were ringed. The overall recovery rate per ringed bird (as a proxy of recovery effort) was broadly similar across the country suggesting minimal regional basis in recovery numbers. For some species, such as Goshawk (*Accipiter gentilis*), Hobby, Long-eared Owl, Marsh Harrier (*Circus aeruginosus*), Peregrine (*Falco peregrinus*) and Short-eared Owl (Asio *flammeus*), there were very few recoveries of any kind, in part due to limited numbers and locations of birds ringed. Overall, there was evidence that increased road length per county (as a proxy for road density) was significantly positively associated with increased numbers of raptor recoveries and road casualties, although further research would be helpful to quantify this effect further. The effect of season (summer/winter) on recoveries and road casualties varied between species and age class; recoveries for most species (apart from Barn Owl, Buzzard and Sparrowhawk) were during the summer season suggesting that recently fledged juveniles and breeding adults are generally more susceptible to road-based mortality.

1. INTRODUCTION

1.1. RAPTOR ROAD MORTALITY: OVERVIEW

Globally, roads have a significant influence on wild animal populations, both through direct effects such as the risk of death (roadkill) and injury, displacement through behavioural avoidance responses and the fragmentation of suitable habitat (Ibisch *et al.,* 2016). In some countries and regions, roads have been identified as a leading cause of human anthropogenic related mortality in both birds and other wildlife taxa (Erritzoe *et al.*, 2003; Calvert *et al*., 2013; Loss *et al.*, 2014; Grilo *et al*., 2020). Such effects are likely to be magnified in areas with a high density of roads, for example, over 70% of Britain being within 700 m of a road (Cooke, *et al.,* 2020a).

Raptors (birds in the orders Accipitriformes and Strigiformes), which are generally long lived, have low reproductive rates and often relatively small population sizes, may be especially sensitive to the high mortality rates potentially associated with roads and other anthropogenic causes (Freire *et al.*, 2020; De Pascalis *et al.*, 2020). Owls (Strigiformes), in particular, have been identified in multiple studies to be highly impacted by roads (Silva *et al*., 2008; Gomes *et al.*, 2009; Pinto *et al*., 2020) and roads have been implicated in local declines in populations in some species (Silva *et al.*, 2012; Borda-de-Água *et al*., 2014). Typical raptors (Accipitrifomes) have also been found to be significantly affected, with a recent study on the recoveries of dead ringed migratory raptors highlighting human-related mortality as being the principal reported cause of death in five of the six species investigated (De Pascalis *et al*., 2020). A recent report based on UK bird ringing road and rail casualty recovery records found raptors, especially Barn Owl (*Tyto alba*) but also to a lesser extent Kestrel (*Falco tinnunculus*), Peregrine (*Falco peregrinus*) and Tawny Owl (*Strix aluco*) to have high road mortality rates (Freire *et al.*, 2020).

Raptor road mortality rates vary seasonally, often being highest in the spring and summer, primarily due to the fledging and dispersal of juveniles as well as territorial and feeding behaviour in adults (Erritzoe *et al.,* 2003, Pinto *et al.,* 2020). However, this varies between species according to their ecology (Freire *et al*., 2020), with winter food shortages potentially driving greater ranging and thus greater risk for some (Grilo *et al*., 2014; Šálek *et al*., 2019; De Pascalis *et al*., 2020), while migratory species may be entirely absent with their mortality occurring elsewhere (De Pascalis *et al*., 2020).

Nevertheless, roads present both opportunities and threats to some raptor species (Meunier *et al*., 2000, Lambertucci *et a*l., 2009). In particular while scavenging species, such as Buzzards (*Buteo buteo*), may suffer high road casualty rates (Vidal-Vallés *et al.*, 2018), they can also benefit from other roadkill as a food source (Meunier *et al*., 2000; Lambertucci *et al*., 2009; Schwartz *et al*., 2018). Likewise, raptors such as Kestrel and some owls frequently hunt along roads due to potentially important concentrations of small mammal prey in road verges (Meunier *et al*., 2000; Ascensão *et al*., 2012; Ruiz-Capillas *et al*., 2013).

Some research has been done to identify potential wildlife mortality hotspots and mitigation both generally and for raptors in particular (Grilo *et al*., 2020; Morelli *et al*., 2020). In general, as should be expected, the presence of otherwise suitable habitat feeding and breeding habitat in close proximity to roads is usually associated with higher mortality rates (Gomes *et al*., 2009). Some mitigation measures around existing road infrastructure such as reducing the availability of good habitat have been recommend in some studies (Gomes *et al*., 2009; Grilo *et al*., 2014), although whether they have been purposefully implemented and tested anywhere is unclear. Indeed, such measures may be counterproductive to overall conservation efforts as roadside verges can provide important refugia for prey species (Meunier *et al*., 2000), which may justify the improvement of such habitat for wildlife (Underhill & Angola, 2000), despite the additional mortality risks.

There are other additional factors that must be accounted for when considering the effects of roads on wildlife mortality, including raptors. In particular, road type has also been identified as having a key effect on wildlife road impacts with major and minor/secondary roads sometimes differing in their apparent effects. Major roads with higher levels of traffic are generally associated with higher mortality rates, reduced habitat connectivity, and generally reduced abundance in the immediate surrounding area; as such, there may be a greater risk but also fewer birds present (Cooke *et al*., 2020b). Minor roads, especially in rural areas in Britain and many other developed countries, may have lesser effects but, with more birds occurring in their vicinity, it may be difficult to separate out the effects due to their widespread prevalence in the landscape (Cooke *et al*., 2020a; Cooke *et al*., 2020b; Kent *et al*., 2021).

Another important issue relates to the recording of road casualties themselves, with both carcass persistence and sampling/recording effort playing important roles

in our understanding. Due to their larger size and longer persistence (up to 1 week; Santos *et al*., 2011; 2016), raptor carcasses are more likely be detected, which may lead to biases in recording (Guinard *et al*., 2012; Husby, 2016; Pinto *et al*., 2020). This bias may be further exacerbated by the limited scale of many dedicated academic studies and low levels of official recording by statutory agencies meaning such estimates may not be representative of the wider scale (Bíl *et al*., 2020; Schwartz *et al*., 2020).

Our understanding of road mortality has been greatly enhanced by national volunteer citizen science surveys such as Project Splatter in the UK (projectsplatter.co.uk), especially for smaller species, although again it is important to consider the same potential recording bias already covered (Vercayie & Herremans, 2015; Bíl *et al*., 2020; Schwartz *et al*., 2020). This is even more important when considering recoveries of dead ringed birds, as carcasses must be found, checked and the details submitted for the casualty to be formally recorded (Robinson *et al*., 2009; Guillemain *et al*., 2011). This further limits the potential volume of information but also provides detailed life history information, such as age and breeding origin (not easily gathered in any other way), that may be vital for understanding mortality patterns and population effects (De Pascalis *et al*., 2020). It is also possible that other causes of mortality, such as persecution, may be deliberately concealed by the relatively high frequency of road mortality, by depositing carcasses in the vicinity of roads. However, there is little, if any, formally published research on this subject.

To explore and quantify the importance of road collision in raptor mortality, we summarise the records of birds marked by the British and Irish Bird Ringing Scheme and subsequently found dead.

2. METHODS

All data processing and analysis was undertaken in R version 4.0.3 (R Core Team, 2020).

2.1. DATA SETS

The raptor bird families considered were Accipitridae (hawks, eagles, buzzards, harriers and kites), Falconidae (falcons), Pandionidae (ospreys), Strigidae (typical owls) and Tytonidae (barn owls). These represent the commonest species of raptor occurring regularly in the UK (status summary provided in Appendix 1). Of these, Osprey (*Pandion haliaetus*), Hobby (*Falco subbuteo)* and to some extent Marsh Harrier (*Circus aeruginosus*) are breeding migrants in the UK. Eagles, Honey Buzzard (*Pernis apivorus*) and the other harrier species were not included at this time due to their relatively low and often geographically remote or sensitive breeding populations.

Since 1939, BTO has co-ordinated the ringing and marking of individual birds in the UK and a proportion of these are subsequently encountered, either dead or alive, each year (Robinson *et al*., 2009; Guillemain *et al*., 2011). Data were drawn from the period 2002 to 2019, for which all ringing and re-encounter records have been computerised. Almost all initial raptor ringing records were of nestlings in all species (apart from Sparrowhawk, where only 31% were), as full-grown raptors are rarely encountered during standard ringing activities outside of specific targeted studies. When a bird is re-encountered and it is reported, its condition and presumed cause of death are recorded, although for some individuals only part of this information is submitted.

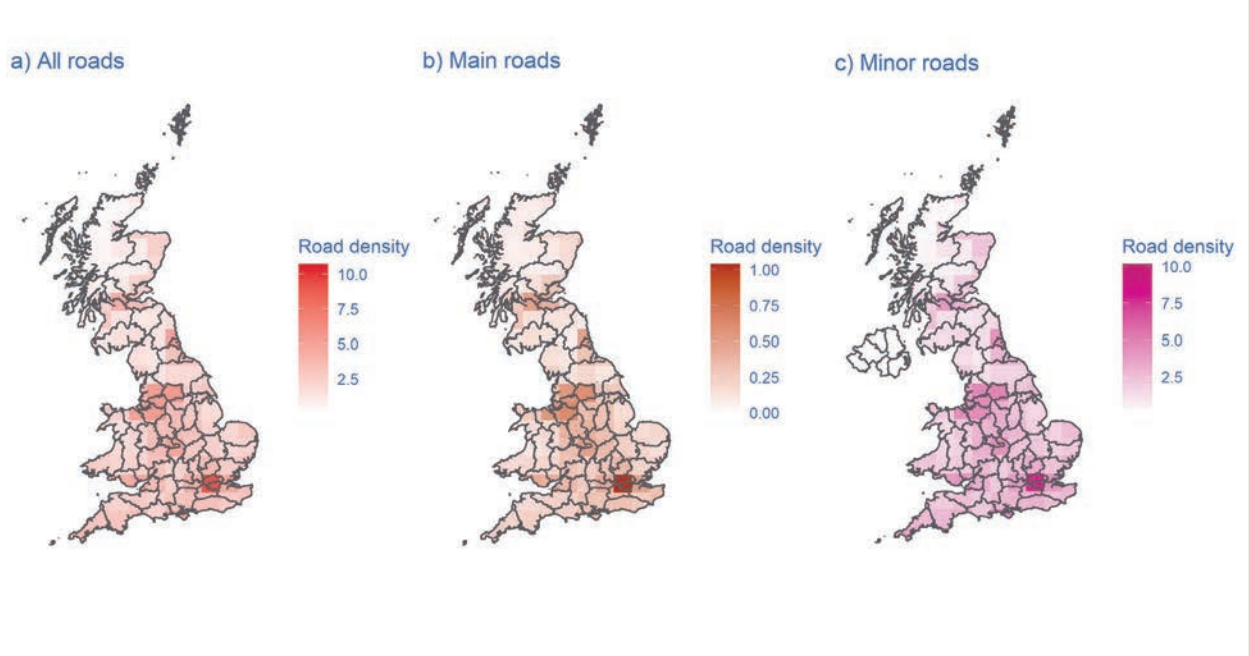
Cause of death was classified according to a Europe-wide standardised coding scheme (du Feu *et al*., 2018). For this analysis, as mortality is of primary interest, records for dead re-encounters (hereafter recoveries) were selected and summarised including specific finding circumstances were recorded (Table 1). Note that more than half of recoveries were reported without an associated finding circumstance. While most of these are likely to be from 'natural causes' (e.g. starvation, disease) where no obvious symptoms are present, some of these individuals may have been road traffic casualties but this was simply not evident from the recovery reports. It is also important to bear in mind that the reported cause of death may not reflect the actual cause of death, for example, a bird killed at the side of a road by a predator that was subsequently disturbed may be reported as an apparent traffic casualty even though this was not the actual cause of death, but these specific caveats should not detract from the overall patterns presented.

Species distribution (breeding and winter) and relative breeding abundance maps were produced for each species adapted from *Bird Atlas 2007–2011* (Balmer *et al.*, 2013), which also acted as a source for written individual species accounts. Public road data were sourced from the Ordnance Survey (OS) Open Roads March 2019 vector data set for Britain (Ordnance Survey, 2019). A comparable road data set was not readily available for Northern Ireland, so analysis and summaries relating to road data were only for Britain (Figure 1).

Table 1. Summary of some of the primary recorded finding circumstances for dead raptor recoveries in the UK.

Simplified finding circumstances	Detailed finding circumstances and examples
Natural	Weather (cold, hot, violent, etc.)
	Poor condition/disease
	Predation
	Tangled/collided with natural object
	Drowned
Human related	Road casualty
	Other transport casualty (rail, aircraft)
	Tangled/collided with other human object (hit glass, wires, etc.)
	Active human enterprise (shot, poisoned, etc.)
Not reported	Unknown or not specifically recorded

Figure 1. Total road length per km (density) for each simplified British county for a) all roads, b) main roads (motor ways and A roads) and c) minor roads (B, C and unclassified roads). Note differing scales between the three maps.



2.2. SUMMARIES AND ANALYSIS

The raptor ringing, recovery and roadkill data were summarised overall and per UK 50-km grid square based on the British and Irish National Grid. The length of road per per 50-km grid square was calculated in kilometres, both overall and for main/major (A roads and motorways) and minor/secondary (B, C and unclassified public roads) specifically. The number of dead recoveries and dead road casualties per km of main, minor and all roads was also calculated for each 50-km grid square.

For overall summaries of seasonal recoveries, summer was defined as April to September (the breeding season for the majority of species) and winter as October to March; both periods are of equal length (6 months). Bird age at death, where known, was classified as young (first summer/winter) and adult (at least second summer/winter) during the relevant season.

To facilitate interpretation, plots relating to raptor ringing, recovery and recovery circumstances (including road casualties) are generally displayed in green, blue and pink/red respectively. In addition, seasonal data are displayed in red and blue for the summer and winter respectively.

3. RESULTS & SUMMARY

3.1. Overall raptor ringing and recovery summary

In the UK between 2002 and 2019, 279,100 raptors were ringed and 17,241 recovered dead (Table 2). Barn Owls were by far the commonest species both ringed and recovered (49.6% and 66.3% of overall records respectively; Table 2). Overall, the finding circumstance was reported for 43.3% of dead recoveries, with similar percentages across all individual species (Table 2; Figure 2). Of those where the finding circumstances were reported, human-related activity accounted for the vast majority of records across all species, with road casualties being the single commonest recorded finding circumstances across eight species including Barn Owl (Table 2; Figure 2). Most recoveries across all considered species, apart from Hobby, Long-eared Owl (*Asio otus*) and Sparrowhawk (*Accipiter nisus*), were of young birds in their first summer or first winter (Figure 3).

Figure 2. Reported finding circumstances for dead raptor recoveries in the UK 2002–2019 (examples of each category can be found in Table 1).

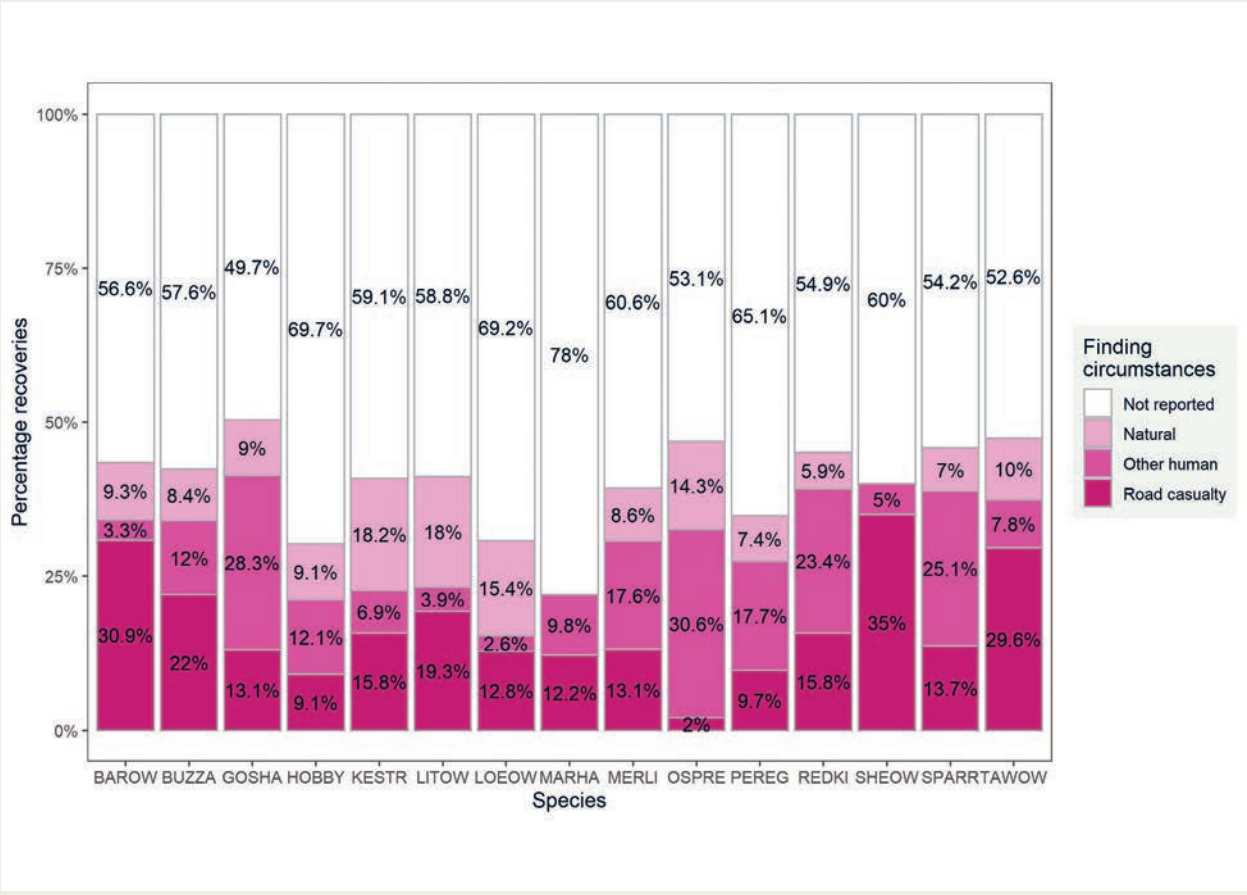
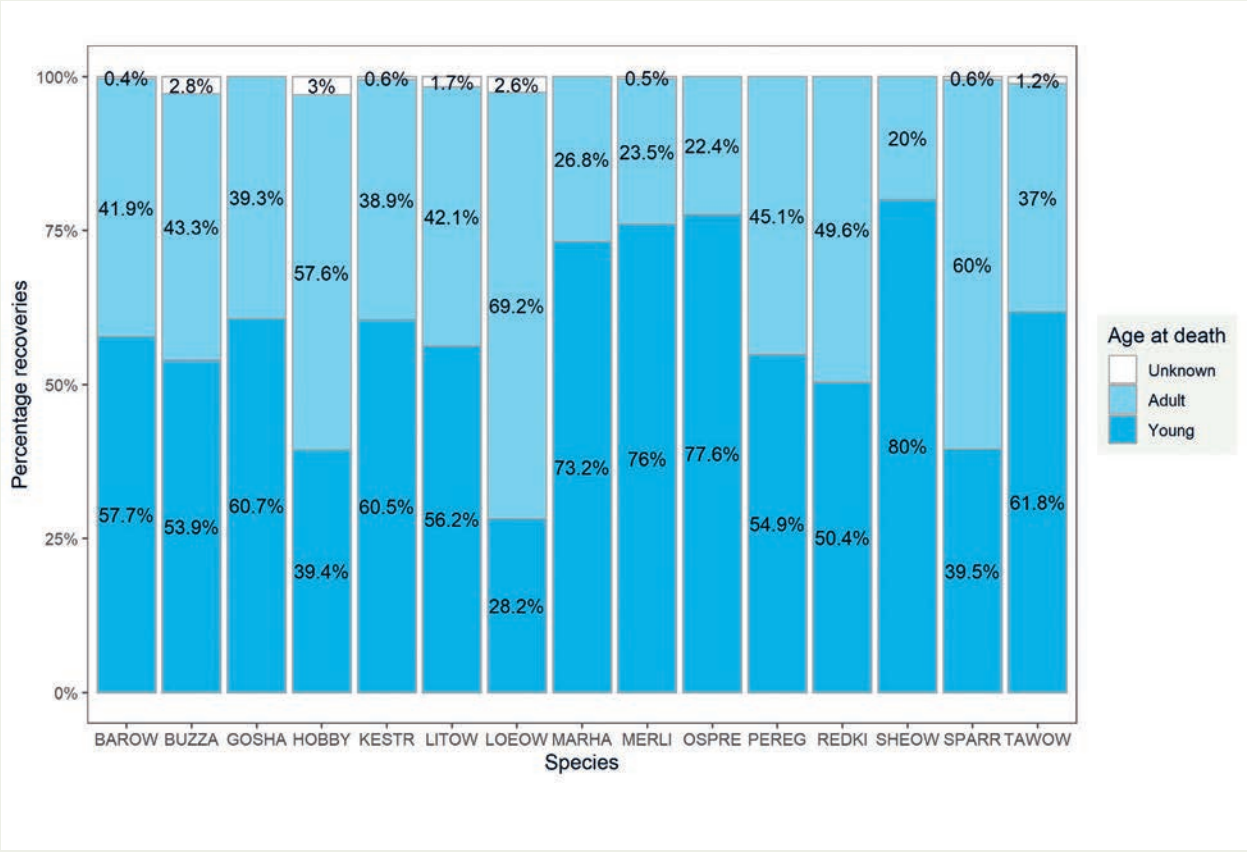


Table 2. Total new and recovery records and finding circumstances for raptors ringed in the UK 2002–2019.

Species	Species code	Total new birds ringed	Total dead recoveries	Recovery circumstances			
				Road casualty	Other human	Natural	Not reported
Barn Owl	BAROW	138,297	11,434	3,533 (30.9%)	373 (3.3%)	1,060 (9.3%)	6,468 (56.6%)
Buzzard	BUZZA	9,965	573	126 (22.0%)	69 (12%)	48 (8.4%)	330 (57.6%)
Goshawk	GOSHA	5,103	145	19 (13.1%)	41 (28.3%)	13 (9.0%)	72 (49.7%)
Hobby	HOBBY	1,935	33	3 (9.1%)	4 (12.1%)	3 (9.1%)	23 (69.7%)
Kestrel	KESTR	41,794	1,671	264 (15.8%)	116 (6.9%)	304 (18.2%)	987 (59.1%)
Little Owl	LITOW	7,795	233	45 (19.3%)	9 (3.9%)	42 (18.0%)	137 (58.8%)
Long-eared Owl	LOEOW	1,221	39	5 (12.8%)	1 (2.6%)	6 (15.4%)	27 (69.2%)
Marsh Harrier	MARHA	1,730	41	5 (12.2%)	4 (9.8%)	NA NA	32 (78.0%)
Merlin	MERLI	7,660	221	29 (13.1%)	39 (17.6%)	19 (8.6%)	134 (60.6%)
Peregrine	PEREG	5,722	49	1 (2.0%)	15 (30.6%)	7 (14.3%)	26 (53.1%)
Osprey	OSPRE	5,722	350	34 (9.7%)	62 (17.7%)	26 (7.4%)	228 (65.1%)
Red Kite	REDKI	8,884	546	86 (15.8%)	128 (23.4%)	32 (5.9%)	300 (54.9%)
Short-eared Owl	SHEOW	921	20	7 (35.0%)	1 (5.0%)	NA NA	12 (60.0%)
Sparrowhawk	SPARR	15,860	889	122 (13.7%)	223 (25.1%)	62 (7.0%)	482 (54.2%)
Tawny Owl	TAWOW	26,491	997	295 (29.6%)	78 (7.8%)	100 (10.0%)	524 (52.6%)
Grand total		**279,100**	**17,241**	**4,574 (26.5%)**	**2,856 (6.7%)**	**1,207 (10.0%)**	**8,604 (56.7%)**

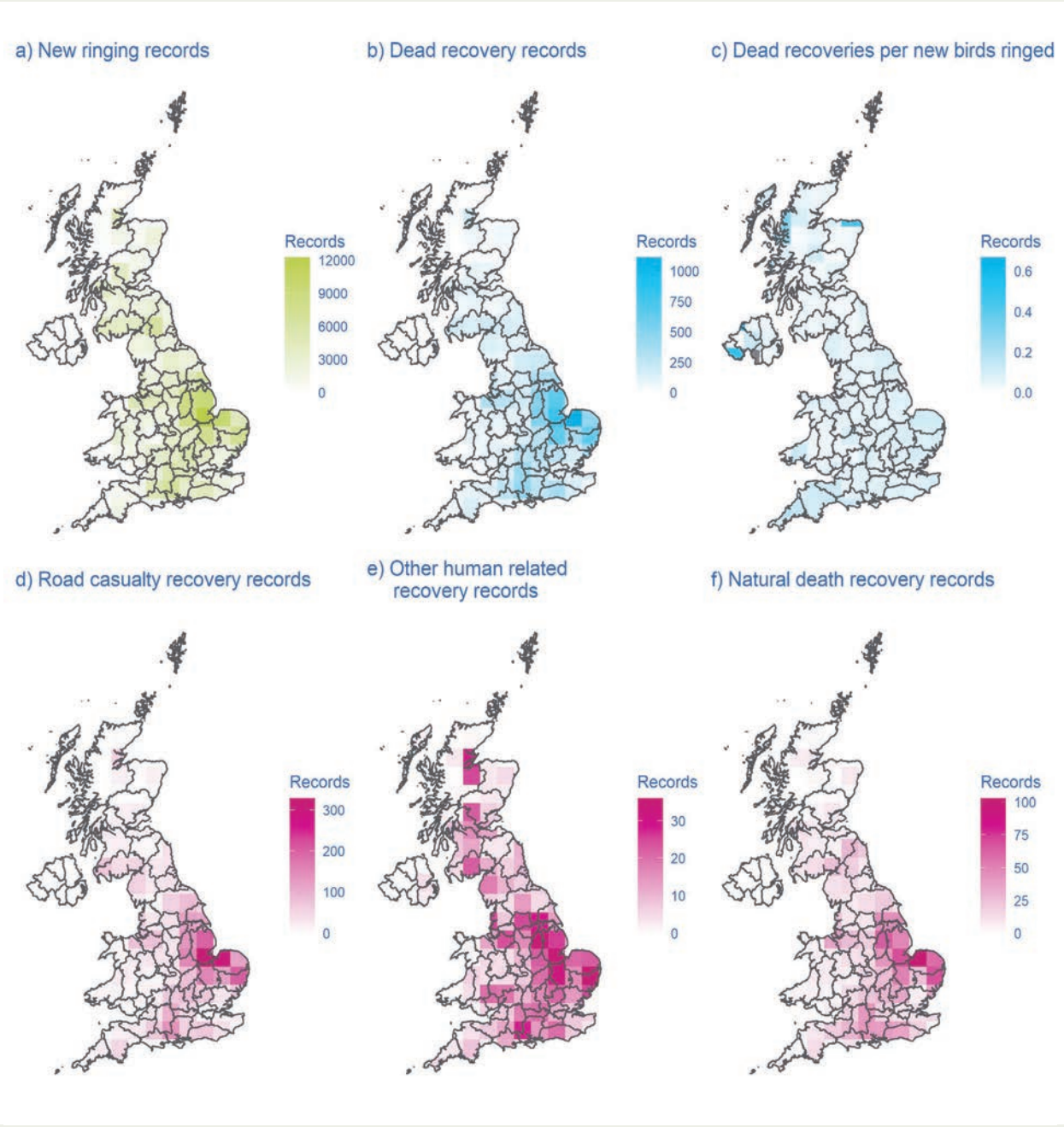
Figure 3. Age at death by species for raptors recovered in the UK. Young are birds < 1 year old.



3.2. Spatial distribution of records

Across the UK, counties with a higher number of birds ringed typically also had higher incidences of dead recoveries, including road casualty recoveries (Figure 4), indicating that, across all species, most recoveries occurred in the same area they were ringed in and that recovery rates/effort (the ratio or recoveries to new birds ringed) was relatively uniform nationally. This suggests that the recovery effort was broadly uniform nationally with minimal regional biases in recovery numbers (Figure 4c). Norfolk and Lincolnshire were highlighted as having especially high numbers of records across all categories due to the large numbers of Barn Owls ringed and recovered in these counties (Figure 4; Figure 9; see the Barn Owl species account). Maps for comparing between species, of the numbers of birds ringed, recovered overall and as road casualties, are included in Appendix 2 for 50-km grid squares using log scales to aid comparisons. For all species, the numbers of new and recovered birds in a given 50-km square were significantly correlated overall, further indicating that most birds were recovered in the same area they were ringed in and that recovery rate/effort was broadly uniform and proportional to ringing effort, although the actual strength of the correlation varied between species (Appendix 3).

Figure 4. Total records of a) newly ringed, b) dead recoveries and c) reported road casualty recovery of raptors per 50-km grid square. Grey indicates there were no records of the relevant type from that square. Overlaid with UK ceremonial county outlines. Note differing scales between maps.



For Britain specifically, the number of recoveries and recorded road casualties per kilometre of road across all road types was highest in Norfolk and Lincolnshire with relatively high totals recorded in most of the neighbouring counties and Wiltshire (Figure 5).

There were weak but significant positive linear relationships between increased length of road across all types (all, main and minor) and increased recovery totals and specifically increased road casualties per 50-km grid square (Figure 6). A similar pattern was observed if records Barn Owl (much the commonest species) were excluded.

Figure 5. Dead and road casualty records within each 50-km grid square per km of road in Great Britain (all roads, main roads and minor roads). Overlaid with UK ceremonial county outlines. Note differing scales between maps.

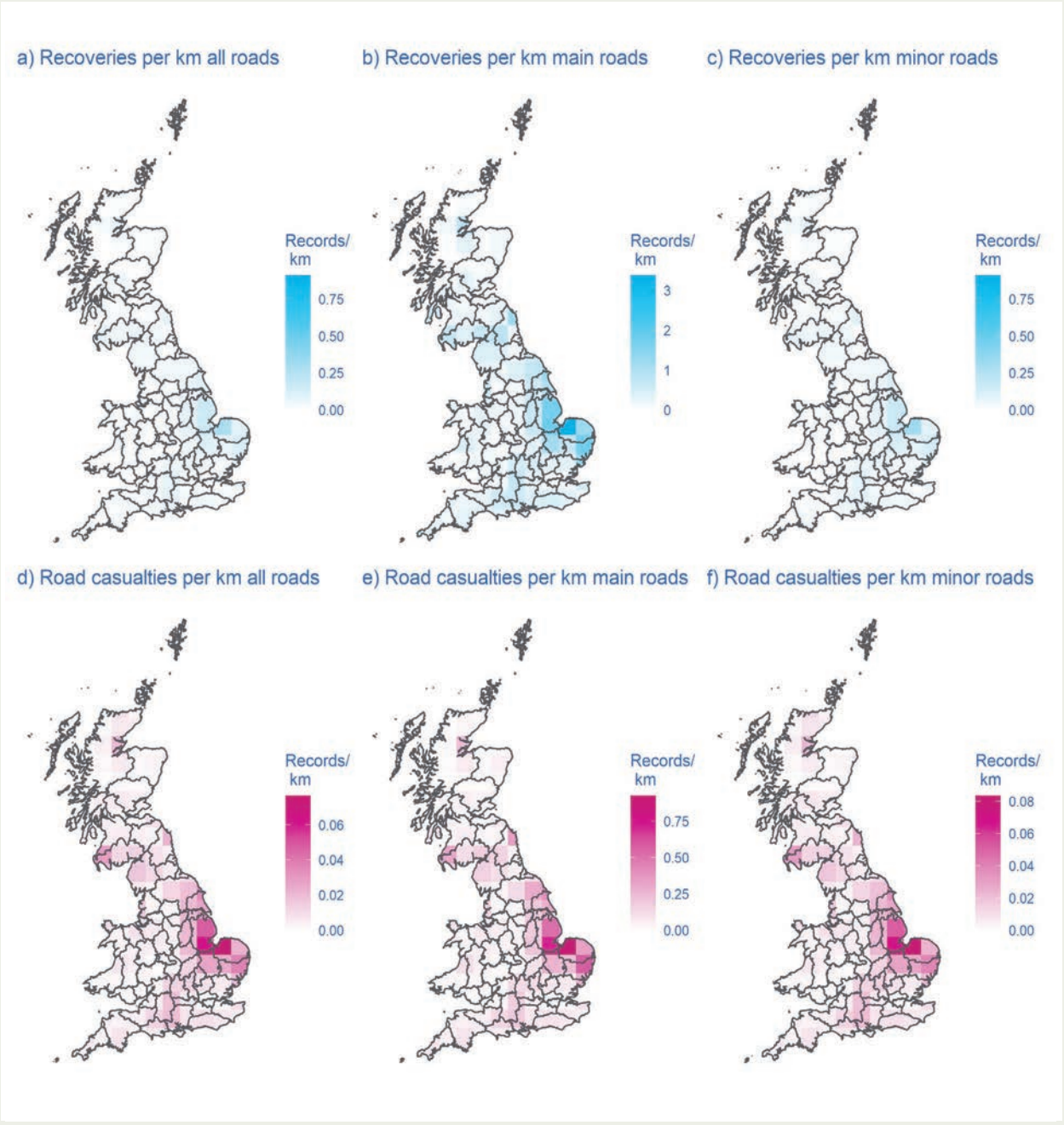
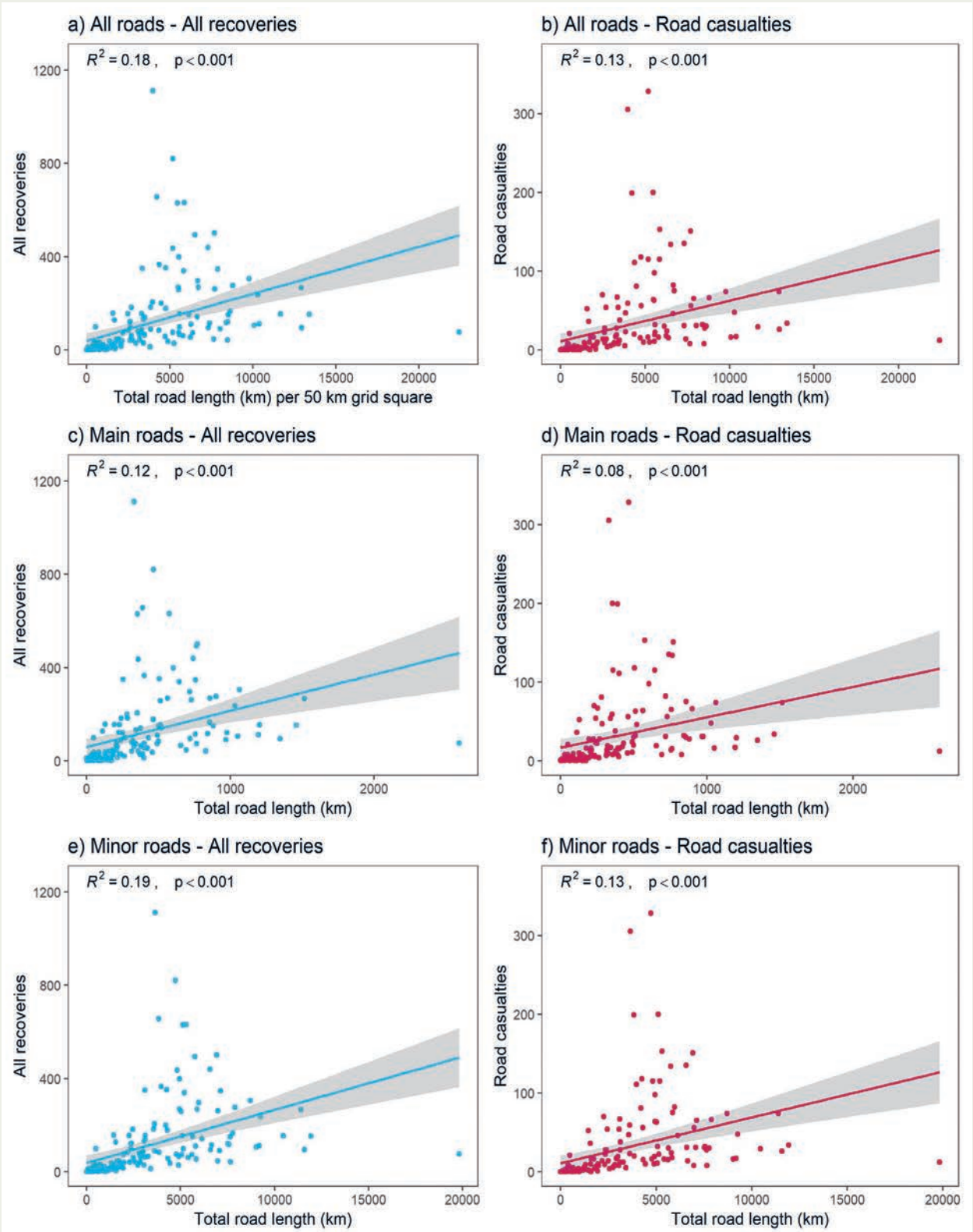


Figure 6. The relationship between the total length of road by type (all roads, main roads or minor roads) within a 50-km grid square and the combined total number of recoveries or reported road casualties of all species combined for that square. Plotted with a linear logistic regression line, 95% confidence intervals, R^2 and p values. Note differing scales between plots.



3.3. Seasonal distribution of records

Overall, for most species, apart from Barn Owl, Buzzard and Sparrowhawk, the majority of recoveries came during the summer season (Figure 7). However, apparent seasonal mortality rates varied slightly between young and adult birds. Adult recovery frequencies were higher during the breeding season across all species and in 11 species for young birds (Figure 7). As already noted, Osprey, Hobby and some Marsh Harriers are breeding migrants in the UK and so had few winter records of any kind.

Similarly, for reported road casualties specifically, the majority occurred during the summer months apart from in Barn Owl, Buzzard and Sparrowhawk (Figure 8). For these three species and Tawny Owl, most young bird road casualties also occurred in the winter whereas for all others and for all adults they primarily occurred during the summer (Figure 8).

Figure 7. Percentage of dead recoveries by species and season of finding overall, and by age at death where known.

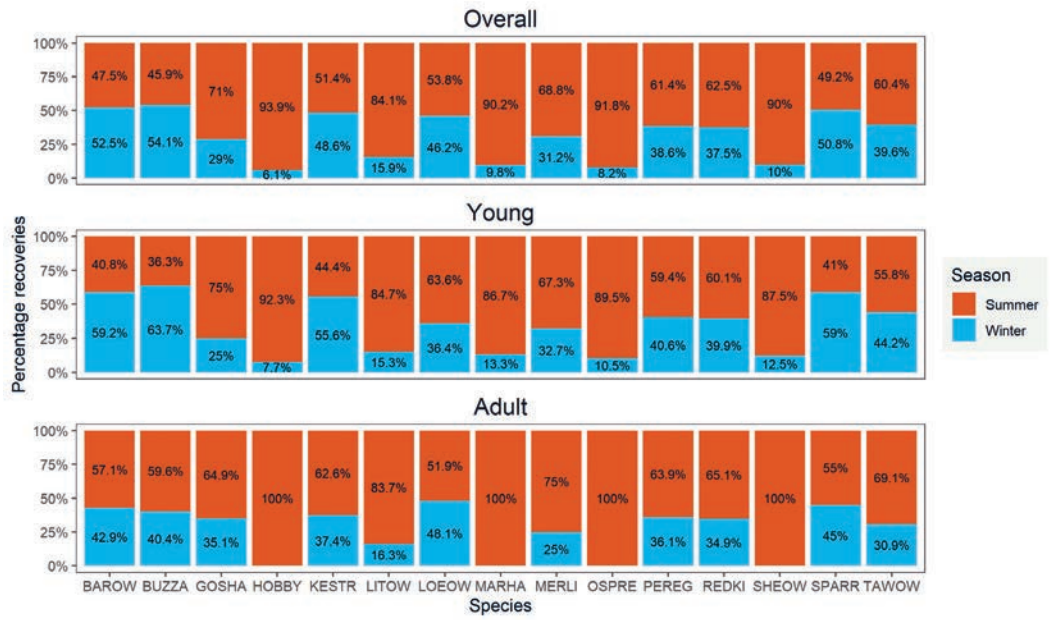
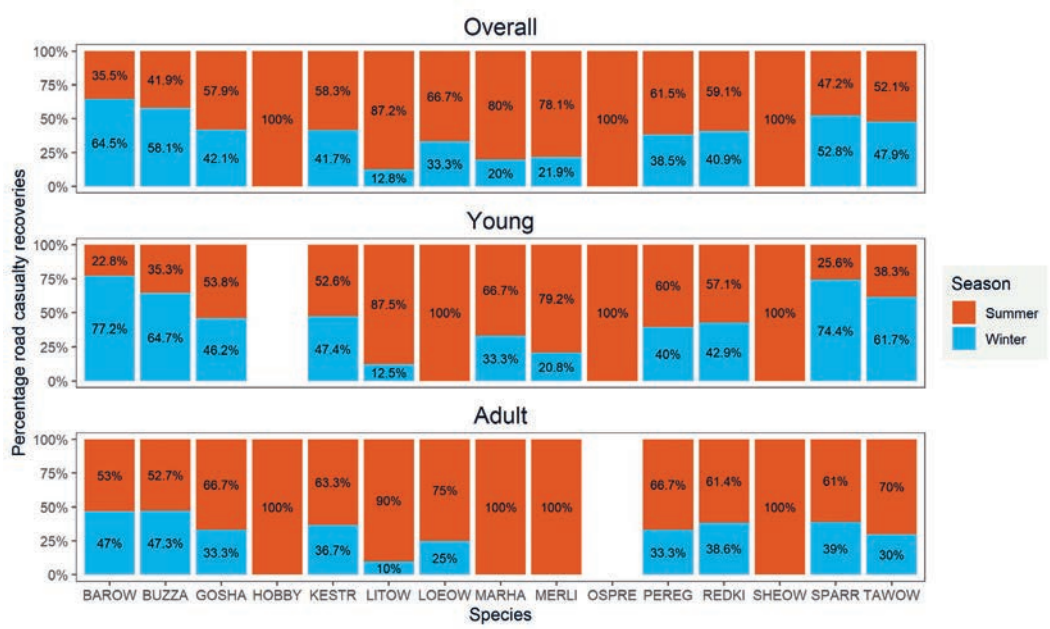


Figure 8. Percentage of total reported road casualty recoveries by species and season of finding overall, and by age at death where known.



Barn Owl (BAROW)
Tyto alba

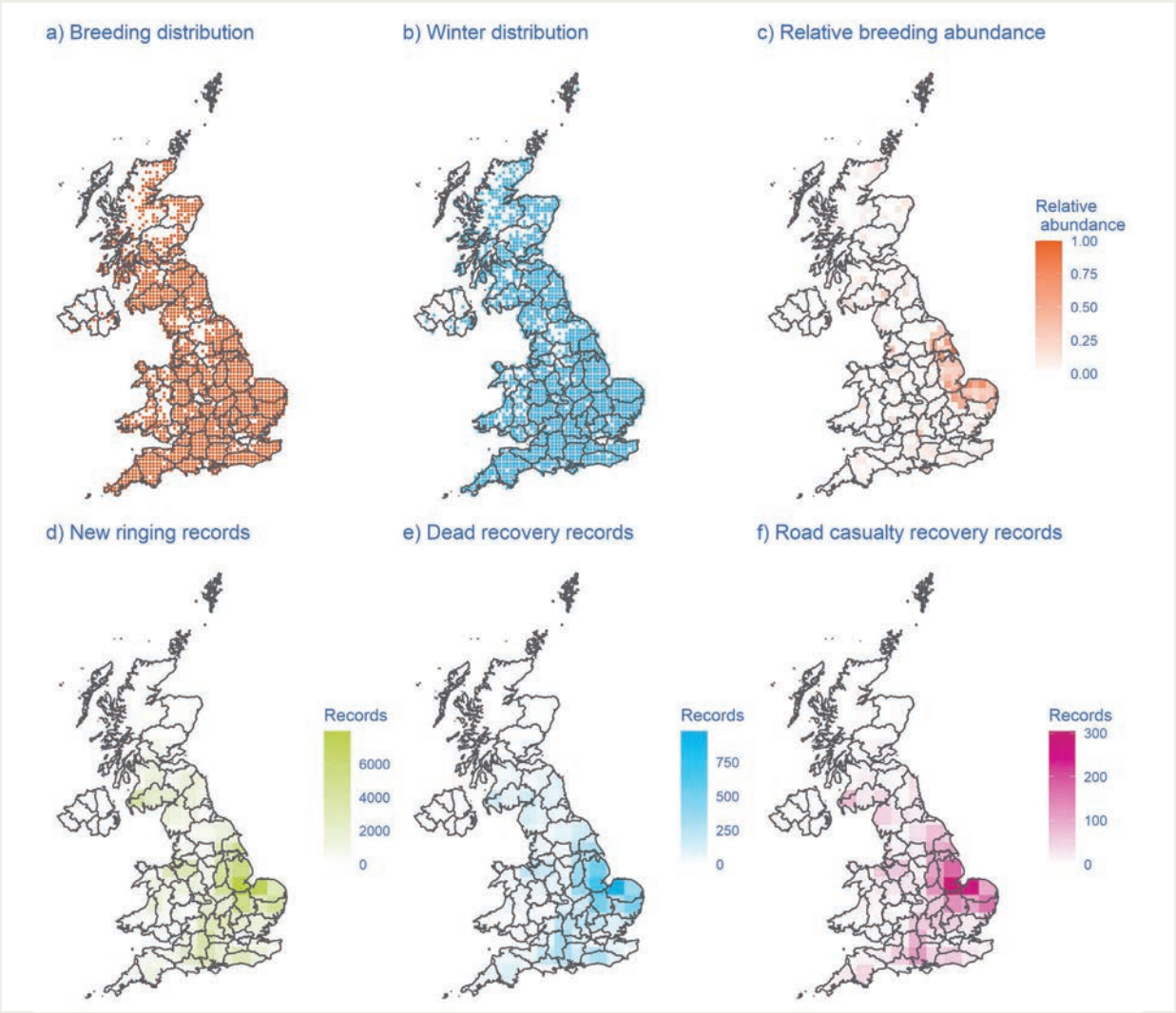
Number ringed:	138,297
Number recovered:	11,434
Number of road casualties:	3,692

Barn Owls are widely distributed in the UK, except in most upland areas, some remote islands and in Northern Ireland. Having undergone declines in the past, their populations have recovered significantly in recent decades. The largest population density lies in the east of England, especially Norfolk and Lincolnshire. They are found primarily in open agricultural landscapes in high densities and so are relatively likely to encounter road traffic, especially at dusk, when the risk of mortality may be higher.

Ringing and recovery records (including road casualties) are distributed across their range although the majority of records come from their population stronghold in the east of England.

Most Barn Owl recoveries were of young birds (57.7%), in the first winter of life (59.2% of young bird recoveries), whereas most adult recoveries came during the summer breeding season (57.1%). Road collision-related casualties formed the single largest reported recovery circumstance (30.9% of all recoveries) with most road casualties reported from the winter (64.5%), due to the high percentage of young bird casualties.

Figure 9. Barn Owl a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



(Common) Buzzard (BUZZA)

Buteo buteo

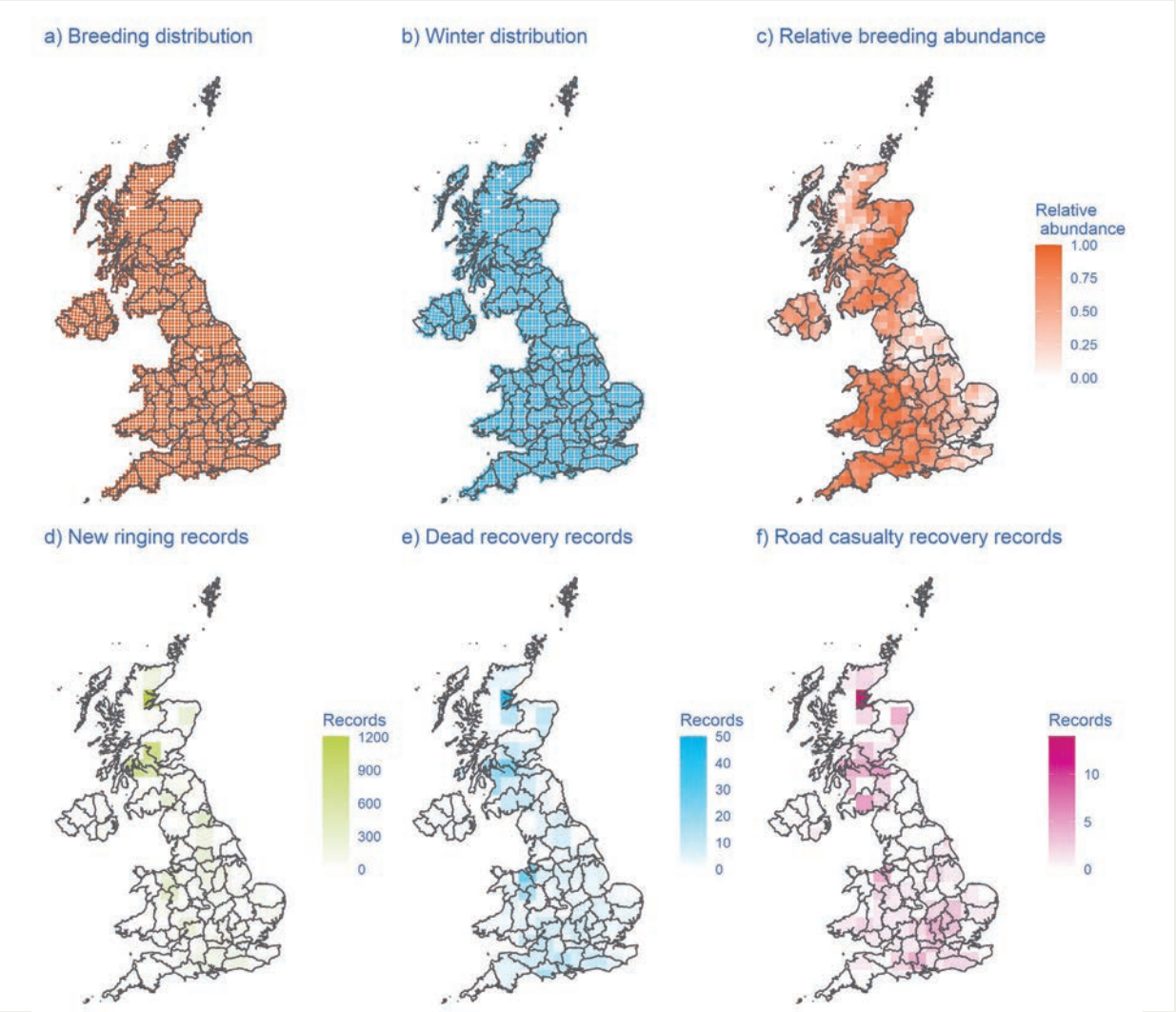
Number ringed:	9,965
Number recovered:	573
Number of road casualties:	136

Buzzards are common and widespread in the UK, having increased significantly in recent years with the highest population densities in Scotland, Wales and southwest England, and a slight increase in winter range due to juvenile dispersal. They are found across a wide range of habitats from uplands to lowlands, and frequently scavage from roadsides putting them at higher risk of road traffic collisions.

Although ringed and recovered across the UK, the largest number of records including recorded road casualties come from a limited area in the Highlands of Scotland. As such, ringing recoveries may not provide a representative picture for the UK because even though Buzzards are common in many areas lacking road casualty recoveries, the relative difficulty of monitoring Buzzard breeding attempts means the numbers of birds ringed and recovered varies regionally.

Most Buzzard recoveries were of young birds (53.9%), in the first winter of life (63.7% of young bird recoveries) whereas most adult recoveries came during the summer breeding season (59.6%). Road collision-related casualties formed the single largest reported recovery circumstance (22.0 % of all recoveries) with most road casualties reported from the winter (58.1%), due to the high percentage of young bird casualties reported above.

Figure 10. Buzzard a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



(Northern) Goshawk (GOSHA)
Accipiter gentilis

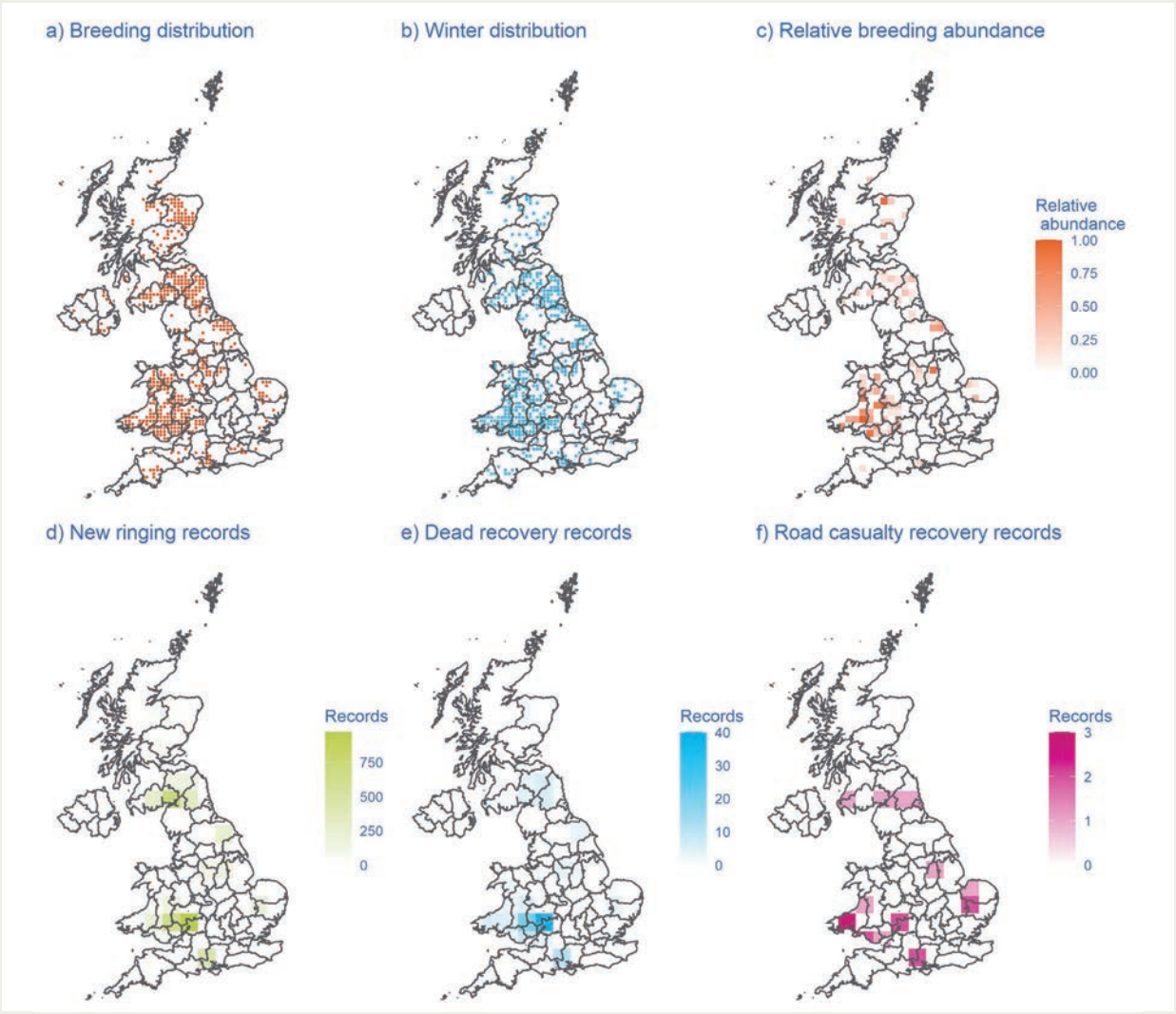
Number ringed:	5,103
Number recovered:	145
Number of road casualties:	19

Goshawks have a relatively restricted distribution, occurring in Wales, adjacent areas of England and the English/Scottish border area and are largely clustered in scattered forestry areas with few records from Northern Ireland. They have a slightly larger winter range, due to juveniles dispersing. In the UK, they are found mainly in areas of extensive forestry and old open woodlands, so are less likely to encounter roads than some species.

There are relatively few ringing and even fewer recovery records anywhere, with most records coming from the population strongholds of southern Wales and Dumfries and Galloway.

Most Goshawk recoveries were of young birds (60.7%), in the first summer as juveniles (75.0% of young bird recoveries) with most adult recoveries also occurring during the summer breeding season (64.9%). Most recorded recovery circumstances came from other human-related causes (28.3%), such as persecution, with road casualties being a secondary cause of mortality (13.1%). Most road casualties were reported in the summer (42.1%).

Figure 11. Goshawk a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



(Eurasian) Hobby (HOBBY)
Falco subbuteo

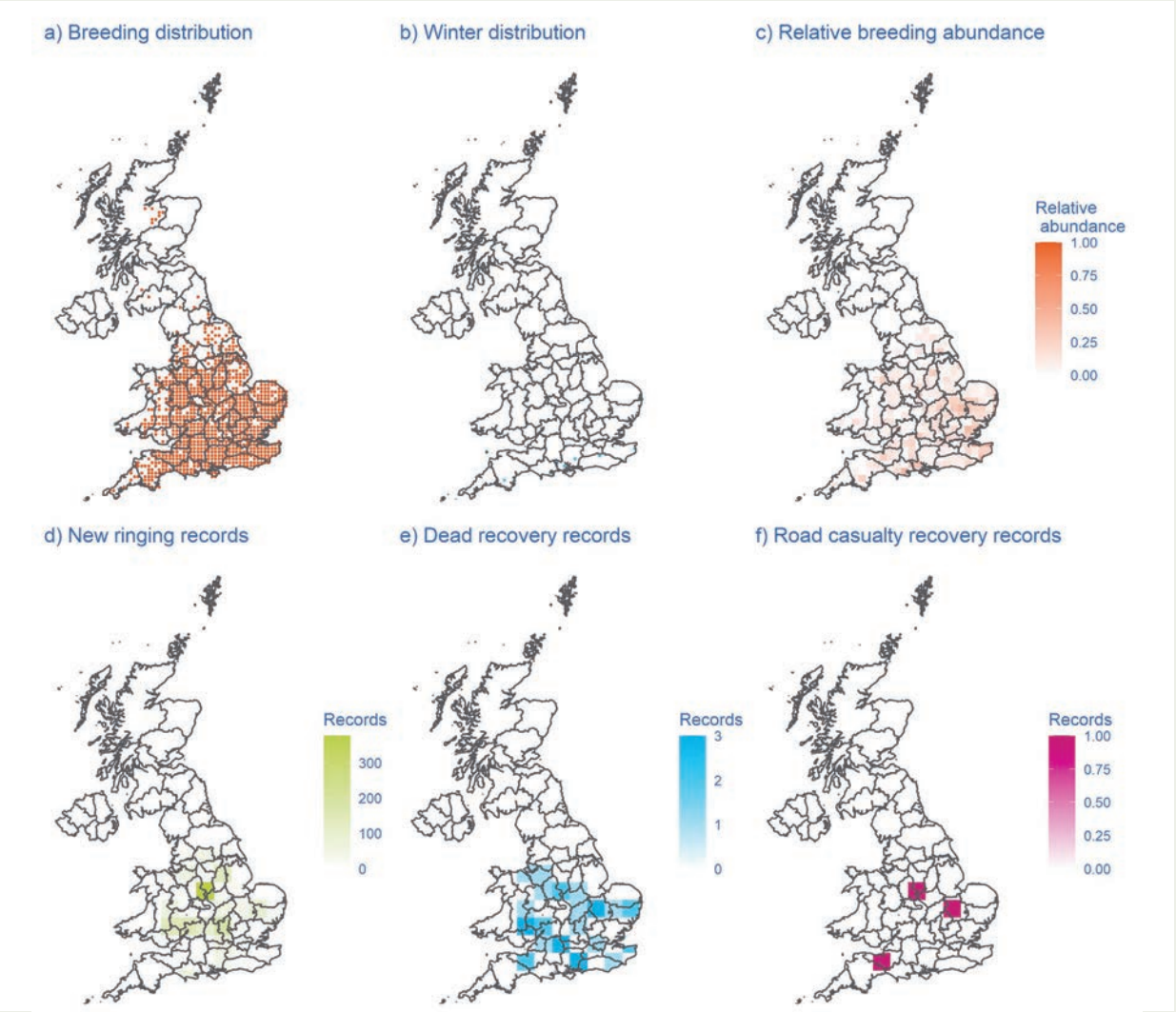
Number ringed:	1,935
Number recovered:	33
Number of road casualties:	4

Hobby is a relatively widespread breeding species in southern Britain, with limited populations elsewhere and absent from Northern Ireland. The breeding highest densities occur in eastern England, particularly East Anglia and Kent. As a breeding migrant, they are effectively absent during the winter months with any winter records likely representing late passage birds. They breed mainly in open woodland but regularly hunt over open areas such as farmland, wetland and grassland where they are aerial predators, so they are less likely to come into contact with traffic than certain other falcons.

Relatively small numbers of birds have been ringed across their range, with only a handful of recoveries recorded during the period of interest Single road casualty recoveries come from three English counties.

Most Hobby recoveries were of adult birds (57.6%) likely due to much of the juvenile mortality occurring outside the UK, during migration or on their wintering grounds rather than during the limited time there are in the UK. Of the few recorded recovery circumstances, other human-related causes were the most important (12.1%) followed by road casualties and natural causes (both 9.1%).

Figure 12. Hobby a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



(Common) Kestrel (KESTR)
Falco tinnunculus

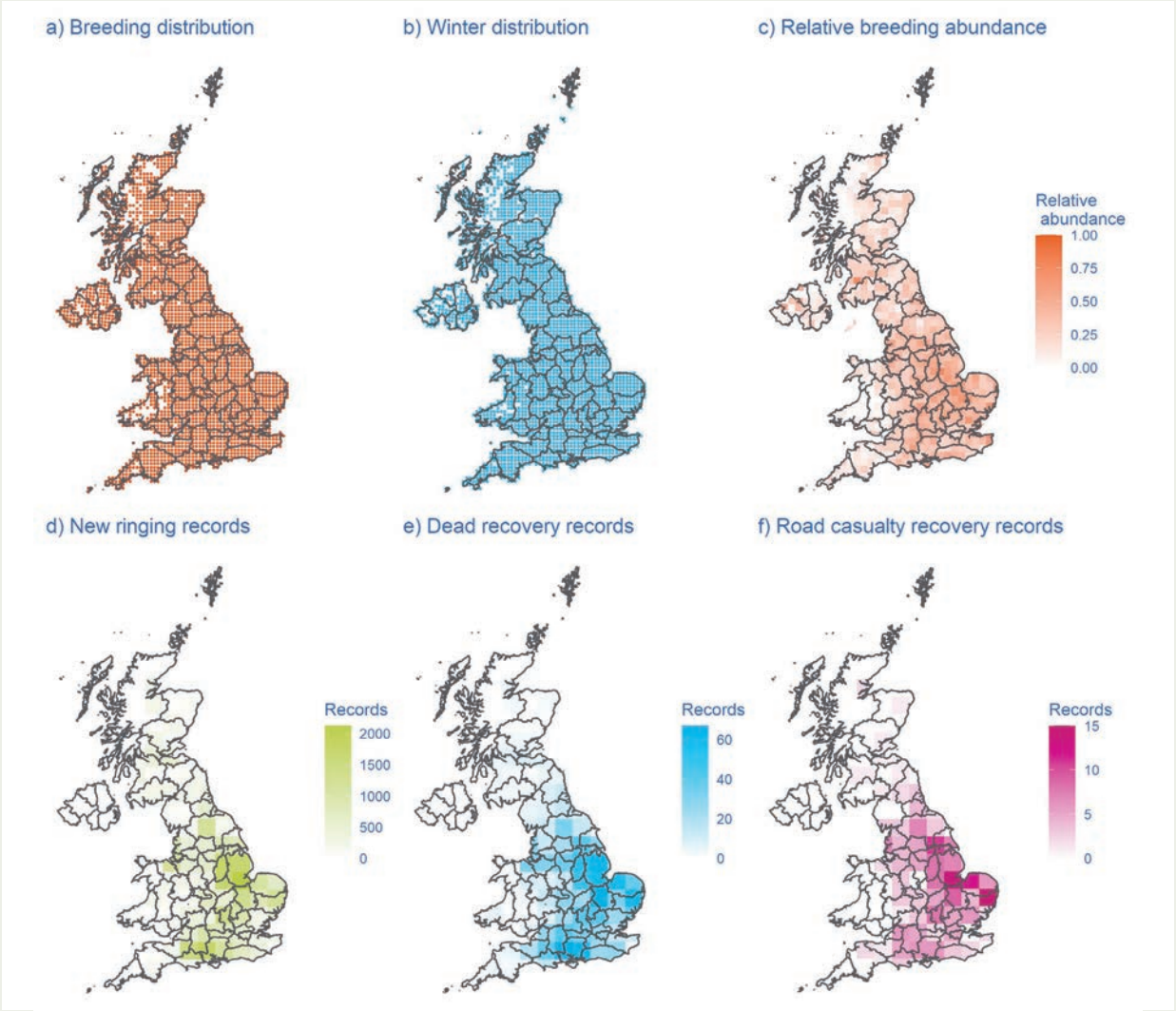
Number ringed:	41,794
Number recovered:	1,671
Number of road casualties:	309

Kestrels are widespread and abundant across the UK during the summer and winter, absent only from small patches in Wales, Northern Ireland and Scotland, although they have undergone recent population declines. They are a species of open landscapes such as farmland and upland, often hunting in road margins for small mammals, putting them at high risk of traffic collisions.

They are ringed and recovered across much of their range apart from most of Northern Ireland, although ringing effort and consequently recoveries including road causalities are concentrated in Norfolk, Lincolnshire, Wiltshire and Yorkshire with monitoring often associated with Barn Owl projects (Kestrels will also nest in boxes).

Most Kestrel recoveries were of young birds (60.5%), in the first winter of life (55.6% of young bird recoveries) whereas most adult recoveries came during the summer breeding season (62.6%), although overall the seasonal split of records was approximately equal. Natural circumstances was the leading cause of death (18.2%), followed by road casualty (15.8%), with most road casualties reported from the breeding season (58.3%).

Figure 13. Kestrel a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Little Owl (LITOW)
Athene noctua

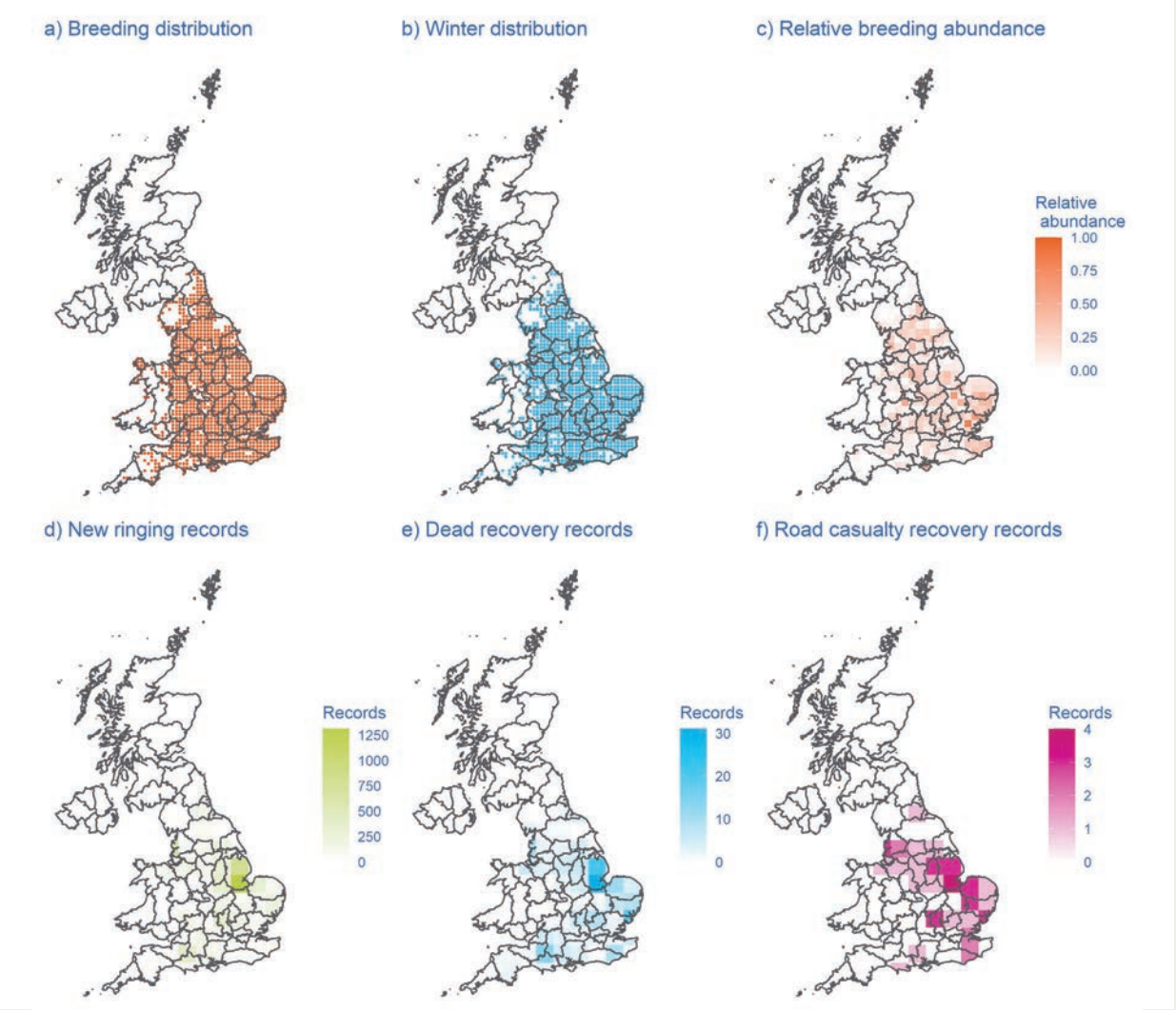
Number ringed:	7,795
Number recovered:	233
Number of road casualties:	47

Little Owl, an introduced breeder, is a widespread but declining species in southern Britain, primarily concentrated in eastern England with small, relatively isolated populations in Wales. This is primarily a bird of farmland although the species may stray into urbanised areas, putting individuals at risk from collision with motor vehicles on minor roads.

Although ringed (in relatively low numbers) across much of their range, most ringing and recovery records, including road casualty records, come from Lincolnshire with large parts of their range lacking any recovery records.

Most Little Owl recoveries were of young birds (56.2%), with the vast majority of recoveries of both young birds and adult coming during the summer (84.7% and 83.7% respectively). Road casualty was the single largest recorded death circumstance (19.3%) closely followed by natural causes (18.0%), with most road casualties reported from the breeding season (87.2%).

Figure 14. Little Owl a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Long-eared Owl (LOEOW)

Asio otus

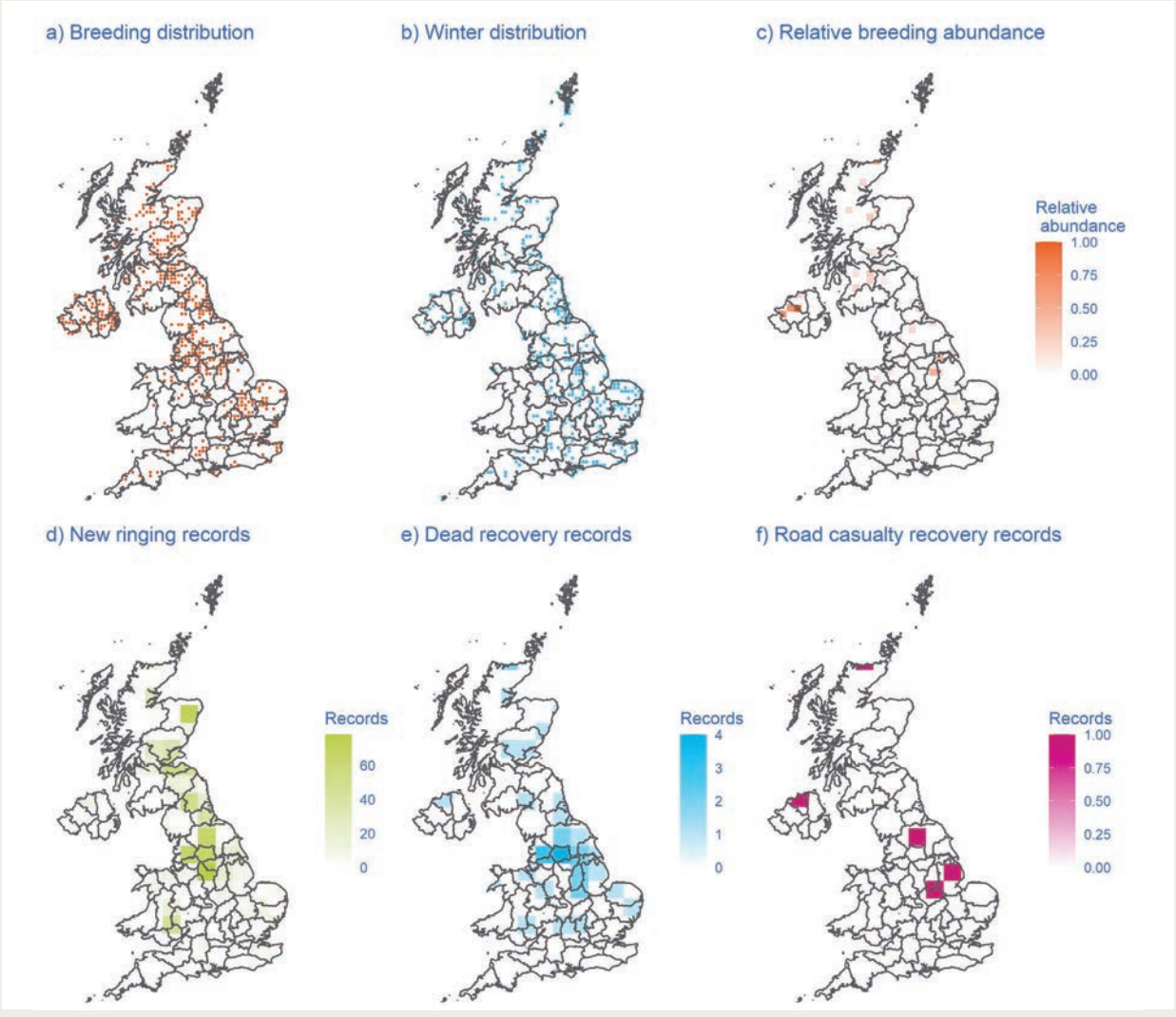
Number ringed:	1,221
Number recovered:	39
Number of road casualties:	6

Long-eared Owl is a widespread but under-recorded species in the UK. The apparently resident breeding population is augmented by variable numbers of overwintering birds from elsewhere in Northern Europe leading to a more widespread winter distribution, although this may be linked to seasonal detectability as much as distribution. In the UK they are found primarily in coniferous and mixed woodland away from roads, although they often roost during the winter months in scrub habitat (including roadside vegetation).

Ringing and recovery encounters were concentrated in Scotland and Northern England with few recoveries elsewhere. Only a handful of road casualty recoveries have been reported. Many of the initial ringing encounters from this species come from coastal ringing sites, likely of migrating birds, and as such recoveries of this species may not be representative of the UK breeding population.

Most of the few Long-eared Owl recoveries were of adult birds with a roughly even split between the seasons of adults while more young birds were recovered in the summer soon after fledging (63.6%). Natural circumstances were the leading cause of death (15.4%) followed by road casualties (12.8%), with most of the few road casualties reported coming from the breeding season (66.7%).

Figure 15. Long-eared Owl a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



(Western) Marsh Harrier (MARHA)

Circus aeruginosus

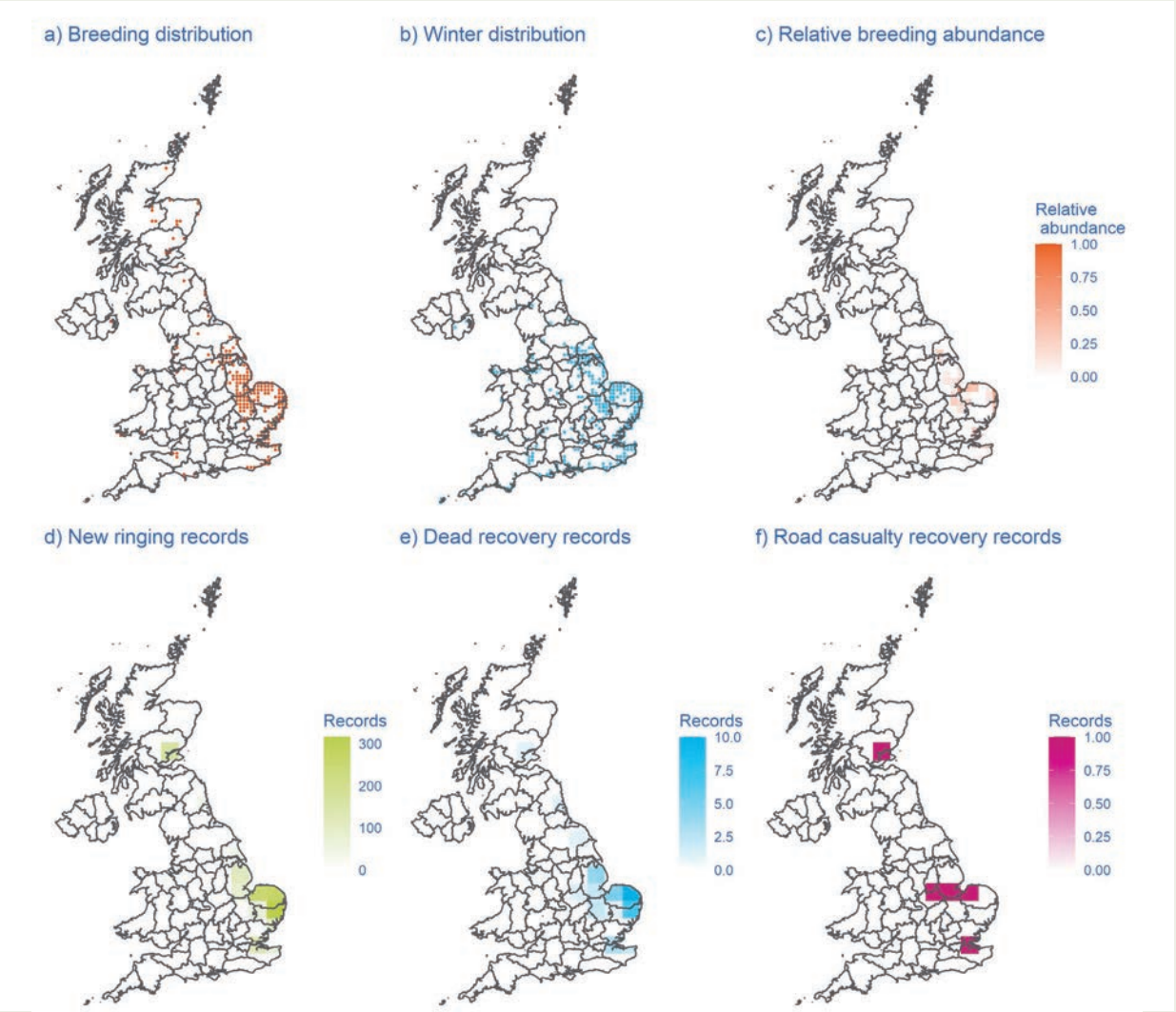
Number ringed:	1,730
Number recovered:	41
Number of road casualties:	5

Marsh Harriers are concentrated primarily in the east of England with an increasing proportion of their slowly expanding population present year-round. They primarily breed (and winter) around marshes and reedbeds and so rarely come into contact with roads normally, although the risk may be increased in migrating individuals.

Ringing and recovery encounters are also concentrated in the east of England, especially in Norfolk. Only a handful of road causality recoveries have ever been reported.

Most Marsh Harrier recoveries were of young birds (73.2%) with the vast majority of young bird (89.5%) and all adult recoveries coming from the summer season. Of those reported recoveries, 12.2% can from road casualties and 9.8% from other human related causes. The majority of the few road casualties came from the breeding season (80%). Of all the species considered here, Marsh Harrier had the most birds reported without a specific finding circumstance (78%).

Figure 16. Marsh Harrier a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



MERLIN (MERLI)
Falco columbarius

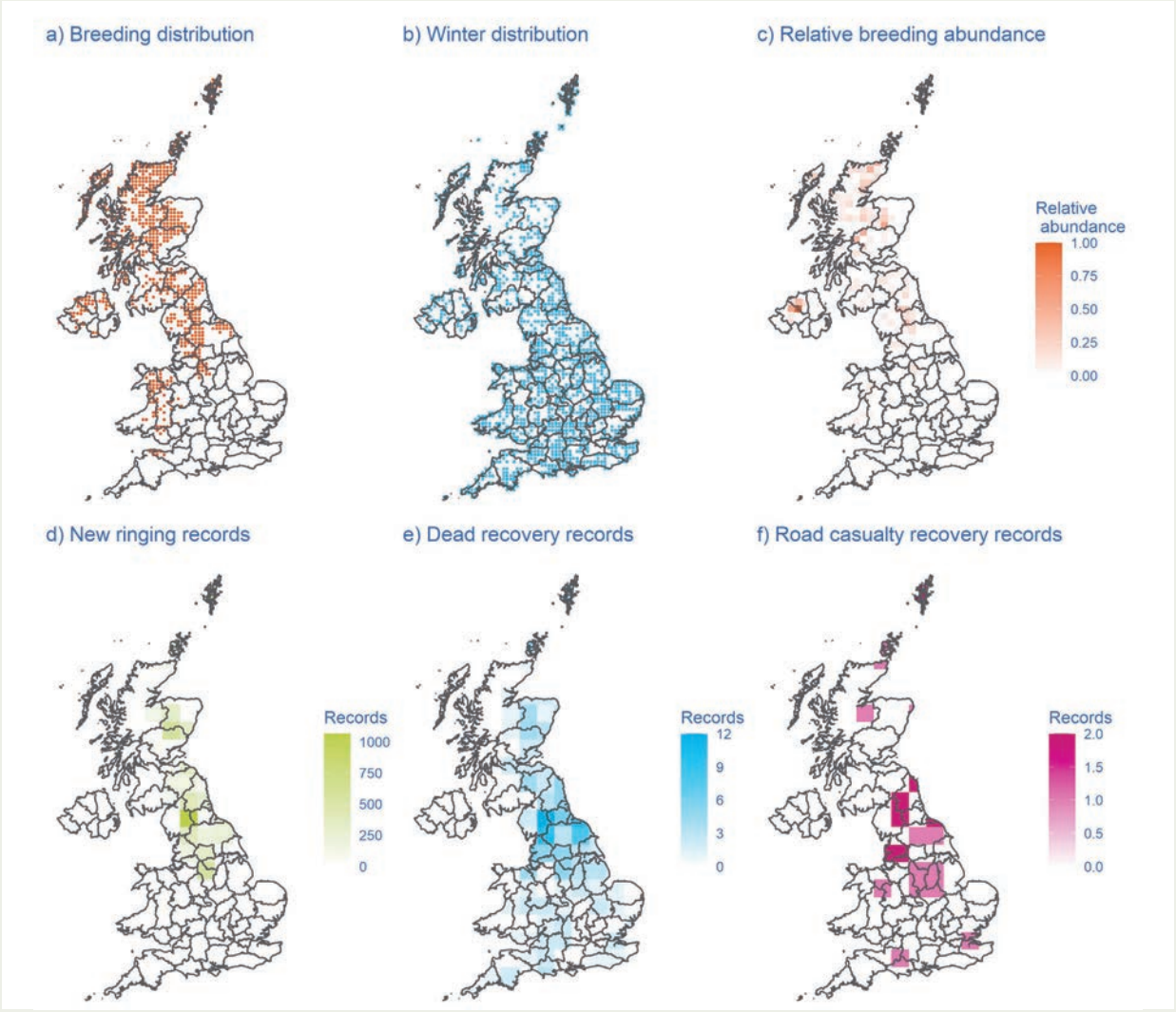
Number ringed:	7,660
Number recovered:	221
Number of road casualties:	32

Merlin are primarily an upland breeding bird in the UK, with their breeding population concentrated in the Scottish, Northern English and Welsh uplands and an additional poorly understood population in Northern Ireland. Although their breeding population has undergone declines in recent years, their winter population is far more widespread as the population is supplemented by immigrants, primarily from Iceland and can be found wintering in lowland and coastal areas such as saltmarshes and heathland.

Ringing and recovery records are primarily concentrated in Scotland and northern England, most of the few road casualty recoveries also coming from this area.

Most Merlin recoveries were of young birds (76.0%) with the majority of both young and adult recoveries occurring during the summer (67.3% and 75% respectively). Of the reported recovery circumstances, 17.6% were from other human causes, 13.1% from road casualties and 8.6% from natural causes. The majority of the few road casualties came from the breeding season (78.1%).

Figure 17. Merlin a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Osprey (OSPRE)
Pandion haliaetus

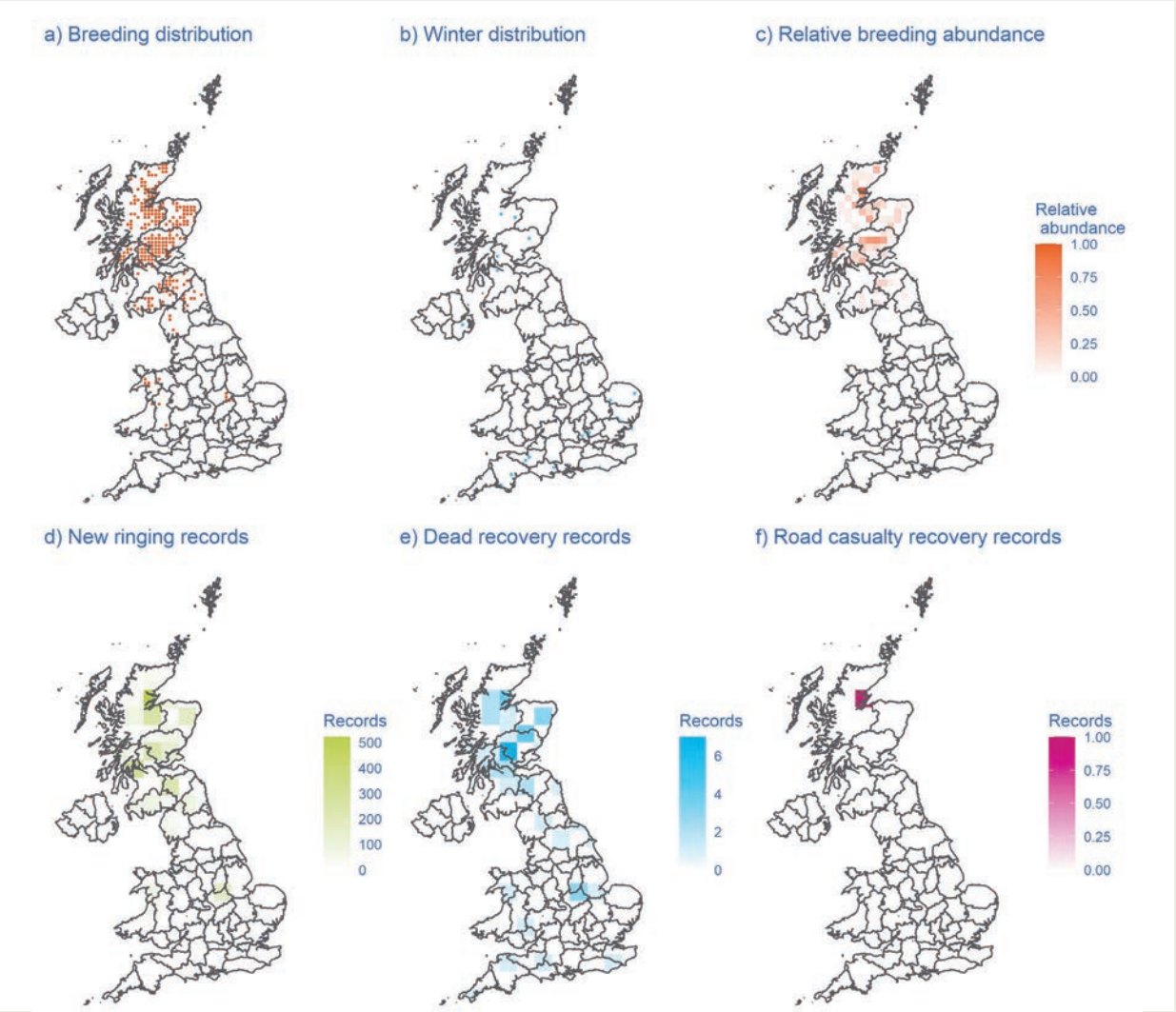
Number ringed:	3,030
Number recovered:	49
Number of road casualties:	1

Ospreys have spread successfully from their stronghold in Scotland to elsewhere in the UK through natural recolonisation and re-introduction schemes, although most breeding records are still concentrated in Scotland. As a breeding migrant they are effectively absent during the winter months, with any winter records likely to be from late passage birds. They primarily breed around large, undisturbed bodies of water and as such rarely come into close contact with roads outside of their migration periods (April and late August/early September).

Most ringing and within-UK recovery records also come from Scotland, especially the Scottish Highlands. Only one UK road casualty recovery was reported in this period.

Most Osprey recoveries were of young birds (77.6%), with virtually all records coming from the summer as should be expected from a breeding migrant. Of the few recoveries 30.6% came from other human causes, 14.3% from natural causes and only 2% came from road casualties (the single record reported above).

Figure 18. Osprey a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Peregrine (PEREG)
Falco peregrinus

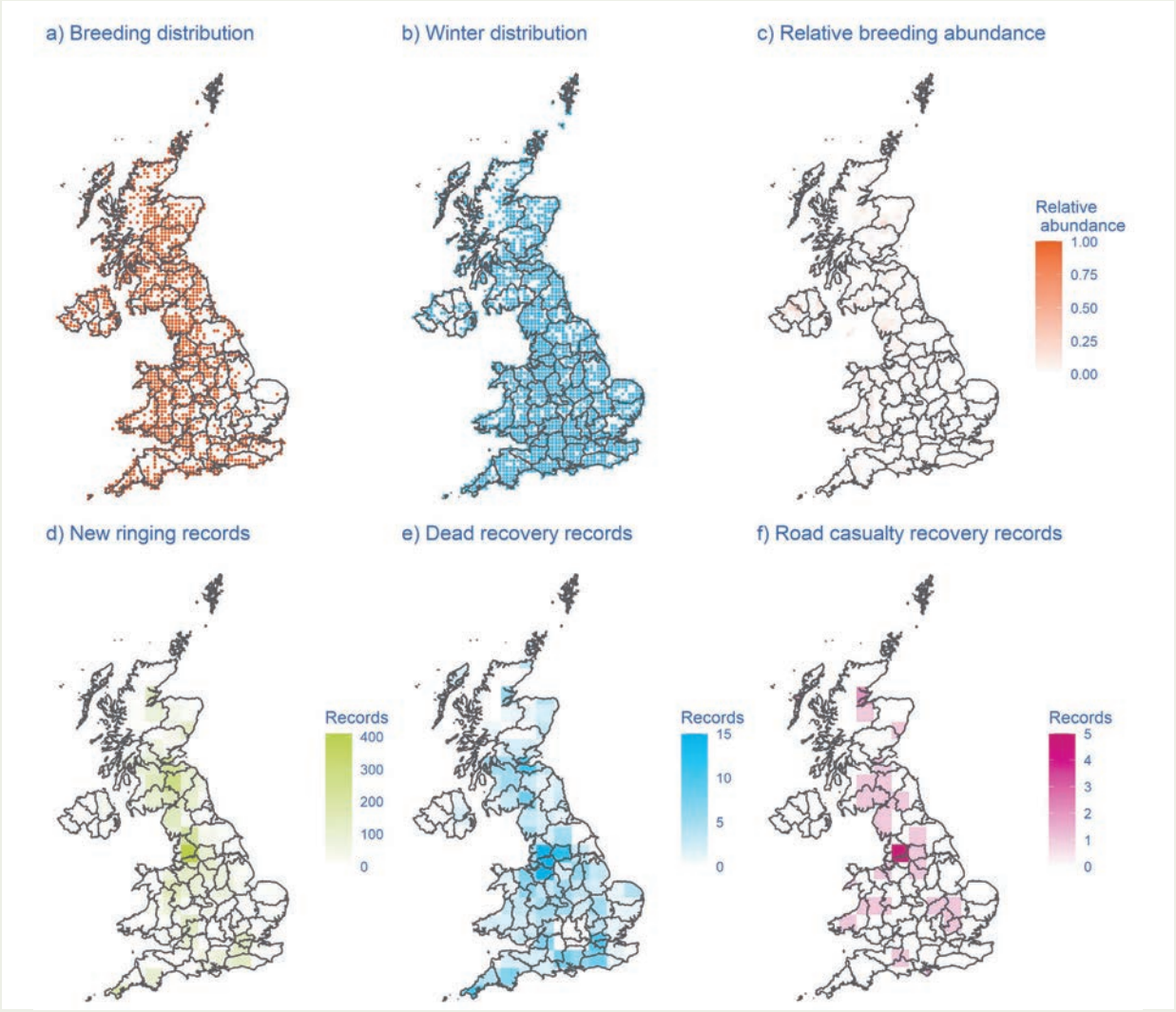
Number ringed:	5,722
Number recovered:	350
Number of road casualties:	39

Peregrine populations have expanded significantly in recent decades following the banning of organochlorine pesticides and reductions in persecution. They now breed across much of the UK, including in many major cities, with highly mobile first-winter birds increasing their winter range even further. Although originally a species of upland and coastal cliffs, Peregrines now regularly breed in urban areas, which will likely increase their road traffic risk.

Ringing and recovery records come from across the UK although most records, including the small number of road casualty recoveries, come from Scotland and western England.

Most Peregrine recoveries are from young birds (54.9%), with the majority of both young and adult recoveries occurring during the summer (59.4% and 63.9% respectively). Of the reported recovery circumstances, 17.7% were from other human causes, 9.7% from road casualties and 7.4% from natural causes. The majority of the reported road casualties came from the breeding season (61.5%).

Figure 19. Peregrine a) confirmed or suspect breeding distribution (by 10 km-grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Red Kite (REDKI)
Milvus milvus

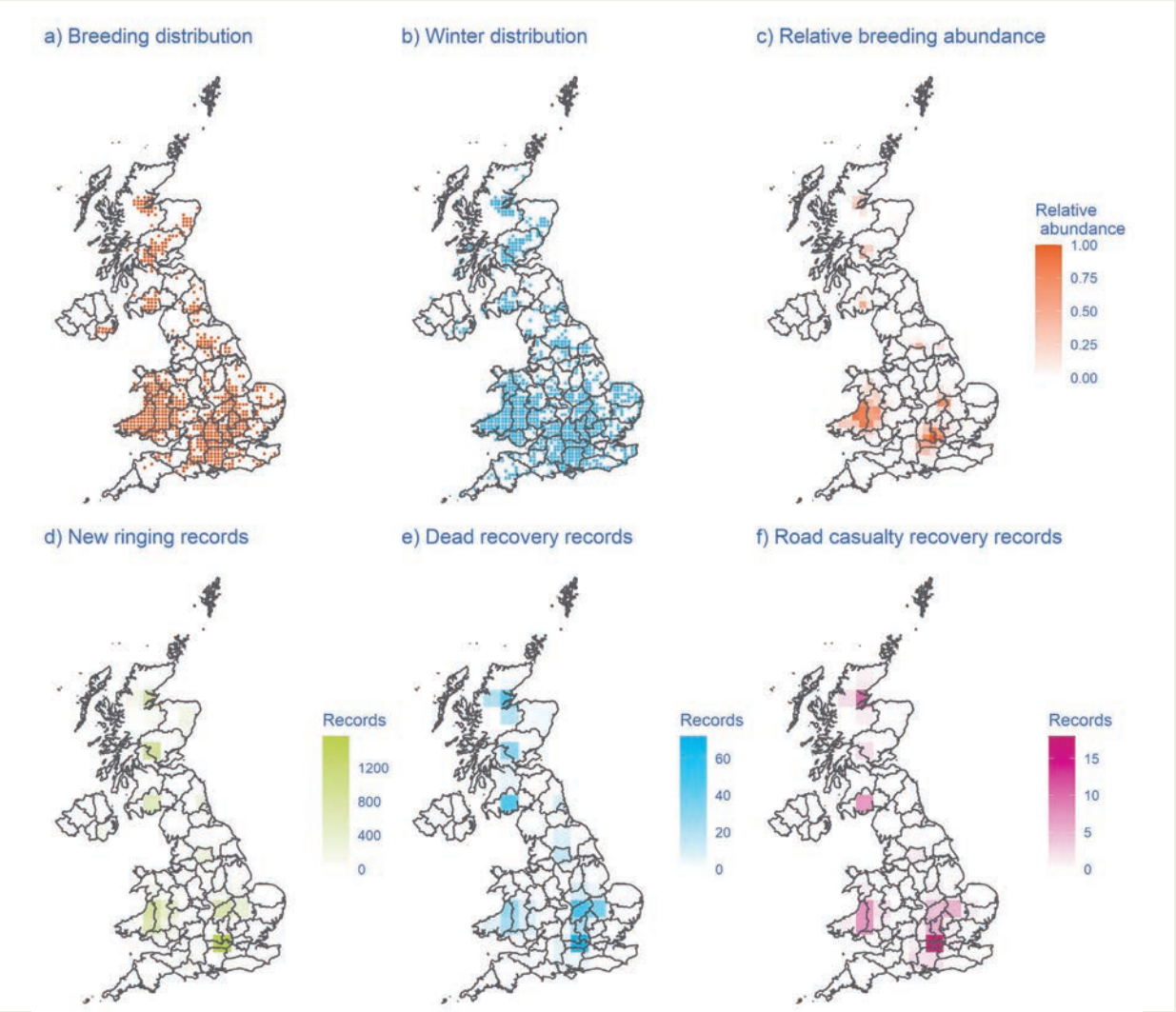
Number ringed:	8,884
Number recovered:	546
Number of road casualties:	93

Red Kites have spread significantly in the UK in recent decades following a highly successful re-introduction program, with concentrations in their original stronghold in Wales and around release sites such as the Chilterns (southern England) and Black Isle (Highland Scotland). They are found primarily in areas of open pasture and woodland and frequently scavage from roadsides putting them at risk of traffic collisions.

These areas are also where most ringing and recovery records come from, including road casualty records.

Red Kite recoveries are split approximately equally between young and adult birds (50.4% and 49.6% of records respectively), with most records for both coming from the summer (60.1% and 65.1% respectively). Road casualties and other human related causes accounted for 15.8% and 23.4% of finding circumstances, respectively. The majority of the reported road casualties came from the breeding season (59.1%).

Figure 20. Red Kite a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Short-eared Owl (SHEOW)
Asio flammeus

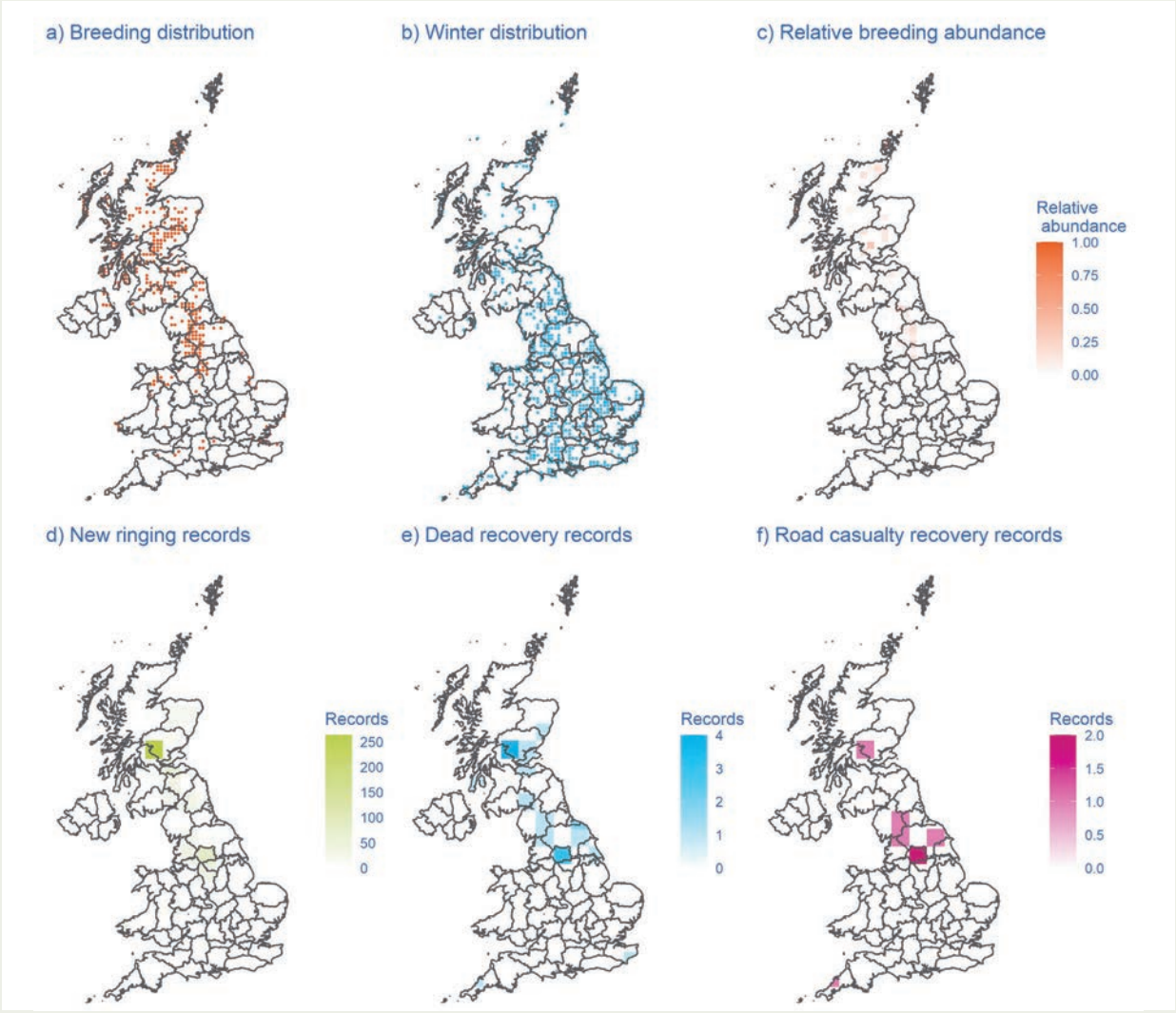
Number ringed:	921
Number recovered:	20
Number of road casualties:	7

Short-eared Owls are concentrated in the uplands in northern England and Scotland, with scattered breeding records elsewhere and the species believed to be declining. Migrating birds from Scandinavia and elsewhere significantly add to the UK wintering population, although recent BTO tracking research has found this species to be highly nomadic both within and between breeding seasons (Calladine in prep). They breed primarily in the uplands and tend to winter in the uplands and coastal marshland. They are most at risk of road traffic collisions while roaming between seasons.

Most ringing and the few recovery records came from the Tayside area of Scotland, with additional recoveries from Yorkshire and single recoveries in some other areas. Only a handful of road casualty recoveries have been recorded.

Most Short-eared Owl recoveries were of young birds (80%), with the vast majority of young (87.5%) and all adult recoveries coming from the summer. Road casualties made up 35% of all recoveries with 5% coming from other human causes. All the few road causality records came during the summer.

Figure 21. Short-eared Owl a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



(Eurasian) Sparrowhawk (SPARR)

Accipiter nisus

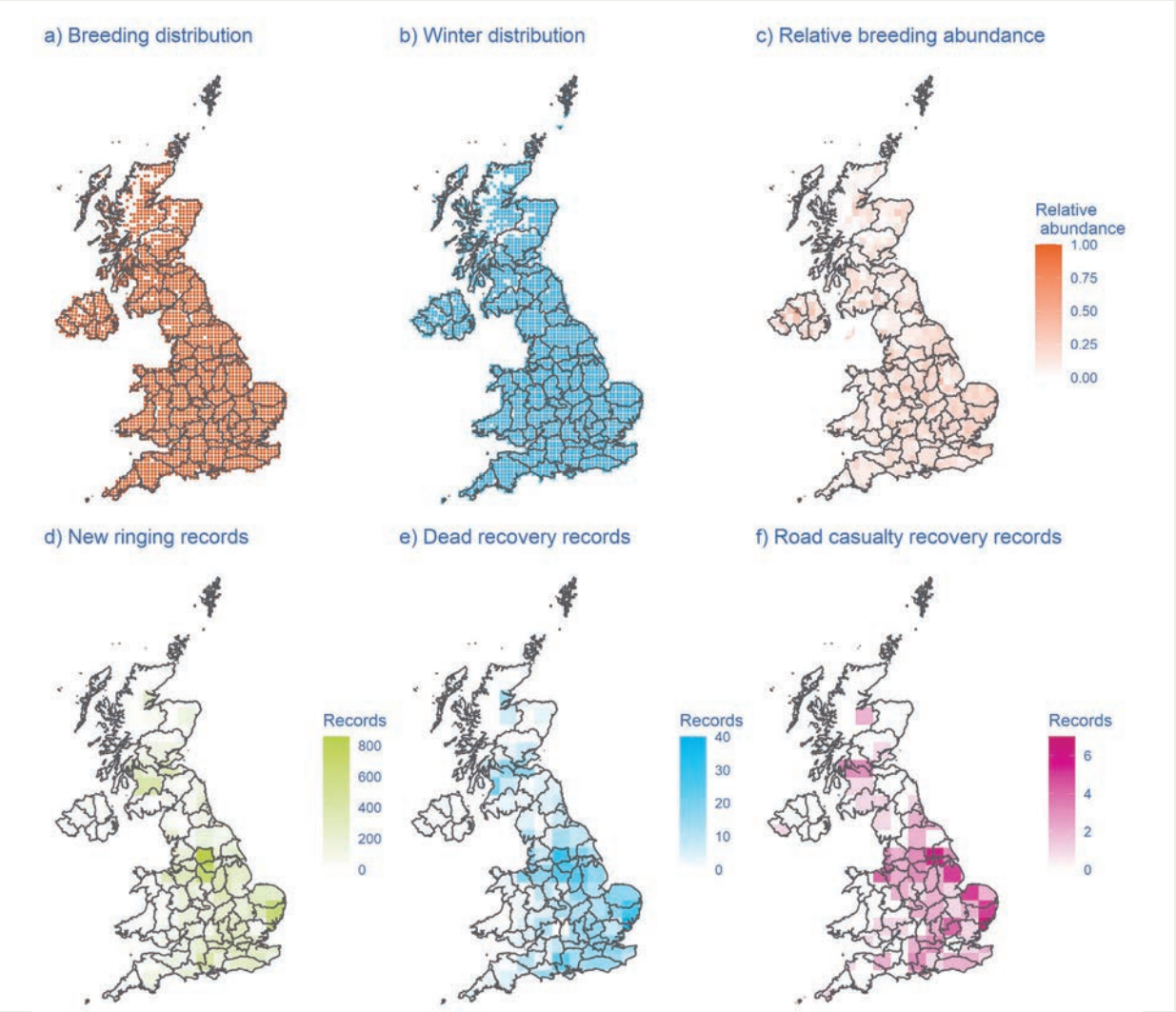
Number ringed:	15,860
Number recovered:	889
Number of road casualties:	127

Sparrowhawks are widespread and relatively abundant breeding and resident wintering bird across the UK, aside from some unsuitable areas in the Scottish uplands. Although traditionally a species of woodland and woodland edges, they also now occur commonly in urban areas, putting them at increased risk of road traffic collisions.

Ringing and recovery records are spread across the UK, including relatively small numbers of road casualty records. The majority of encounters come from free flying young and adult birds (69.2% of ringing records); hence the number of adult recoveries is likely to be inflated due to relatively few nestlings being ringed and subsequently recovered as juveniles.

Most Sparrowhawk recoveries were of adults (60%), with seasonal recovery patterns differing between ages. More young birds were recovered in their first winter (59.0%), whereas most adult recoveries came from the summer (55%). Road casualties and other human-related causes accounted for 15.8% and 23.4% of finding circumstances, respectively. Roughly equal numbers of reported road casualties came from the two seasons (47.2% and 52.8% for breeding and winter respectively) primarily driven by differences between age class recoveries, with 74.4% of young bird road casualties occurring in the winter and 61% of adult road casualties coming from the breeding season.

Figure 22. Sparrowhawk a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



Tawny Owl (TAWOW)
Strix aluco

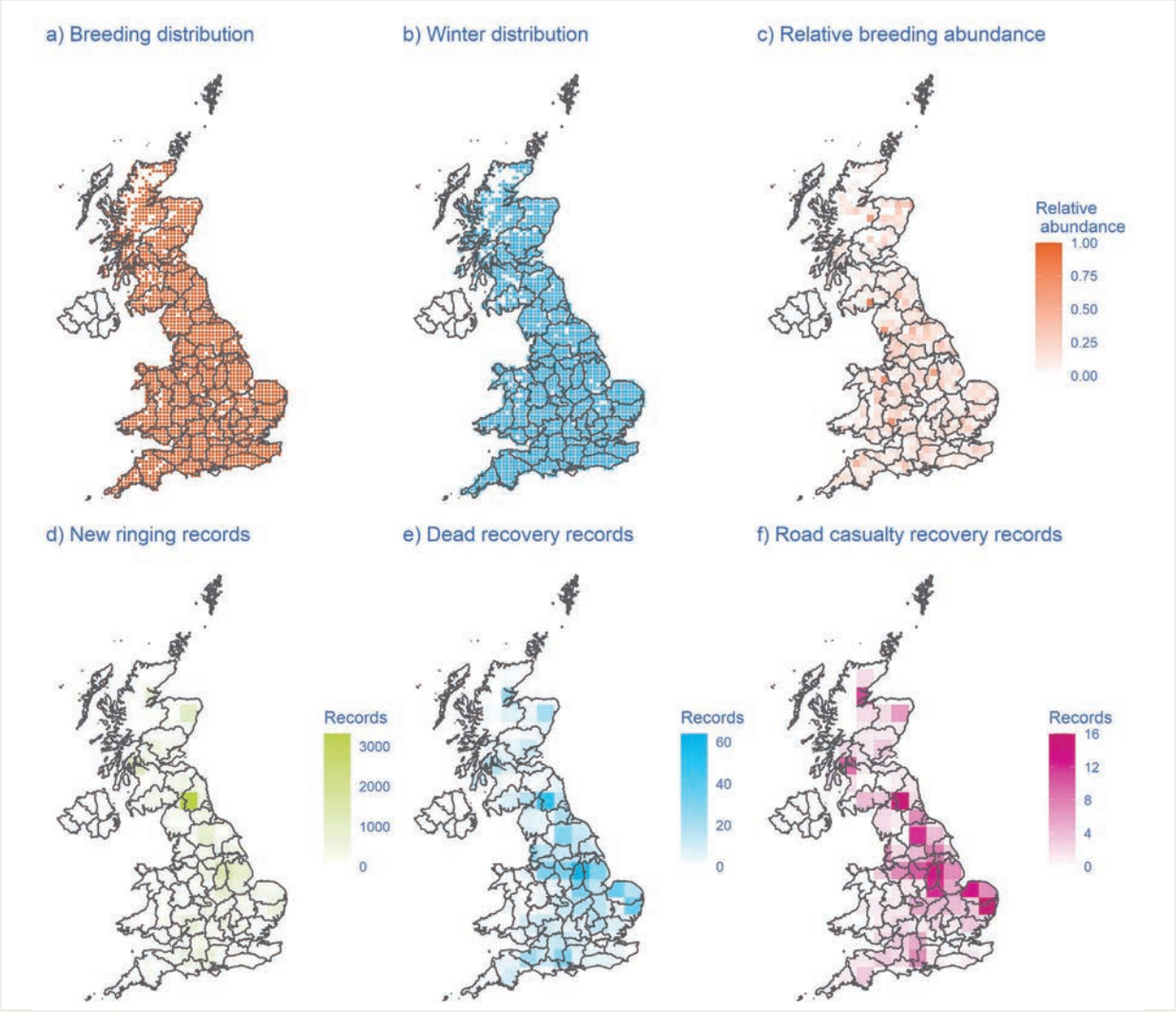
Number ringed:	26,491
Number recovered:	997
Number of road casualties:	330

Tawny Owls are widespread residents in forestry and woodland through mainland Britain but absent from Ireland and some more remote islands such as the Northern and Western Isles. They can also occur in urban areas with high tree densities which may increase their risk of traffic collisions.

Ringing and recovery records including road casualty recoveries are fairly evenly spread across their range.

Most Tawny Owl recoveries were of young birds (61.8%), with the majority of both young and adult recoveries occurring during the summer (55.8% and 69.1% respectively). Road casualties were by far the commonest reported finding circumstance (29.6%), but most reported young bird road casualties were from their first winter (61.7%) whereas for adults most came from the summer (70%).

Figure 23. Tawny Owl a) confirmed or suspect breeding distribution (by 10-km grid square), b) winter distribution (by 10-km grid square), c) relative abundance (by 20-km grid square), d) total new birds ringed (by 50-km grid square), e) Total dead ringing recovery records (by 50-km grid square) and f) total road casualties (by 50-km grid square). Maps a), b) and c) were adapted from the *Bird Atlas 2007–2011* (Balmer *et al.*, 2013). Note differing scales between maps.



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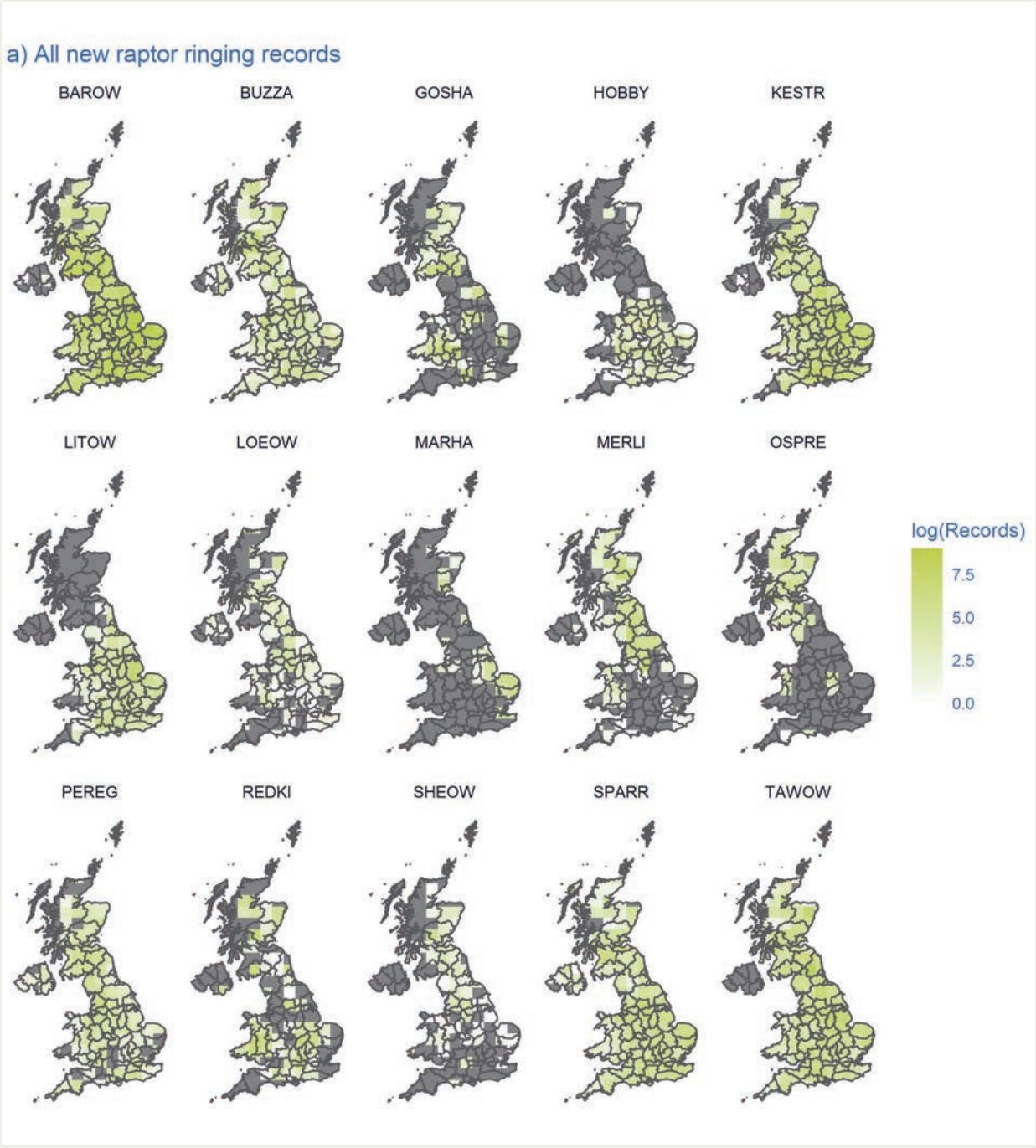
6. APPENDICES

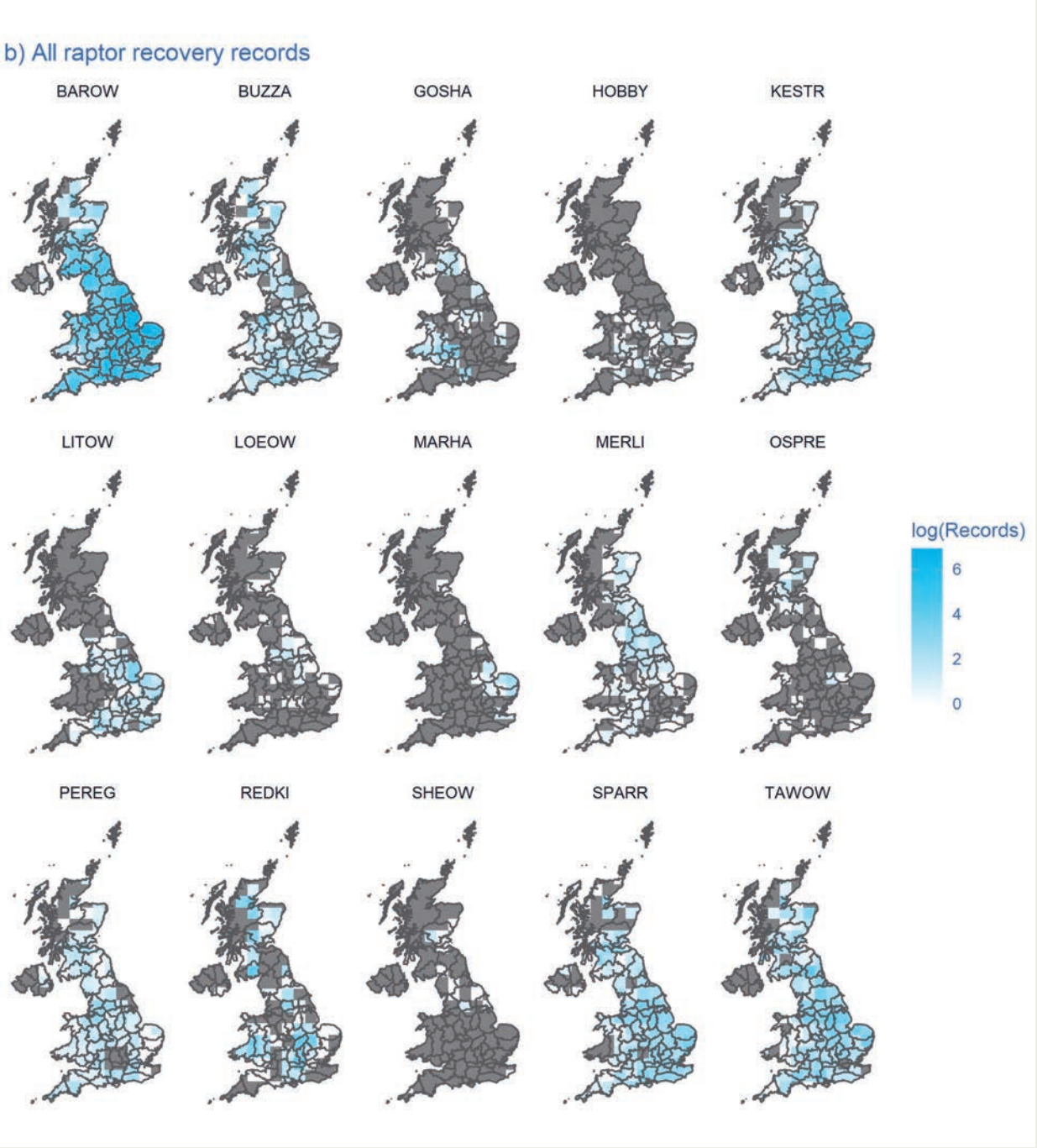
Appendix 1. Summary of the status of each considered raptor species in the UK along with BTO species codes and scientific names. Estimated UK breeding pairs are from the APEP4: Population estimates of birds in Great Britain and the United Kingdom (Woodward *et al.*, 2020).

Species name	Species Code	Scientific name	Status	Estimated UK breeding pairs
Barn Owl	BAROW	*Tyto alba*	Resident Breeder	4,000–14,000
(Common) Buzzard	BUZZA	*Buteo buteo*	Resident Breeder, Passage/Winter Visitor	63,000–87,500
(Northern) Goshawk	GOSHA	*Accipiter gentilis*	Re-introduced Breeder	620
(Eurasian) Hobby	HOBBY	*Falco subbuteo*	Migrant Breeder, Passage Visitor	2,050
(Common) Kestrel	KESTR	*Falco tinnunculus*	Migrant/Resident Breeder, Passage/Winter Visitor	31,000
Little Owl	LITOW	*Athene noctua*	Introduced Breeder	3,600
Long-eared Owl	LOEOW	*Asio otus*	Resident Breeder, Passage/Winter Visitor	1,800–6,000
(Western) Marsh Harrier	MARHA	*Circus aeruginosus*	Migrant/Resident Breeder, Passage Visitor	590–695
Merlin	MERLI	*Falco columbarius*	Migrant/Resident Breeder, Passage/Winter Visitor	1,150
Osprey	OSPRE	*Pandion haliaetus*	Migrant Breeder, Passage Visitor	240
Peregrine	PEREG	*Falco peregrinus*	Resident Breeder, Passage/Winter Visitor	1,750
Red Kite	REDKI	*Milvus milvus*	Resident/Introduced Breeder, Passage Visitor	4,400
Short-eared Owl	SHEOW	*Asio flammeus*	Resident/Nomadic Breeder, Passage/Winter Visitor	620–2,200
Sparrowhawk	SPARR	*Accipiter nisus*	Resident Breeder, Passage/Winter Visitor	30,500
Tawny Owl	TAWOW	*Strix aluco*	Resident Breeder	50,000

Appendix 2. Direct comparisons for considered raptor species for a) new birds ringed, b) dead recoveries and c) road casualty recoveries per 50-km UK grid square. Plotted on log scales to facilitate comparisons within each category of data.

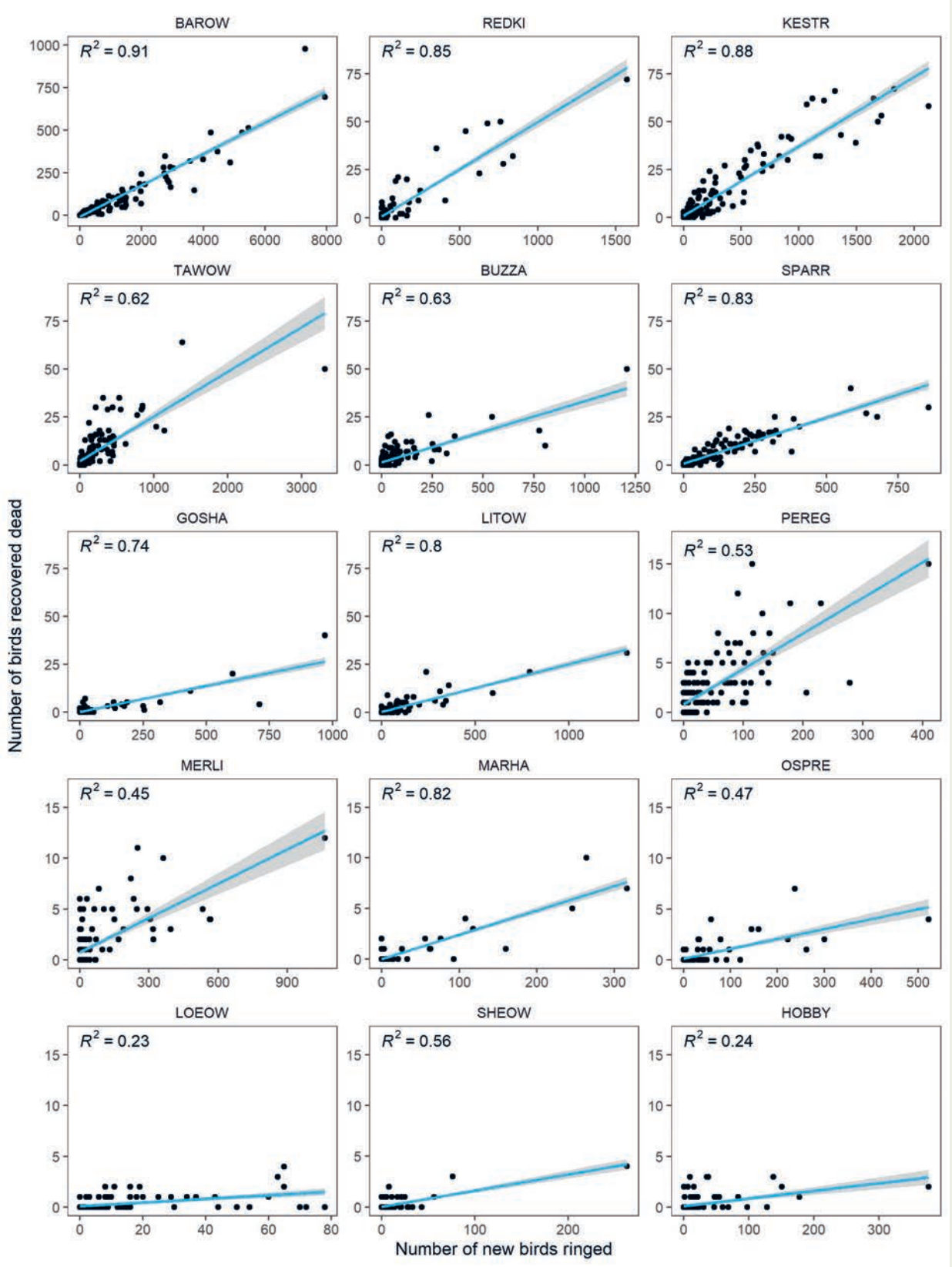


Appendix 2. Direct comparisons for considered raptor species for a) new birds ringed, b) dead recoveries and c) road casualty recoveries per 50-km UK grid square. Plotted on log scales to facilitate comparisons within each category of data.



Appendix 2. Direct comparisons for considered raptor species for a) new birds ringed, b) dead recoveries and c) road casualty recoveries per 50-km UK grid square. Plotted on log scales to facilitate comparisons within each category of data.

Appendix 3. The relationship between the numbers of birds ringed and subsequently recovered dead per 50-km grid square in the UK by raptor species. Plotted with a linear logistic regression line, 95% confidence intervals and R^2 values. All p values were <0.001. Species plots are ordered in descendant order by the maximum recorded number of recoveries in an individual 50-km grid square with the y axes adjusted to facilitate comparisons between species with similar numbers of recoveries.



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Incidence of road mortality in ringed raptors and owls: a spatial analysis

Roads represent a significant threat to wildlife through both behavioural effects and the increased direct risk of mortality from collisions with vehicles. The effects of roads may be further increased in countries with dense road networks such as the UK. Some wildlife taxa such as raptors (typical birds of prey and owls) may be especially vulnerable and are often reported as road casualties. However, the true scale and importance of road casualties and other human caused (anthropogenic) mortality on raptors is poorly understood, primarily due to a lack of systematic data gathering and general under reporting. Here we use the existing BTO ring recovery dataset to explore the location and, where reported, circumstances of mortality for ringed raptors in the UK between 2002 and 2019. Within this we consider variations in recoveries and specifically road casualties in relation to species, location, age, season and the presence of roads.

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