Cyfoeth Naturiol Cymru
Natural Resources Wales

Population estimates and spatial distribution for eight Welsh breeding bird species

Report No: 611

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Crynodeb Gweithredol

Mae Cyfoeth Naturiol Cymru (CNC) yn cynnal adolygiad eang o'i ddull o saethu a dal adar gwyllt yng Nghymru. Mae wyth rhywogaeth o adar gwyllt (brain tyddyn *Corvus corone*, piod *Pica pica*, sgrechod y coed *Garrulus glandarius*, jac-dos *Corvus monedula*, colomennod gwyllt *Columba livia domestica*, ysguthanod *Columba palumbus*, gwyddau Canada *Branta canadensis* a hwyaid coch *Oxyura jamaicensis*) wedi'u rhestru ar un neu fwy o'r trwyddedau cyffredinol yng Nghymru ar hyn o bryd.

Er mwyn asesu ei ddull o drwyddedu, mae BTO yn darparu gwybodaeth gyd-destunol ar ffurf amcangyfrifon o boblogaethau bridio Cymru ar gyfer saith o'r wyth rhywogaeth a restrir ar drwyddedau ar hyn o bryd, yn ogystal ag ydfrain *Corvus frugilegus*. Mae dau ddull bras o amcangyfrif maint poblogaethau adar yng Nghymru o ystyried bodolaeth amcangyfrifon cyhoeddedig ar gyfer Prydain Fawr a'r DU. Mae un dull yn cynnwys dosrannu cyfran o amcangyfrif cyhoeddedig y DU fel y'i cyhoeddir o bryd i'w gilydd gan y Panel Amcangyfrifon o Boblogaeth Adar (APEP), sef APEP3 ac APEP4 yn fwyaf diweddar, i Gymru yn seiliedig ar batrymau gofodol o doreithrwydd ledled Prydain Fawr. Cynhyrchir y patrymau gofodol drwy brosesau gwahanol gan gynnwys modelu data’r Atlas Adar ar ddosbarthiad, data ar doreithrwydd cymharol ar raddfa ofodol o 20km^2 a data tetradau a fodelwyd, o fapiau o ddwysedd neu ddwysedd toreithrwydd cymharol a gyfrifir gan ddefnyddio data'r Arolwg o Adar Bridio (BBS). Mae ail ddull amgen yn defnyddio map o amcangyfrifon dwysedd gan ddefnyddio modelau samplu pellter â sgwariau’r BBS yng Nghymru wedi'u modelu i gynhyrchu amcangyfrif ar gyfer yr ardal gyfan. Ar gyfer y ddau ddull, caiff amcangyfrifon o boblogaethau sy'n deillio o hynny eu diweddaru gymaint â phosib gyda data sy'n bodoli eisoes, hyd at 2018, gan ddefnyddio tueddiadau poblogaethau Cymru wedi’u llyfnhau. Mae'r adroddiad hwn hefyd yn darparu mapiau o ddosbarthiad bridio a gaeafu pob rhywogaeth, mapiau o doreithrwydd bridio cymharol ar gyfer y ddau Atlas Adar diweddaraf a, lle bo'n bosib, fapiau o doreithrwydd a dwysedd cymharol yn seiliedig ar ddata BBS.

Mae cafeatau'n gysylltiedig â phob dull ond gan fod pob dull dosrannu yn tybio bod yr anawsterau o ran cyfrif (Atlas neu BBS) yr un mor berthnasol yng Nghymru a gweddill Prydain Fawr, nid oedd fel arfer yn bosib eu rhestru'n ddibynadwy. Felly ar gyfer y rhan fwyaf o rywogaethau, yr amcangyfrif gorau a argymhellir yw cymedr y tri neu bedwar dull dosrannu gorau, ac eithrio amcangyfrifon sy'n deillio o ddosrannu amrediad. Cymharwyd yr amcangyfrifon hyn â'r dull annibynnol a gyfrifodd ddwyseddau unigolion gan ddefnyddio dadansoddiadau pellter o ddata BBS, ond nid oeddem o'r farn bod y cyfrifiadau dwysedd yn fwy dibynadwy ar gyfer unrhyw un o'r rhywogaethau heidio neu rannol gytrefol hyn.

Dyma amcangyfrifon o boblogaethau bridio Cymru ar gyfer yr wyth rhywogaeth (pan yn dalgrynnu): **gwyddau Canada 8,800 o barau**, **colomennod gwyllt 31,200 o barau** (amrediad 24,450 i 41,245), **ysguthanod 222,000 o barau** (amrediad 179,886 i 295,385), **sgrechod y coed 27,400** o barau (amrediad 20,431 i 35,422), **piod 61,700 o barau** (amrediad 52,888 i 79,329), **jac-dos 138,000 o barau** (amrediad 117,624 i 155,317), **ydfrain 32,400 o barau** (amrediad 23,295 i 49,413) a **brain tyddyn 121,000 o barau** (amrediad 93,661 i 157,822).

Executive Summary

Natural Resources Wales (NRW) is undertaking a broad review of their approach to the shooting and trapping of wild birds in Wales. Seven species of wild birds (carrion crow *Corvus corone*, magpie *Pica pica*, jay *Garrulus glandarius*, jackdaw *Corvus monedula,* feral pigeon *Columba livia domestica*, wood pigeon *Columba palumbus* and Canada goose *Branta canadensis*) are currently listed on one or more of the general licences in Wales.

NRW commissioned BTO to provide contextual information in the form of Wales breeding population estimates for the seven breeding species currently listed on licences as well as rook *Corvus frugilegus*. There are two broad approaches to estimating population sizes of bird populations in Wales given the existence of published estimates for the GB and the UK. One approach involves apportioning a fraction of the published UK estimate as published periodically by the Avian Population Estimates Panel (most recently APEP3 and APEP4) to Wales based on spatial patterns of abundance across Great Britain. The spatial patterns are produced through different processes including the modelling of Bird Atlas data on distribution, relative abundance data at the 20k spatial resolution and modelled tetrad data, from maps of density or relative abundance density calculated using Breeding Bird Survey (BBS) data. An alternative second approach involves using a map of density estimates from using distance sample modelling BBS squares within Wales modelled to produce an estimate for the whole area. For both methods, derived population estimates are subsequently brought as up to date as possible with existing data, to 2018, using smoothed Wales population trends. This report also provides maps of the breeding and wintering distribution of each species, relative breeding abundance maps for the two latest Bird Atlases, and where possible maps of relative abundance and density based on BBS data.

There are caveats associated with all approaches but since all apportioning methods simply assume that the counting difficulties (atlas or BBS) are equally applicable in Wales and the rest of GB, it was not usually possible to rank them reliably. Hence for most species, the recommended best estimate is the mean of the three or four best apportioning approaches, excluding estimates derived by apportioning range. We compared these estimates to the independent method that calculated densities of individuals using distance analysis of BBS data but we did not consider the density calculations to be more reliable for any of these flocking or partly colonial species.

The Wales breeding population estimates (when rounded) for the eight species are: **Canada goose 8,800 pairs**, **feral pigeon 31,200 pairs** (range: 24,450 to 41,245), **woodpigeon 222,000 pairs** (range: 179,886 to 295,385), **jay 27,400 pairs** (range: 20,431 to 35,422), **magpie 61,700 pairs** (range: 52,888 to 79,329), **jackdaw 138,000 pairs** (range: 117,624 to 155,317), **rook 32,400 pairs** (range: 23,295 to 49,413) and **carrion crow 121,000 pairs (**range: 93,661 to 157,822).

1. Background

Natural Resources Wales (NRW) is undertaking a broad review of their approach to the shooting and trapping of wild birds in Wales. Seven species of wild birds (carrion crow *Corvus corone*, magpie *Pica pica*, jay *Garrulus glandarius*, jackdaw *Corvus monedula,* feral pigeon *Columba livia domestica*, wood pigeon *Columba palumbus* and Canada goose *Branta canadensis*) are currently listed on one or more of the following general licences in Wales:

GEN/WCA/001/2021 ("GL001") – Licence to kill or take certain wild birds to prevent serious damage to livestock, foodstuffs for livestock, crops, vegetables or fruit or to prevent the spread of disease to livestock, foodstuffs for livestock, crops, vegetables or fruit. Species covered: carrion crow, magpie, jackdaw, feral pigeon, woodpigeon, Canada goose.

GEN/WCA/002/2021 ("GL002") – Licence to kill or take certain wild birds for the purpose of preserving public health and preventing the spread of disease. Species covered: feral pigeon.

GEN/WCA/004/2021("GL004") – Licence to kill or take certain wild birds for the purpose of conserving wild birds. Species covered: carrion crow, magpie, jackdaw, jay

The quality of information about breeding birds in Wales has improved greatly over recent decades; in particular, robust trend information is now available for 60 species through the BTO/JNCC/RSPB Breeding Bird Survey (Harris *et al*., 2020). There is, however, limited information on the sizes of breeding bird populations in the country. Since 1997, the Avian Population Estimates Panel (APEP) has published a series of reports that quantify the population sizes of both breeding and wintering birds in Great Britain (GB) and in the United Kingdom. The first report was in 1997, and Woodward *et al*. (2020) compiled the fourth such report, providing revised GB and UK population estimates up to 2016, but there has been no similar exercise for Wales.

NRW require Welsh breeding population estimates for eight breeding bird species, the seven listed above plus rook *Corvus frugilegus*. Population estimates for these eight bird species are presented with discussion of their accuracy together with any potential bias relevant to a particular species.

2. Approach, requirements and outputs

Although many historical population estimates for terrestrial bird species are based ultimately on territory mapping analyses from the Common Birds Census, more current population estimates have been generated for most of these species by applying spatial data on distribution or relative abundance patterns from Bird Atlas 2007-11 (Balmer *et al*., 2013) to these previous estimates. Following the standard protocol for estimating up-to-date population sizes for the UK and Great Britain in APEP (e.g. Woodward *et al*., 2020), such estimates are then projected to contemporary estimates using the population trends for breeding birds generated by the UK Breeding Bird Survey (BBS) (Harris *et al*., 2020). There are two broad approaches to determine what proportion of the overall UK or GB population estimate can be assigned at an individual country level, these are application of either simple spatial range or spatial-abundance. Population estimates may be vulnerable to specific under- or over-estimation for a given method and species; for example, the simple spatial method may under-estimate the Welsh population size of a species that tends to occur at a higher density in Wales than in other parts of its British range (Hughes *et al*., 2020).

An alternative approach developed by British Trust of Ornithology (BTO) uses the distance-band information from counts during BBS surveys to produce an independent estimate of relative abundance, which with caution and certain assumptions could be used to estimate total population sizes for any specified geographical area, including population estimates for Wales. A small number of distance-based population estimates, albeit calculated more than ten years ago and hence projected forward using population trends, are included in Woodward *et al.* (2020).

These approaches each have specific strengths and weaknesses relevant to individual species. Along with a full description of methods, their feasibility for each species will be described and discussed; along with a discussion of their likely accuracy and precision and any significant issues associated with seasonal, spatial or abundance change noted.

This paper will present a population estimation method for each of the eight target species (carrion crow, magpie, jay, rook, jackdaw, feral pigeon, wood pigeon and Canada goose) including preparation of the data and data accuracy and a corresponding set of population estimates, expressed as either number of breeding pairs or individuals including a level of precision. The workings and final population estimate obtained by each method are provided in the tables within each species section. In addition, for each species, we will provide a recommendation for the best population estimate, highlighting any limitations and/or assumptions, and where relevant, how such estimates could be improved through new data or novel analyses.

3. Methods

3.1 Derivation of Wales Population Estimates

Given the available data there are two broad ways of estimating population sizes in Wales. Method 1 involves apportioning some fraction of an existing published UK or GB estimates to Wales. For this method the challenges are: a) having a robust GB or UK estimate as a basis, and b) correctly apportioning said estimates to Wales. Method 2 involves using density estimates wholly from within Wales and summing these to produce an estimate. Here the challenge is having a Wales-wide data source of robust density estimates. A challenge common to both methods is if the datasets are even a few years old, any derived population estimates may need to be adjusted in the light of known population trends to bring them up to date. More details on each method and the data sources used are given below.

Method 1 – apportioning existing GB or UK estimates to Wales

This method can be summarised as:

$$\left[\text{Published GB population estimate} \times \text{Estimated proportion of GB birds in Wales}\right] \times \text{Recent Wales population trend} = \text{Wales population estimate}$$

Published GB population estimates come from the Avian Populations Estimate Panel (APEP), a consortium of experts from the UK bird conservation organisations and statutory bodies that regularly updates estimates of breeding and wintering populations in the UK and GB using the best available information. The relevant publications for the GB estimates used in this report are APEP3 (Musgrove *et al.,* 2013) for which estimates are assigned to 2009 and APEP4 (Woodward *et al.,* 2020) for which estimates are assigned to 2016. It is also important to understand that for most species, including all of the corvids, those two published GB estimates are not independent of each other, with the estimate in APEP4 deriving from the APEP3 adjusted for UK-scale change in abundance as determined by population trends from BBS.

For Method 1 there are five different approaches (three using metrics from the latest Bird Atlas and two using metrics from the Breeding Bird Survey) that can be used to estimate the proportion of GB or UK birds residing in Wales:

- Bird Atlas 2007–11 distribution data at 10-km resolution. From these data we can determine the number of occupied 10-km squares in Wales and express this value as a fraction of the number of occupied squares in GB. These data are time stamped to 2009, i.e. the middle of the latest Bird Atlas data collection period.
- Bird Atlas 2007–11 20-km resolution average relative abundance data. These data provide a relative abundance measure for each 20-km square in GB. The measure is the number of birds detected per hour of survey, and is the average calculated over Timed Tetrad Visits. The numbers are not absolute densities, so the summed counts cannot be used as population estimates in isolation. However, assuming the detectability of these species is broadly similar between Wales and the rest of GB, the values can be summed across Britain and separately across Wales, with the proportion of the total relative abundance found in Wales used as a proxy for the proportion the GB population residing in Wales. In some 10-km squares a large number of TTVs were completed. Bootstrapping can be applied when calculating the 10-km summed estimates, and the corresponding GB and Wales estimates, and the final proportion of abundance in Wales figure. Repeating the resampling enables production of confidence limits around the estimate of the percentage of GB abundance in Wales. These data are time stamped to 2009, i.e. to the middle of the latest Bird Atlas data collection period.
- Bird Atlas 2007–11 relative abundance modelled at 2-km resolution from 2-km data. These data are derived from species abundance models that related Timed Tetrad Visit count data to covariates (climate, land cover, elevation) to extrapolate relative abundance estimates for all 2-km squares in GB. As with the previous dataset, the values are not absolute densities, so the summed counts cannot be used as population estimates in isolation. However, assuming the detectability of these species is broadly similar between Wales and the rest of GB, the proportion of the

total modelled relative abundance found in Wales can be used as a proxy for the proportion the GB population residing in Wales. These data are also time stamped to 2009, the middle of the latest Bird Atlas data collection period.

- Breeding Bird Survey 1-km resolution modelled density data. These data are derived from species abundance models that related BBS density data to covariates (climate, land cover, elevation) to extrapolate density estimates for all 1-km squares in UK (Massimino *et al*., 2015). The densities are based on distance analyses of BBS counts in distance bands. As the values are absolute densities, the summed counts can also be used as population estimates in isolation (see Method 2 below). However, this relies on good calibration of the models; poorly calibrated models may not yield predictions of the correct magnitude. Nevertheless, provided the models correctly predict spatial patterns, the proportion of the total modelled abundance found in Wales can be used as a proxy for the proportion the GB population residing in Wales. These data are time stamped to 2009 because it was densities based on BBS data from that year that were used.
- Breeding Bird Survey 1-km resolution modelled relative abundance data. These data are derived from species abundance models that related BBS count data to covariates (climate, land cover, elevation) to extrapolate relative abundance estimates for all 1-km squares in UK (Border and Gillings, 2020). This allowed the production of annual maps of relative abundance for a range of species. They use a slightly different modelling approach to Massimino *et al.* (2015) which constrained annual predictions to be correlated, therefore imposing smoothing of year to year changes in abundance. Although based on the same data as in Massimino *et al*. (2015), they span a wider range of years, including up to 2016. The values are not absolute densities, so the summed counts cannot be used as population estimates in isolation. However, assuming the detectability of these species is broadly similar between Wales and the rest of GB, the proportion of the total modelled relative abundance found in Wales can be used as a proxy for the proportion the GB population residing in Wales. The outputs from these analyses can be time-stamped to each year of the BBS included in the models (1994 to 2016) and for calculating the proportion of the GB population in Wales, we used both the 2009 outputs (which are applied to APEP3 estimates) and the 2016 outputs, the latest year modelled in the Border and Gillings (2020) paper and which are applied to APEP4 estimates. Note that the application of this approach in two different time periods (2009 and 2016) results in two different estimates of the proportion of the GB population in Wales. The result based on the modelled 2016 outputs, matched to APEP4 estimates, are provided separately in the species tables.

For the datasets time stamped to 2009 these can be directly applied to the APEP3 GB/UK population estimates which are also time stamped to 2009. This can be done for each of the five methods described above. For the dataset time stamped to 2016 (i.e. one of the calculations of the fifth approach as described above, this can be directly applied to the APEP4 GB/UK population estimates which are also time stamped to 2016. In both cases the estimates derived for 2009 or 2016 are subsequently updated to 2018 by applying the Wales population trend to account for population changes that have occurred since 2009 and/or 2016. For this, we used the BBS smoothed population trend for Wales for each species as described and published in the Breeding Bird Survey annual reports (e.g. Massimino *et al.,* 2019).

Method 2 – summation of density estimates in Wales

This method can be summarised as:

$$\sum \text{1-km densities in Wales} \times \text{Recent Wales population trend} = \text{Wales population estimate}$$

For Method 2, we used modelled bird densities (birds per km) derived from analyses of Breeding Bird Survey data (Massimino *et al.,* 2015). Maps of density were produced for a range of species for 1994–1996 and 2007–2009 based on modelling undertaken at a 1-km resolution. Summing these for GB and for Wales allows an independent estimation of the percentage of the GB population found in Wales. The summed predictions for Wales are the key input to Method 2 but it must be noted that the underlying densities are expressed in units of numbers of birds, rather than numbers of pairs. This is because BBS fieldwork involves counting all adult birds with no attempt made to sex individuals or estimate numbers of territories or of pairs. Also note that not all species can be modelled this way. Hence, although models can generate realistic spatial patterns of abundance as seen on maps (predictions are well correlated with reality), they do not always return the correct absolute values needed to produce population estimates. Therefore, the percentage of abundance in Wales may be robust even if the absolute number of birds estimated to occur in Wales is not. Because these estimates are based on calculations of BBS data in 2007 to 2009, these are also updated to 2018 using smoothed BBS population trends for each species in Wales.

3.2 Contextual maps

Additional to the calculation of population estimates we supply a series of up to five sets of maps to help clarify the status of each species in Wales. These include the following but due to constraints in the modelling approaches as applied to some species, not all of these maps are presented for those species.

1. 10-km distribution map in the breeding season (showing variation in breeding evidence) and in winter (**see Figures 1, 4, 7, 12, 17, 22, 27 and 32**).
2. Breeding season relative abundance in 1988–91 and in 2008–11, and the difference between these as a measure of spatial change in relative abundance. Here relative abundance is approximated by the proportion of surveyed tetrads in each 20-km square that were found to be occupied, which is a non-linear proxy for abundance (**see Figures 2, 8, 13, 18, 23, 28 and 33**).
3. Fine-scale breeding season relative abundance in 2008–11 derived from species abundance models that related Timed Tetrad Visit count data to covariates (climate, land cover, elevation) to extrapolate relative abundance estimates for all 2-km squares in GB (**see Figures 3, 5, 9, 14, 19, 24, 29 and 34**).
4. Maps of density were produced using BBS data for a range of species for 1994–1996 and 2007–2009 by Massimino *et al*. (2015). These provide independent assessments of a) where in Wales the focal species are abundant in the breeding season, and b) how and where breeding-season abundance changed between c1995 and c2008 (**see Figures 10, 15, 20, 25, 30 and 35**).

5. We also present maps of relative abundance based on modelling of BBS data for three time periods (1994, 2009 and 2016) as well as a change map covering the period 1994 to 2016. These are derived from annual modelled maps produced by Border and Gillings (2020) for a range of species (**see Figures 6, 11, 16, 21, 26, 31 and 36).** These used a slightly different modelling approach to Massimino *et al*. (2015) which constrained annual predictions to be correlated, therefore imposing some degree of smoothing of year-to-year changes in abundance. They are based on the same data as the Massimino *et al*. (2015) maps so are not strictly independent, but they span a wider range of years.

The first three of the five map types above are derived from the Bird Atlases. These comprise a comprehensive stock-take of the distribution and status of birds in Britain and Ireland, with breeding season atlases conducted in 1968–72, 1988–91 and 2008–11, and winter season atlases conducted over the winters 1981/82–1983/84 and 2007/08–2010/11. Bird Atlas data offer a way to identify the parts of Wales where focal species are present and where their distribution or numbers may be changing. Different components of the atlas data also provide three ways of estimating the proportion of GB abundance associated with Wales (see above under Method 1).

The first map presented for each species is the 10-km resolution distribution using data collected between 2007-11 from the latest breeding and wintering atlas (Balmer *et al*., 2013). Analyses are based on the 10-km squares that wholly or partly intersect the Wales national boundary (*N* = 288 10-km squares). These distribution data are also used under Method 1 as a way of apportioning published GB-level population estimates to Wales.

The second type of map used was of breeding season relative abundance and change in that metric over the two previous breeding atlases. Representing geographic patterns in density adds a highly informative dimension to breeding and winter bird atlases. Using a standardised method to collect data, such data can be used to generate a relative abundance value that can be used as an index to compare abundance of the species between different areas (see Balmer *et al*., 2013 for further information). Here, we present changes in relative abundance using data from the 1988–91 (Gibbons *et al*., 1993) and 2008–11 (Balmer *et al*. 2013) breeding atlases. As it is easier in the field to measure time than areas searched, for consistency both atlases used a fixed timed-effort field survey method known as Timed Tetrad Visits (TTVs) involving 1-hr duration visits to a minimum of eight 2-km squares (‘tetrads’) in each 10-km square. The proportion of tetrads surveyed that are found to be occupied in a 10-km square is a proxy for abundance (Balmer *et al*. 2013). This method, known as the ‘frequency method’ was the source of all relative abundance maps published in the 1988–91 Atlas. TTV coverage is designed to provide a minimum of eight counts per 10-km square which can be averaged at larger geographic scales and then smoothed. Simple mean abundance maps were produced in each 20-km square to give a local estimate of relative abundance for that square. Rather than 10-km squares, 20-km squares were used as the mapping resolution based on analysis that showed up to 50% of 10-km squares in Ireland would have been deficient in data (Balmer *et al.* 2013). We calculated these relative abundance metrics for each 20-km square in Wales for 1988–91 and 2008–11 to decrease the likelihood of spurious patterns emerging because abundance estimates are based on larger samples of tetrads at a 20-km resolution than would have been the case with a 10-km resolution. Subtracting one set of data from the other provided a measure of relative abundance change for each species in each 20-km square. Note that the relative abundance change maps presented here superficially differ from those published in Bird Atlas 2007–11. This is due to a rescaling of the difference measures when creating the colour palettes for the Britain & Ireland maps in the book. The underlying pattern of change is identical. Equivalent analyses for winter are not possible because the earlier wintering atlas did not use a TTV approach.

The final way in which Atlas data is presented in Wales is to use fine-scaled modelled relative abundance data. Bird Atlas 2007–11 included maps of 2-km resolution modelled abundance, based on statistical models relating counts in surveyed tetrads to environmental variables (Balmer *et al*., 2013). These model predictions of relative abundance can also be summed for GB and for Wales as described above under Method 1 to generate an estimate of the proportion of the GB population in Wales.

4. Results

Results of calculations for each species are first presented separately as follows:

(a) Canada goose Branta canadensis

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 1). Canada goose was recorded with breeding evidence in 240 10-km squares (83% of squares in Wales) and during winter in 240 10-km squares (83%) (Figure 1). Bird Atlas data suggest abundance increased between 1990 and 2010 and BBS trends indicate a further increase from 2009 to 2018. Although Canada geese have been recorded from most 10-km squares in Wales, their abundance is patchy. Their highly aggregated nature makes spatial modelling of abundance difficult, and for this reason we cannot present maps of modelled abundance from BBS data. Modelled densities and relative abundance from BBS are not available as the counts for this highly aggregated species were not easily modelled using the generic method applied to all species in the studies by Massimino *et al*. (2015) and Border and Gillings (2020).

Figure 1. Maps of Canada goose breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al.*, 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

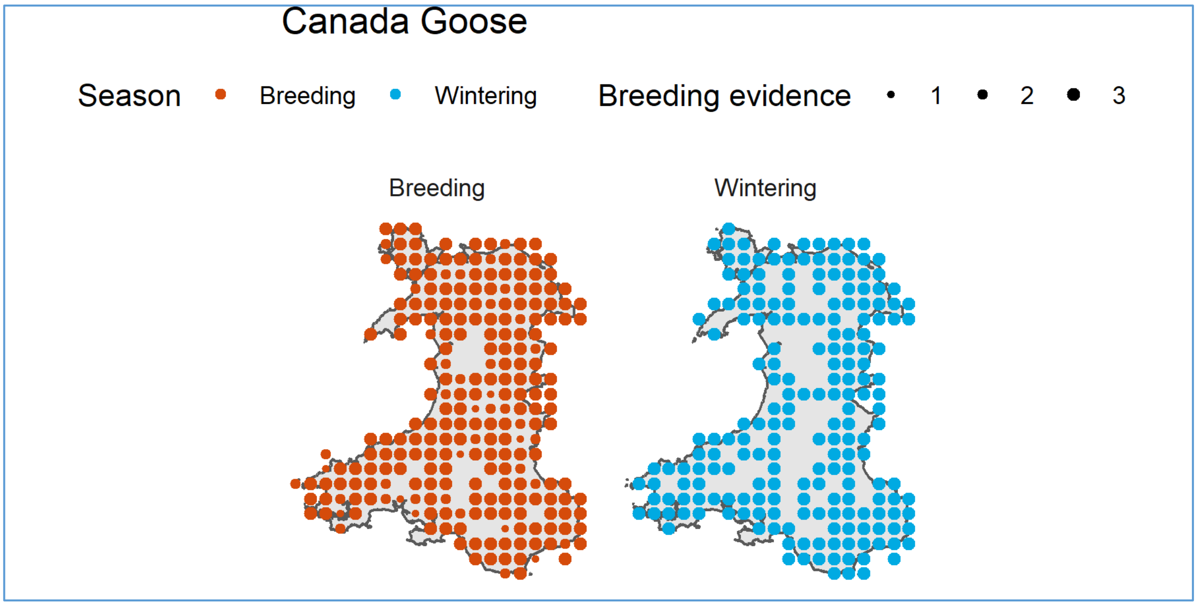


Figure 2. Maps of Canada goose breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change in relative abundance at a 20-km square resolution.

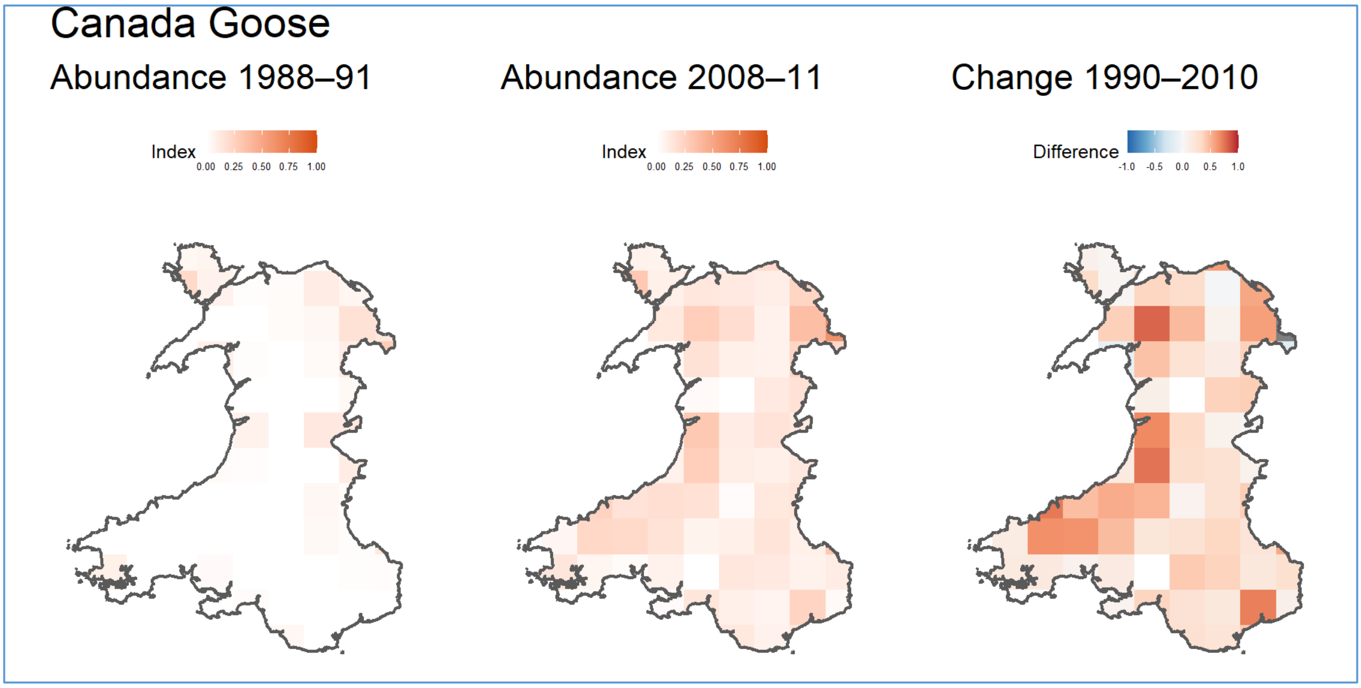
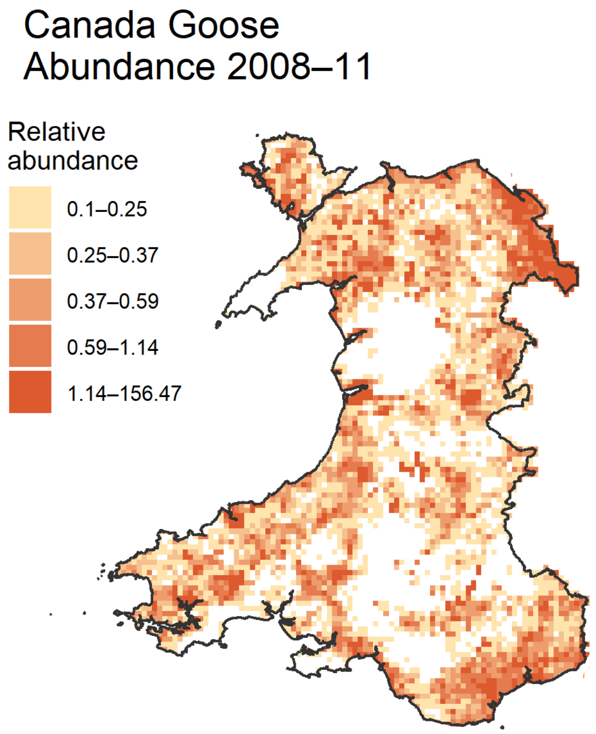


Figure 3. Map of Canada goose fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data (2-km square resolution).



We estimate that between 8.1% and 11.8% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 6,051 to 10,040 pairs (Table 1). Owing to the localised nature of goose breeding habitat, and the spatial aggregation of counts, these estimates should be treated with caution. Excluding the apportioning method using range, because abundance in this colonising species is likely to differ markedly over the area occupied, there are two population estimates for Canada goose. The estimate of 8,842 based on modelling of Atlas data at the 20k level of resolution was considered to be better than the estimate based on finer scale modelling with environmental variables, largely because colonising species tend not to be at equilibrium with habitats in newly colonised areas.

Table 1. Canada goose population estimates (in pairs unless otherwise indicated) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	62000
		Lower confidence limit	-
		Upper confidence limit	-
		Period	2004–08
	APEP 4 population estimate	Point estimate	54000
		Lower confidence limit	-
		Upper confidence limit	-
		Period	2013–17
Estimates of Welsh abundance as % of Great Britain abundance	Bird Atlas 2007–11 (% of range)	Estimate	13.4
	Bird Atlas 2007–11 (% of TTV abundance)	Point estimate	11.8
		Lower confidence limit	9.8
		Upper confidence limit	14.6
	Bird Atlas 2007–11 (% of modelled abundance)	Estimate	8.1
	BBS (% of modelled density 2009)	Estimate	-
	BBS (% of modelled relative abundance 2009)	Estimate	-
	BBS (% of modelled relative abundance 2016)	Estimate	-
Welsh population change measures	Smoothed index 2009	Index value	544.8
	Smoothed index 2016	Index value	685.4
	Smoothed index 2018	Index value	658.4
	Trend 2016-2018	Proportional change	0.96
	Trend 2009-2018	Proportional change	1.21
	Sample size (last 12 yrs)	Number of squares	47
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	8308
		2009 estimate using Atlas TTV abundance	7317
		2009 estimate using Atlas modelled abundance	5007
		2009 estimate using BBS modelled densities	-
		2009 estimate using BBS modelled relative abundance	-
		2018 estimate using Atlas range	**10040**
		2018 estimate using Atlas TTV abundance	**8842**
		2018 estimate using Atlas modelled abundance	**6051**
		2018 estimate using BBS modelled densities	**-**
		2018 estimate using BBS modelled relative abundance	**-**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (to match APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS modelled relative abundance in 2016	-
		2018 estimate using BBS modelled relative abundance in2016	-
	Method 2 - totals from BBS density maps	2009 and 2018 total individuals	-

(b) Feral pigeon Columba livia domestica

Breeding distribution maps were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 4). Feral pigeon was recorded with breeding evidence in 198 10-km squares (69 % of squares in Wales) and during winter in 198 10-km squares (69 %).

Birds resembling rock doves occur in many feral pigeon flocks, and those particularly on cliffs present identification problems. In the 2007-11 bird atlas, owing to the difficulty of assigning recorded birds to either rock or feral pigeon all records of rock and feral pigeons were combined. However, due to inconsistent coding of recent and historical records of feral pigeons and rock doves the archive files used to generate these analyses did not contain a ready-made set of relative abundance measures for evaluating abundance change for feral pigeon. Due to time constraints it was not possible to return to the source data and recreate this from scratch, hence there are no maps of abundance based on the frequency method. Also, modelled maps of densities were not produced by Massimino *et al*. (2015).

Figure 4. Maps of feral pigeon breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

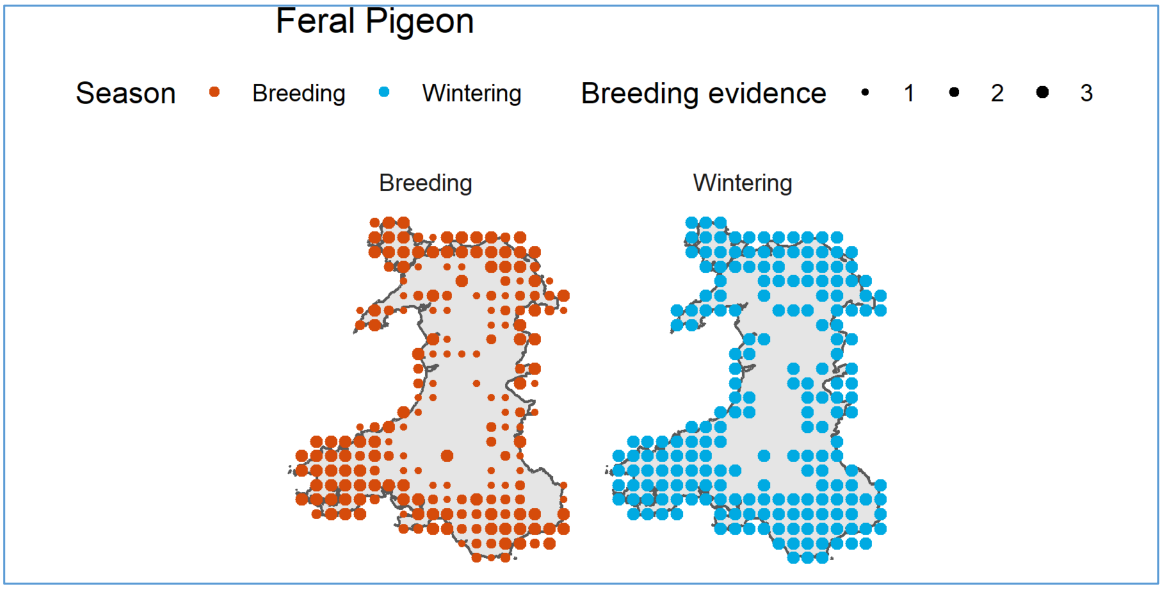


Figure 5. Map of feral pigeon fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution.

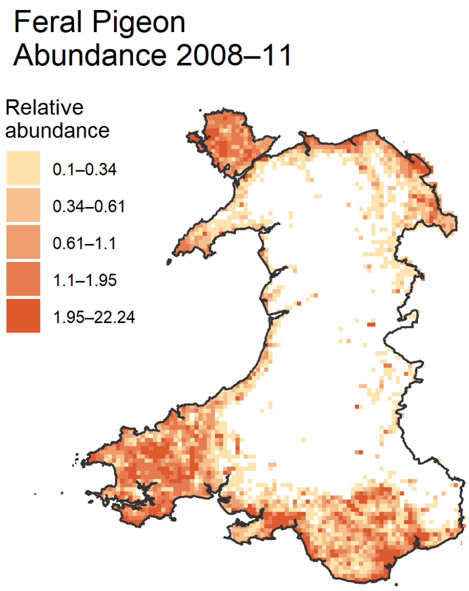
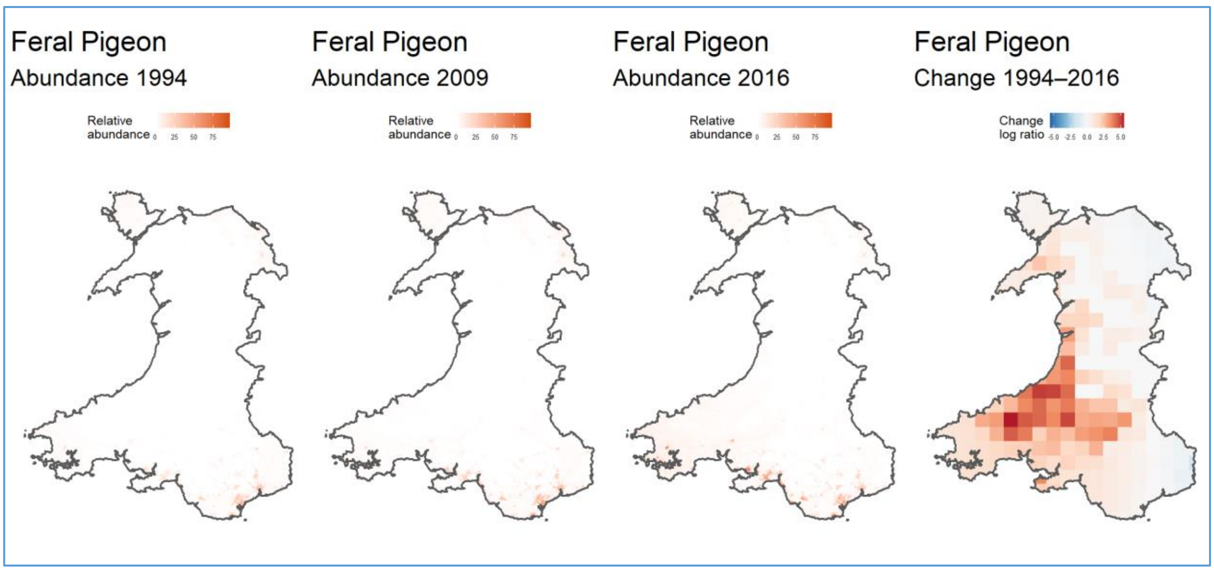


Figure 6. Maps of feral pigeon relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 4.1% and 7.7% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 24,450 to 41,245 pairs (Table 2). The best estimate of 31,213 breeding pairs was based on the mean of the three feasible apportioning approaches (Method 1). Estimates from summed densities (Method 2) are not possible because density maps were not produced for this species.

Table 2. Feral pigeon population estimates (in pairs) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	543043
		Lower confidence limit	442628
		Upper confidence limit	643457
		Period	2009
	APEP 4 population estimate	Point estimate	460000
		Lower confidence limit	375000
		Upper confidence limit	545000
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	8.9
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	6.9
		Lower confidence limit	6.0
		Upper confidence limit	7.8
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	4.7
	BBS (% of modelled density 2009)	Estimate	-
	BBS (% of modelled relative abundance 2009)	Estimate	4.1
	BBS (% of modelled relative abundance 2016)	Estimate	7.7
Welsh population change measures	Smoothed index 2009	Index value	148.7
	Smoothed index 2016	Index value	163.1
	Smoothed index 2018	Index value	164.2
	Trend 2016-2018	Proportional change	1.01
	Trend 2009-2018	Proportional change	1.10
	Sample size (last 12 yrs)	Number of squares	48
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	48331
		2009 estimate using Atlas TTV abundance	37350
		2009 estimate using Atlas modelled abundance	25305
		2009 estimate using BBS modelled densities	-
		2009 estimate using BBS modelled relative abundance	22141
		2018 estimate using Atlas range	**53370**
		2018 estimate using Atlas TTV abundance	**41245**
		2018 estimate using Atlas modelled abundance	**27944**
		2018 estimate using BBS modelled densities	**-**
		2018 estimate using BBS modelled relative abundance	**24450**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (to match APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	35292
		2018 estimate using BBS% of modelled relative abundance 2016	**35527**
	Method 2 - totals from BBS density maps	2009 and 2018 total individuals	**-**

(c) Woodpigeon Columba palumbus

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 7). Woodpigeon was recorded with breeding evidence in 281 10-km squares (98 % of squares in Wales) and during winter in 281 10-km squares (98 %).

Figure 7. Maps of woodpigeon breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

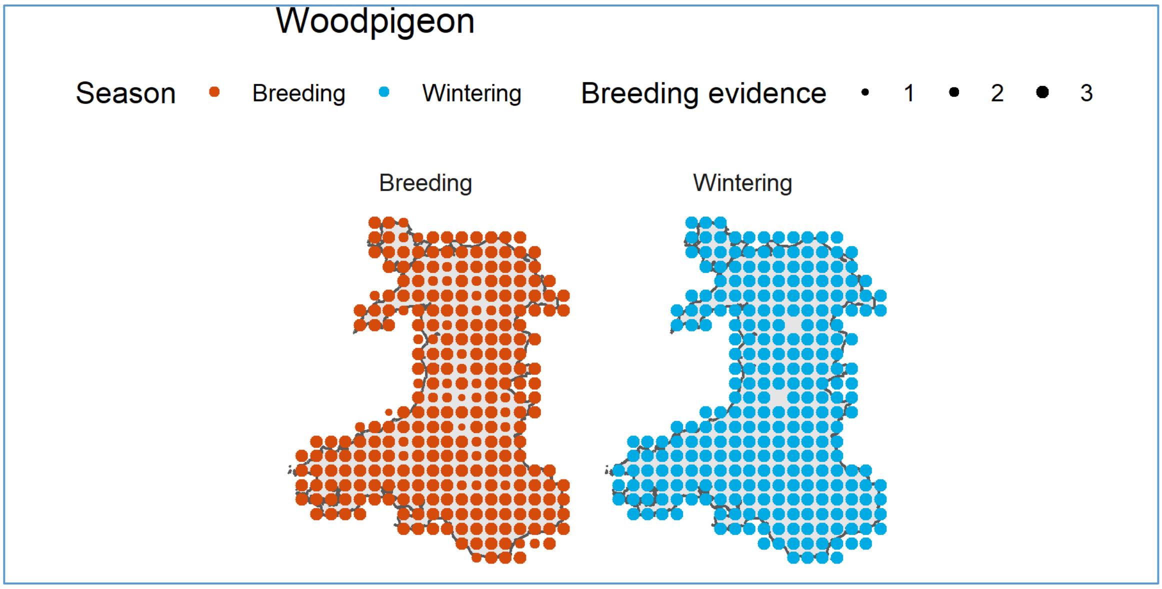


Figure 8. Maps of woodpigeon breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change. Based on a 20-km square resolution.

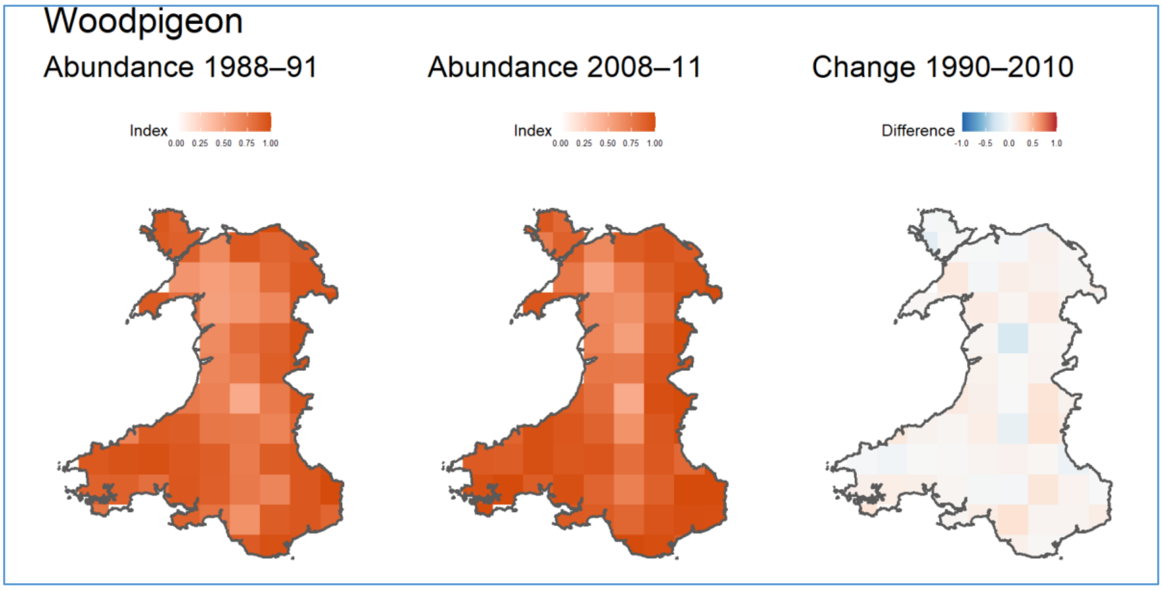


Figure 9. Map of woodpigeon fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution (tetrad).

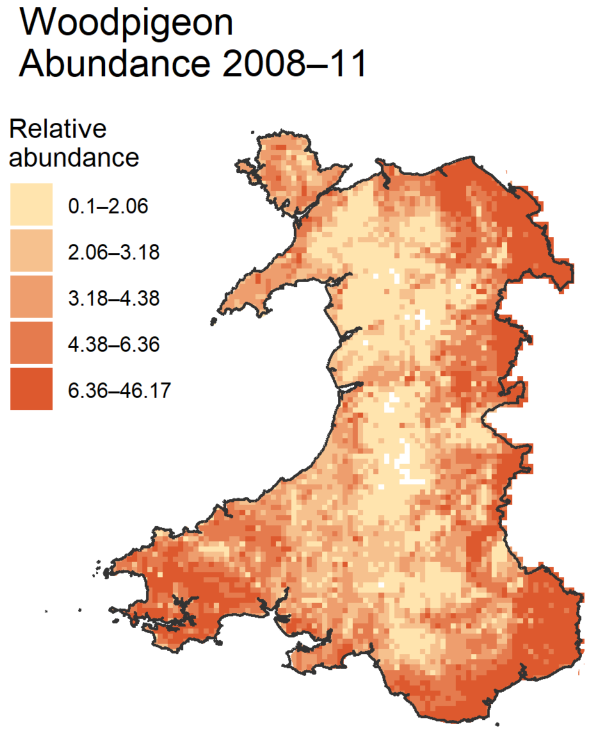


Figure10. Maps of woodpigeon density for two periods, based on statistical models of BBS data, and change in density between those periods (from Massimino *et al.,* 2015). Based on a 20-km square resolution. The change map shows change between the midpoints of each of those periods.

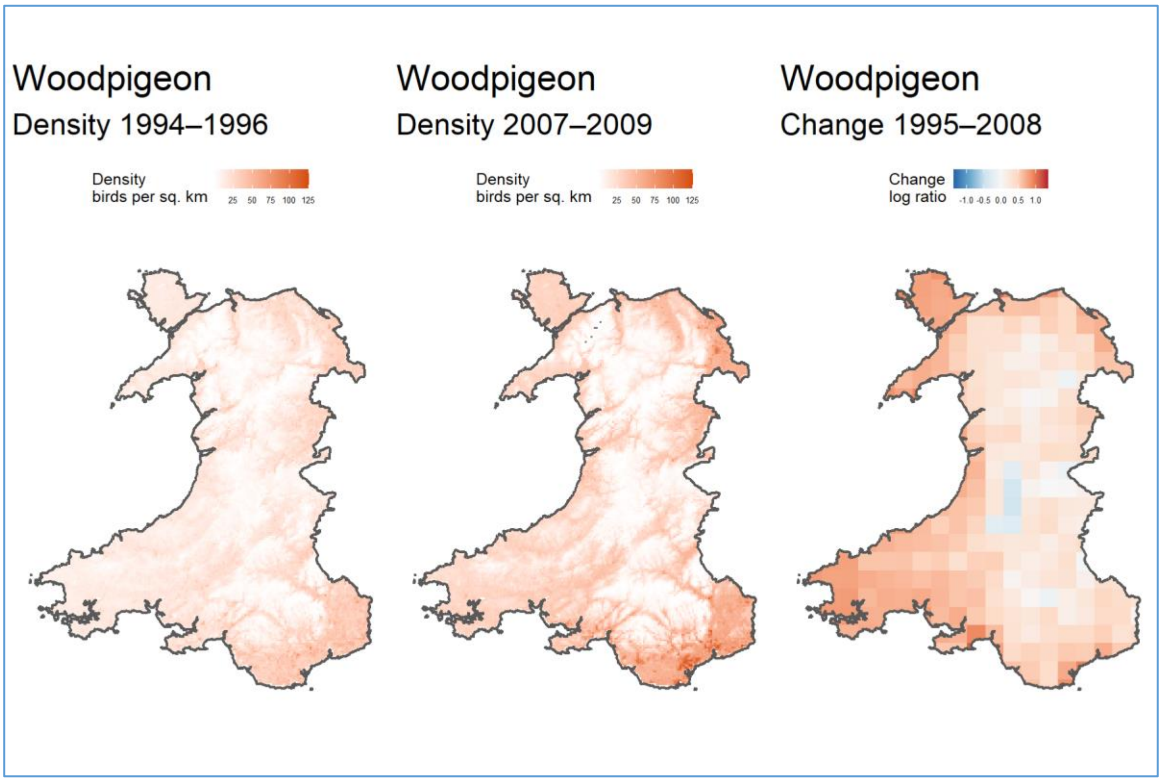
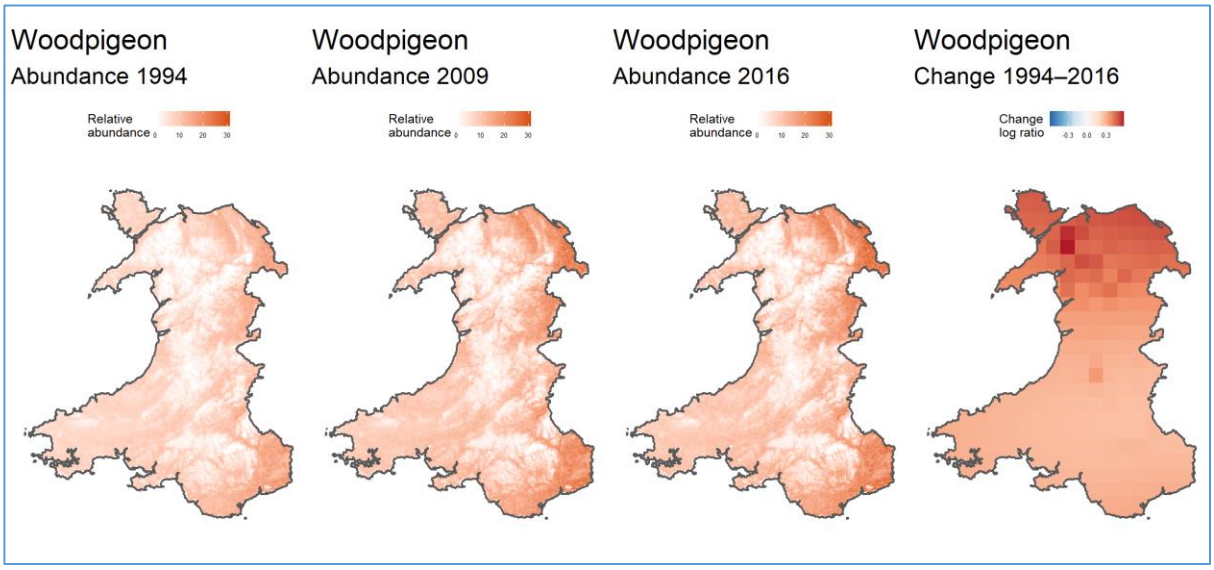


Figure 11. Maps of woodpigeon relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 3.8% and 6.2% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 179,886 to 295,385 pairs (Table 3). The recommended estimate of 222,450 pairs is the mean of the four best apportioning approaches excluding both the distribution method, and the 2016 BBS relative abundance method matched to APEP4. Data matched to APEP3 were considered better because the estimates could be updated to 2018 using Wales specific population trends whereas data matched to APEP4 already include an adjustment based on UK trends which could differ from those in Wales. Method 2 provides a figure of 458,976 individuals, which divided by two yields an estimate of ca 229,488 pairs, similar to the estimates obtained by apportioning.

Table 3. Wood pigeon population estimates (in pairs unless otherwise indicated) and source metrics used in derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	5288246
		Lower confidence limit	4977051
		Upper confidence limit	5599441
		Period	2009
	APEP 4 population estimate	Point estimate	5050000
		Lower confidence limit	4750000
		Upper confidence limit	5350000
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	10.9
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	6.2
		Lower confidence limit	6.0
		Upper confidence limit	6.4
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	3.8
	BBS (% of modelled density 2009)	Estimate	4.2
	BBS (% of modelled relative abundance 2009)	Estimate	4.4
	BBS (% of modelled relative abundance 2016)	Estimate	4.6
Welsh population change measures	Smoothed index 2009	Index value	127.9
	Smoothed index 2016	Index value	117.4
	Smoothed index 2018	Index value	115.5
	Trend 2016-2018	Proportional change	0.98
	Trend 2009-2018	Proportional change	0.90
	Sample size (last 12 yrs)	Number of squares	247
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	576419
		2009 estimate using Atlas TTV abundance	326972
		2009 estimate using Atlas modelled abundance	199123
		2009 estimate using BBS modelled densities	223868
		2009 estimate using BBS modelled relative abundance	234991
		2018 estimate using Atlas range	**520733**
		2018 estimate using Atlas TTV abundance	**295385**
		2018 estimate using Atlas modelled abundance	**179886**
		2018 estimate using BBS modelled densities	**202241**
		2018 estimate using BBS modelled relative abundance	**212289**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (to match APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	233636
		2018 estimate using BBS% of modelled relative abundance 2016	**229973**
	Method 2 - totals from BBS density maps	2009 total individuals	508058
		2018 total individuals	458976

(d) Jay *Garrulus glandarius*

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 12). Jay was recorded with breeding evidence in 262 10-km squares (91 % of squares in Wales) and during winter in 262 10-km squares (91 %).

Figure 12. Maps of jay breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

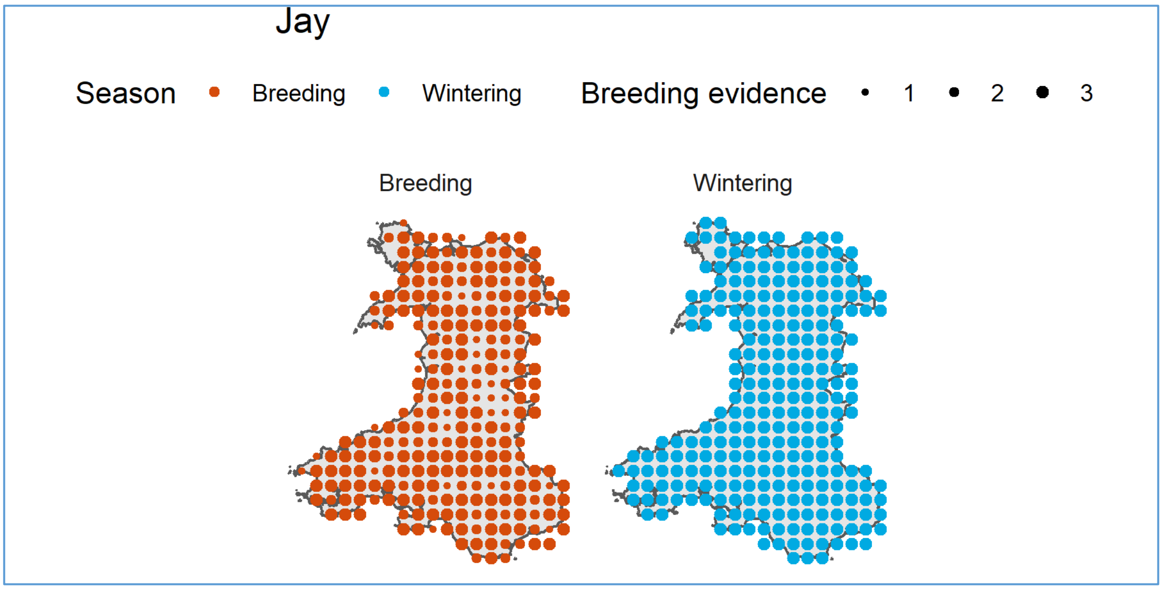


Figure 13. Maps of jay breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change. Based on a 20-km square resolution.

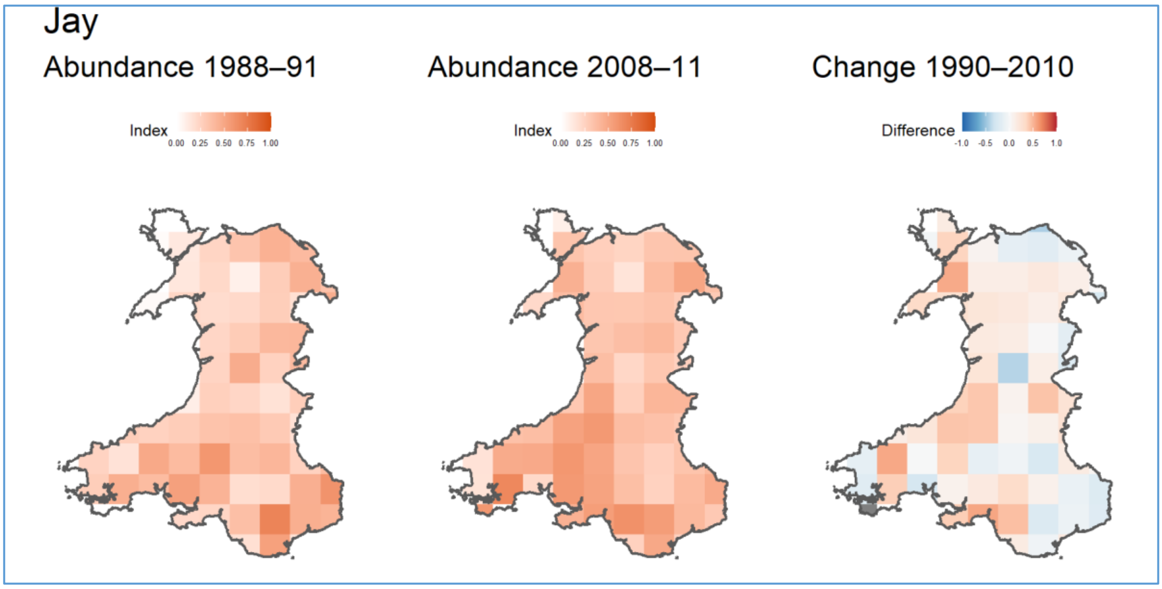


Figure 14. Map of jay fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution (tetrad).

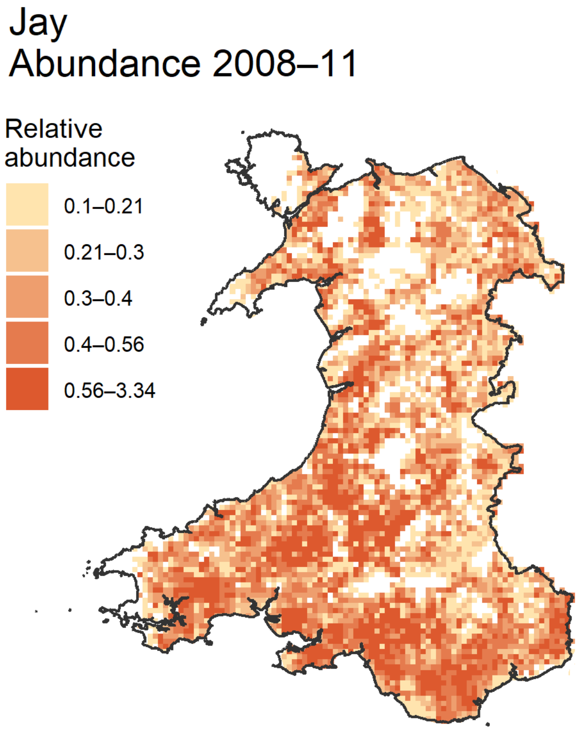


Figure 15. Maps of jay density for two periods, based on statistical models of BBS data, and change in density between the midpoints of those periods (from Massimino *et al*., 2015).

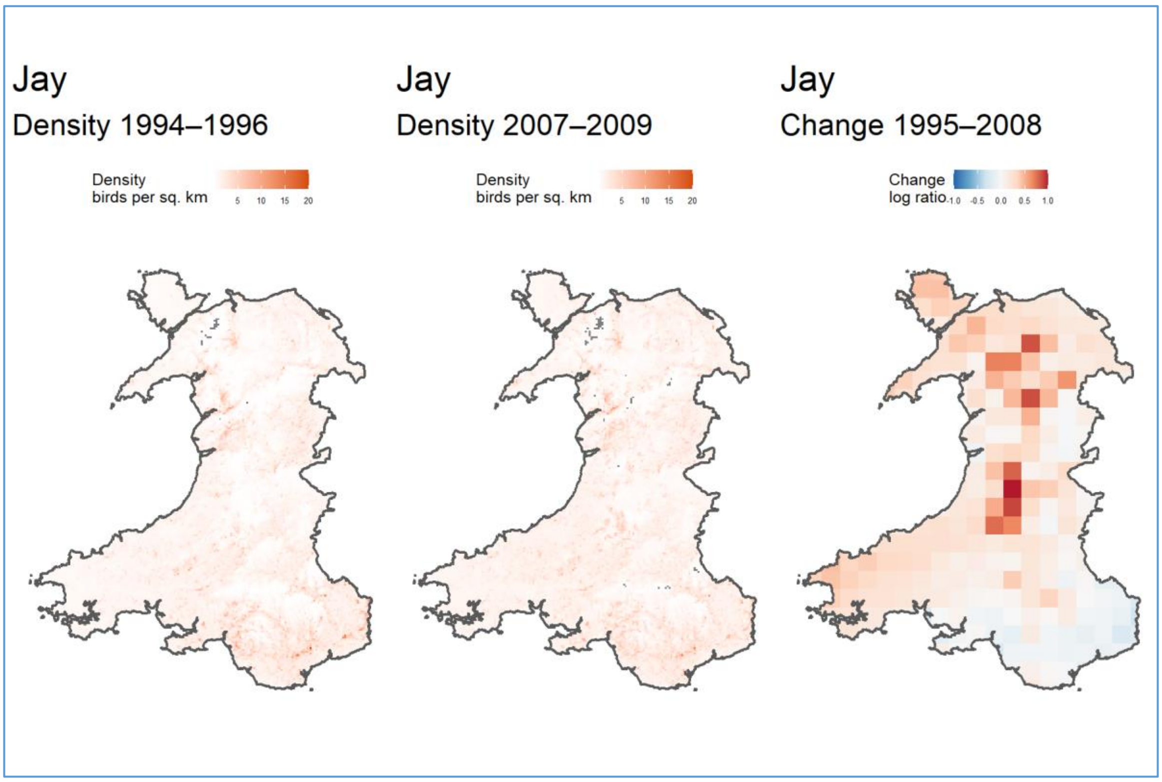
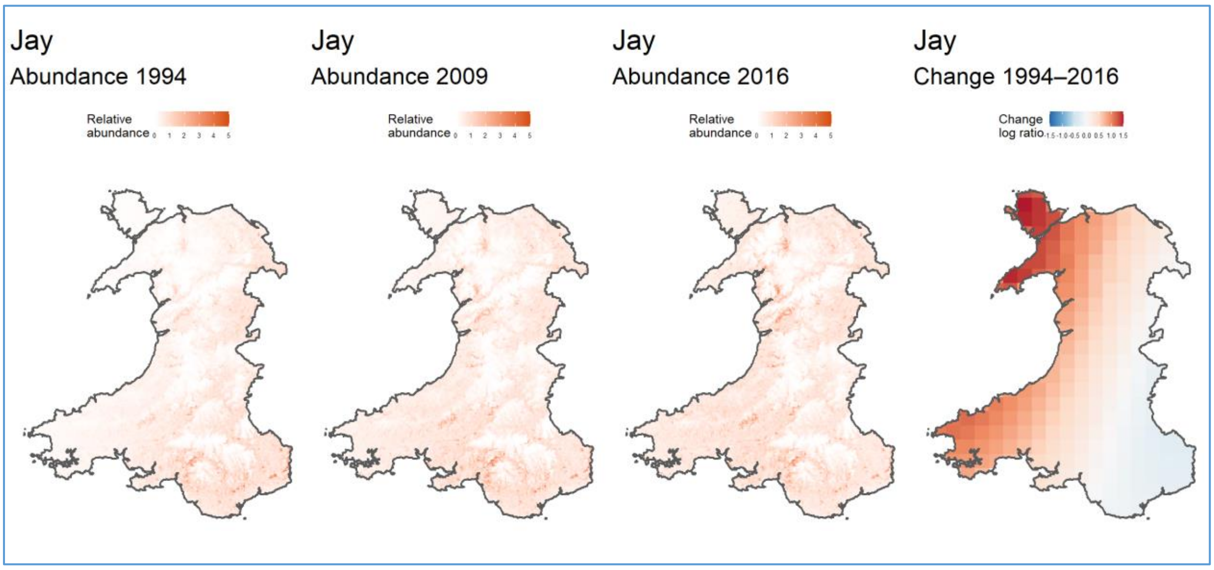


Figure 16. Maps of jay relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 10.8% and 18.8% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 20,431 to 35,422 pairs (Table 4). The recommended population estimate based on a mean value of the four best apportioning approaches, (excluding the approach using distribution data and the method matching 2016 BBS relative abundance to the APEP4 estimates) is 27,353 pairs. Method 2 using distance sampling provides a figure of 32,095 individuals (Table 4), which divided by two yields an estimate of ca 16,048 pairs, lower than the estimates obtained by apportioning. Distance sampling methods have a number of assumptions and the number of individuals seen may not reflect the number of pairs if some birds are cryptic or not detected, so we did not consider this to be a better estimate.

Table 4. Jay population estimates (in pairs unless otherwise indicated) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	173246
		Lower confidence limit	
		Upper confidence limit	
		Period	2009
	APEP 4 population estimate	Point estimate	165000
		Lower confidence limit	
		Upper confidence limit	
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	13.2
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	18.8
		Lower confidence limit	18.0
		Upper confidence limit	19.7
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	15.4
	BBS (% of modelled density 2009)	Estimate	10.8
	BBS (% of modelled relative abundance 2009)	Estimate	13.0
	BBS (% of modelled relative abundance 2016)	Estimate	14.2
Welsh population change measures	Smoothed index 2009	Index value	147.1
	Smoothed index 2016	Index value	142.4
	Smoothed index 2018	Index value	160.0
	Trend 2016-2018	Proportional change	1.12
	Trend 2009-2018	Proportional change	1.09
	Sample size (last 12 yrs)	Number of squares	103
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	22868
		2009 estimate using Atlas TTV abundance	32563
		2009 estimate using Atlas modelled abundance	26741
		2009 estimate using BBS modelled densities	18782
		2009 estimate using BBS modelled relative abundance	22495
		2018 estimate using Atlas range	**24876**
		2018 estimate using Atlas TTV abundance	**35422**
		2018 estimate using Atlas modelled abundance	**29089**
		2018 estimate using BBS modelled densities	**20431**
		2018 estimate using BBS modelled relative abundance	**24470**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (to match APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	23407
		2018 estimate using BBS% of modelled relative abundance 2016	**26305**
	Method 2 - totals from BBS density maps	2009 total individuals	29505
		2018 total individuals	32095

(e) Magpie Pica pica

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 17). Magpie was recorded with breeding evidence in 281 10-km squares (98 % of squares in Wales) and during winter in 281 10-km squares (98 %).

Figure 17. Maps of magpie breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

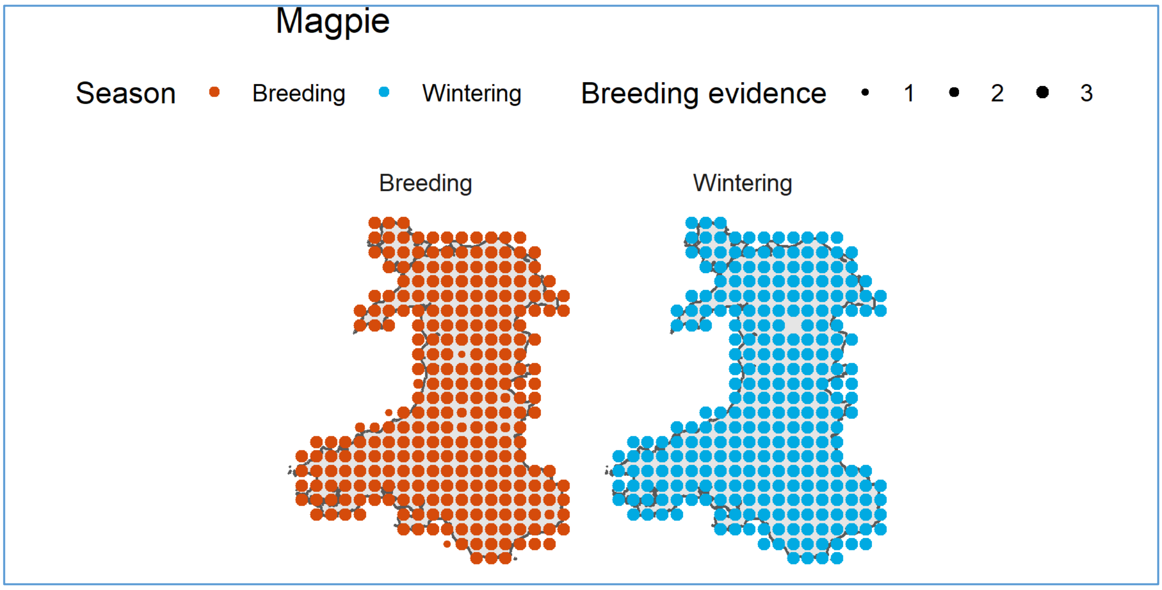


Figure 18. Maps of magpie breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change. Based on a 20-km square resolution.

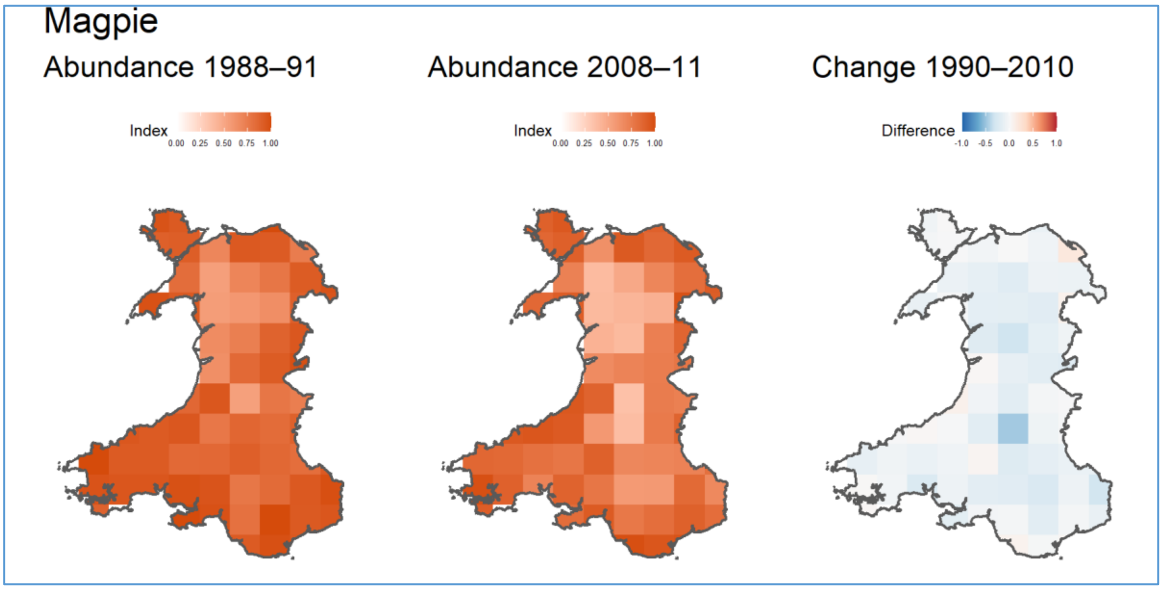


Figure 19. Maps of magpie fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution (tetrad).

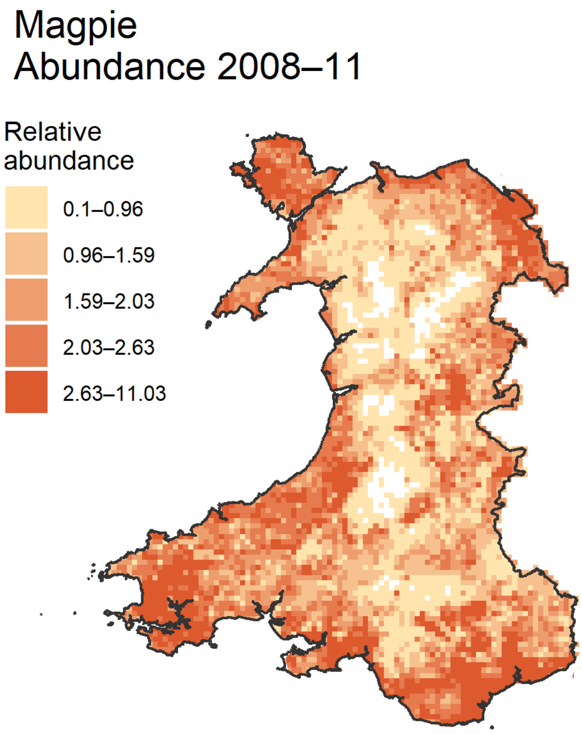


Figure 20. Maps of magpie density for two periods, based on statistical models of BBS data, and change in density between those periods (from Massimino *et al.,* 2015).

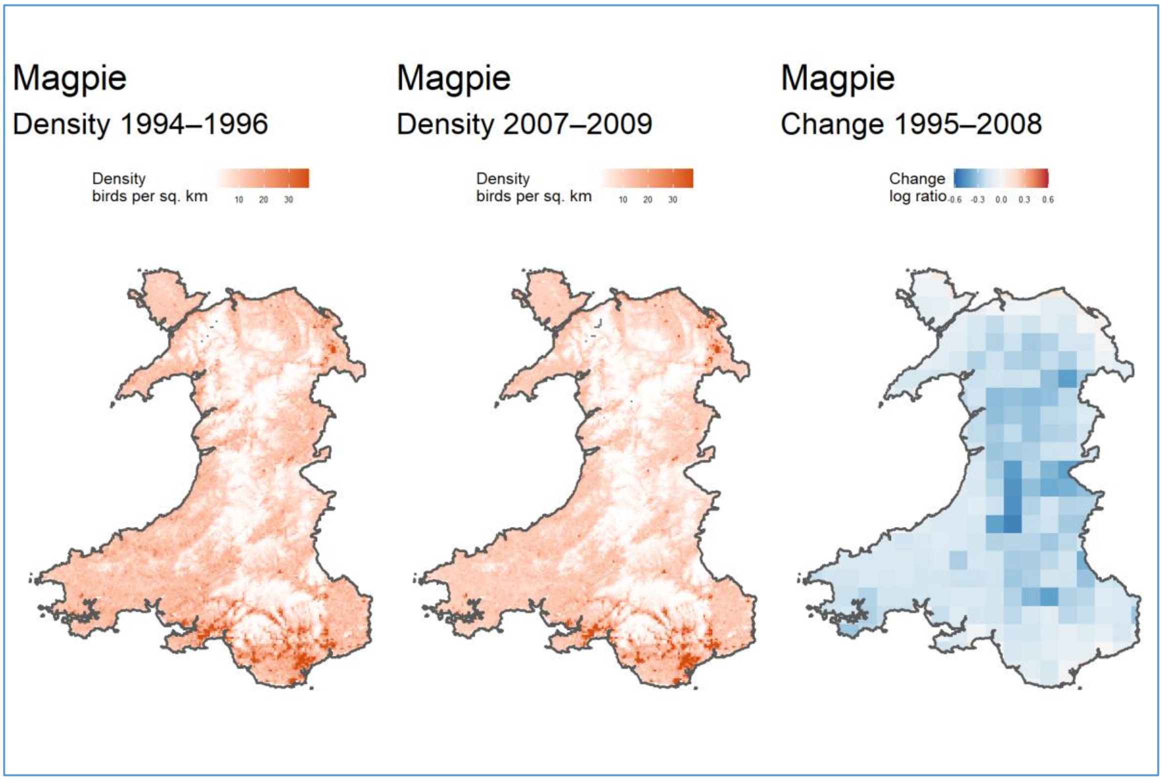
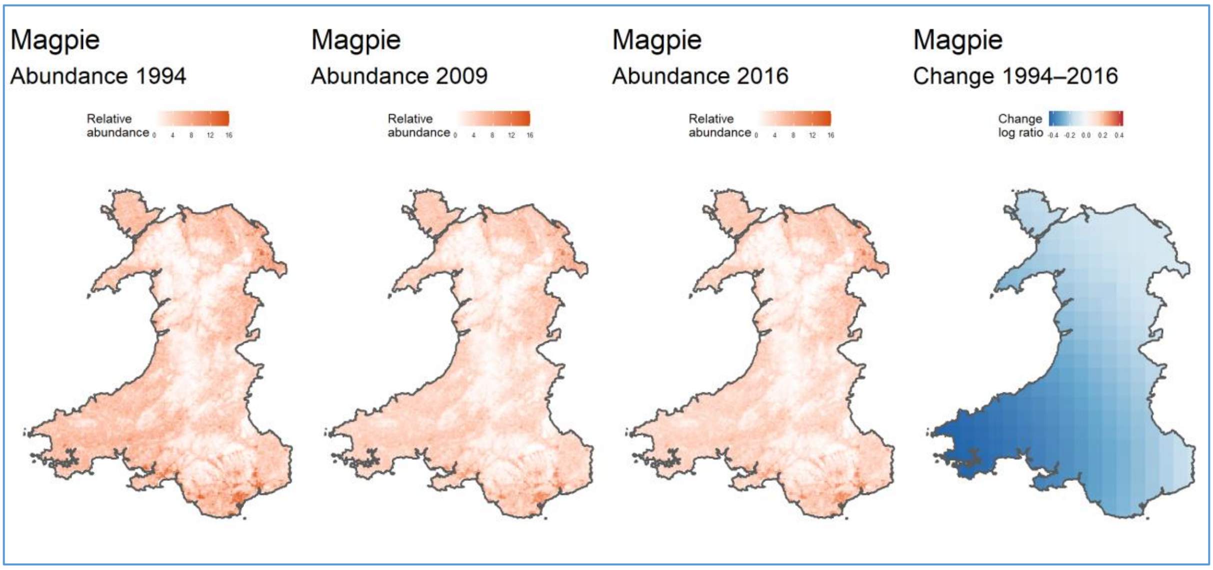


Figure 21. Maps of magpie relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 11.3% and 16.9% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 52,888 to 79,329 pairs (Table 5). The recommended population estimate based on the mean value of the four best apportioning approaches, (excluding the approach using distribution data and the method matching 2016 BBS relative abundance to the APEP4 estimates) is 61,672 pairs. Method 2 using distance sampling provides a figure of 152,328 individuals (Table 5), which divided by two yields an estimate of ca 76,164 pairs, within the range of estimates obtained by apportioning.

Table 5. Magpie population estimates (in pairs unless otherwise indicated) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	545895
		Lower confidence limit	
		Upper confidence limit	
		Period	2009
	APEP 4 population estimate	Point estimate	550000
		Lower confidence limit	
		Upper confidence limit	
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	13.5
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	16.9
		Lower confidence limit	16.5
		Upper confidence limit	17.4
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	11.9
	BBS (% of modelled density 2009)	Estimate	11.3
	BBS (% of modelled relative abundance 2009)	Estimate	12.4
	BBS (% of modelled relative abundance 2016)	Estimate	11.6
Welsh population change measures	Smoothed index 2009	Index value	71.2
	Smoothed index 2016	Index value	63.1
	Smoothed index 2018	Index value	61.3
	Trend 2016-2018	Proportional change	0.97
	Trend 2009-2018	Proportional change	0.86
	Sample size (last 12 yrs)	Number of squares	204
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	73696
		2009 estimate using Atlas TTV abundance	92153
		2009 estimate using Atlas modelled abundance	65131
		2009 estimate using BBS modelled densities	61438
		2009 estimate using BBS modelled relative abundance	67844
		2018 estimate using Atlas range	**63440**
		2018 estimate using Atlas TTV abundance	**79329**
		2018 estimate using Atlas modelled abundance	**56068**
		2018 estimate using BBS modelled densities	**52888**
		2018 estimate using BBS modelled relative abundance	**58403**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (to match APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	64053
		2018 estimate using BBS% of modelled relative abundance 2016	**62267**
	Method 2 - totals from BBS density maps	2009 total individuals	176952
		2018 total individuals	152328

(f) Jackdaw Corvus monedula

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 22). Jackdaw was recorded with breeding evidence in 278 10-km squares (97 % of squares in Wales) and during winter in 278 10-km squares (97 %).

Figure 22. Maps of jackdaw breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

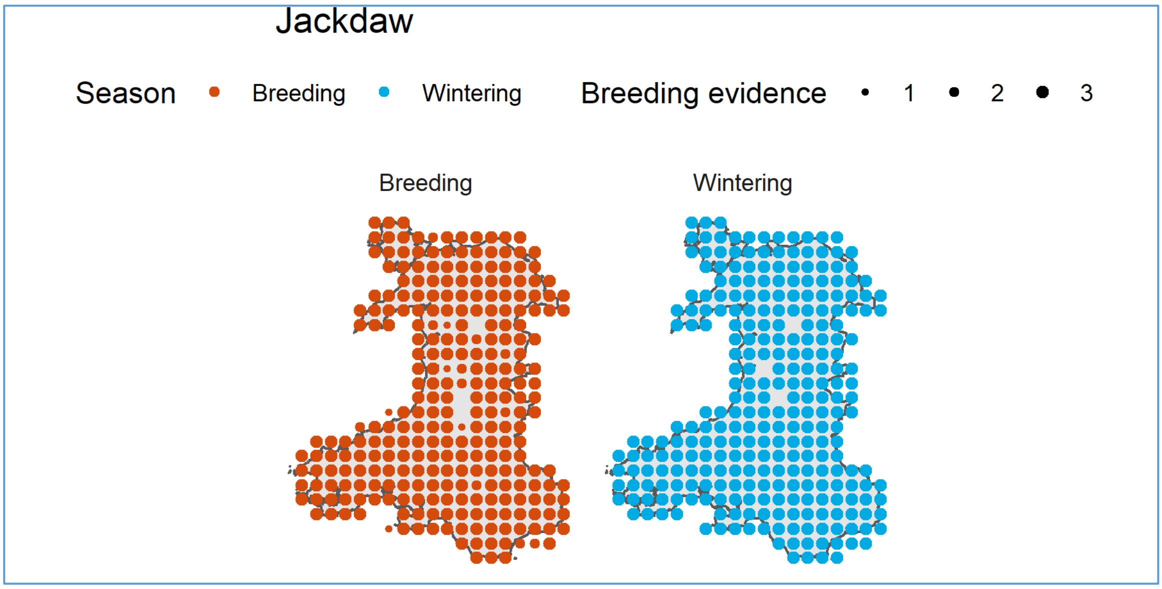


Figure 23. Maps of jackdaw breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change. Based on a 20-km square resolution.

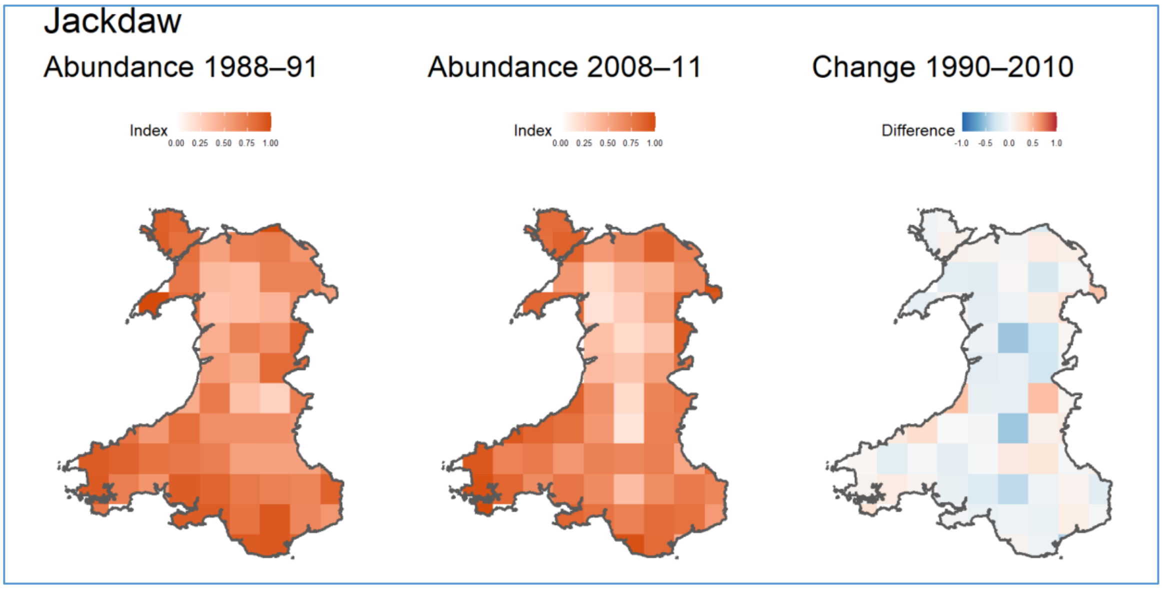


Figure 24. Map of jackdaw fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution (tetrad).

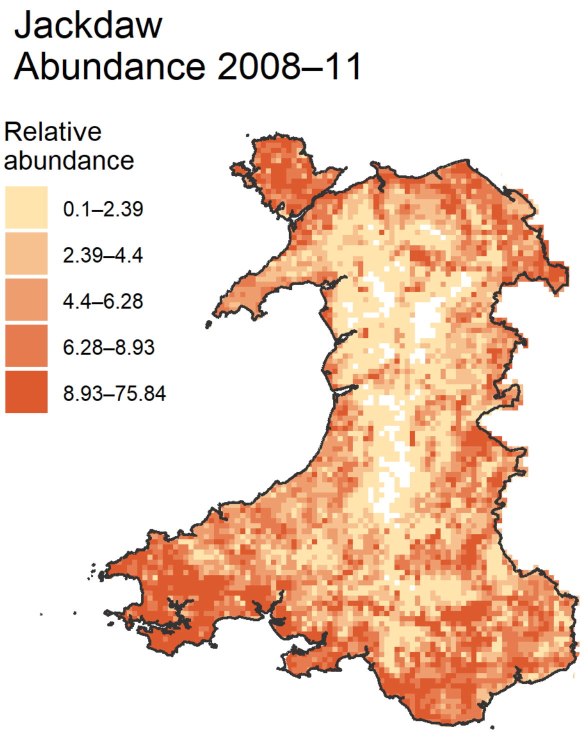


Figure 25. Maps of jackdaw density for two periods, based on statistical models of BBS data, and change in density between those periods (from Massimino *et al*., 2015).

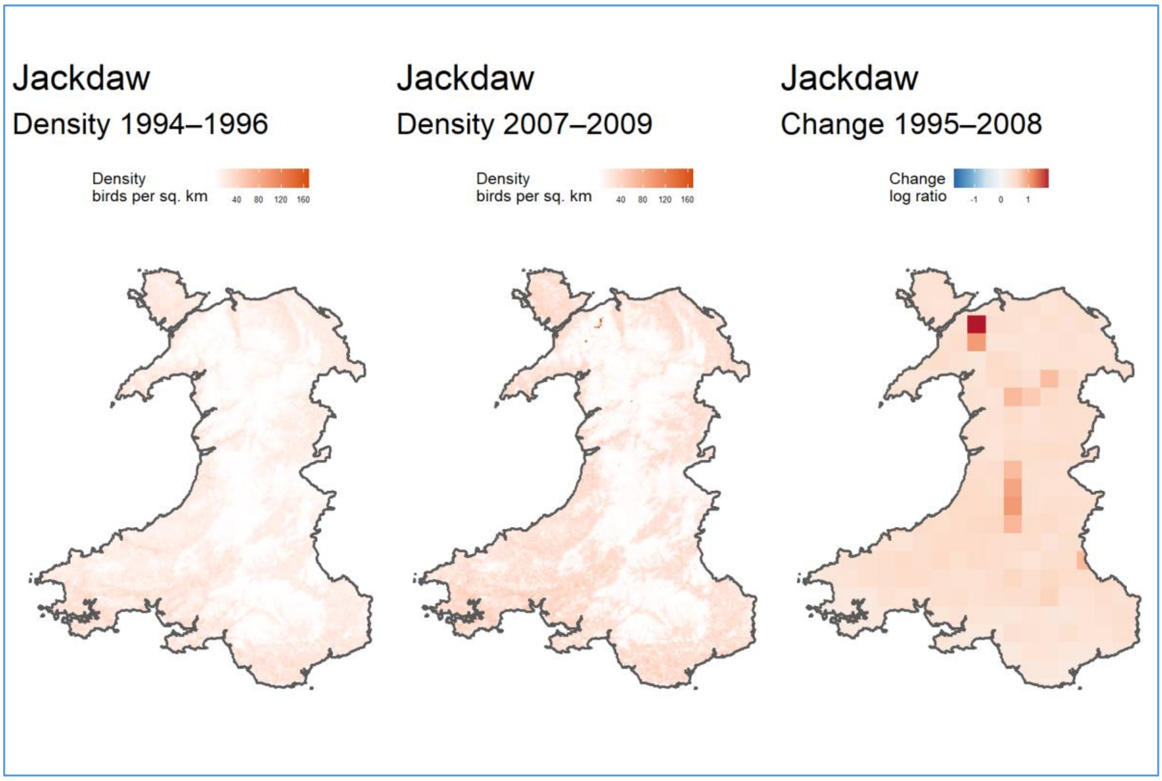
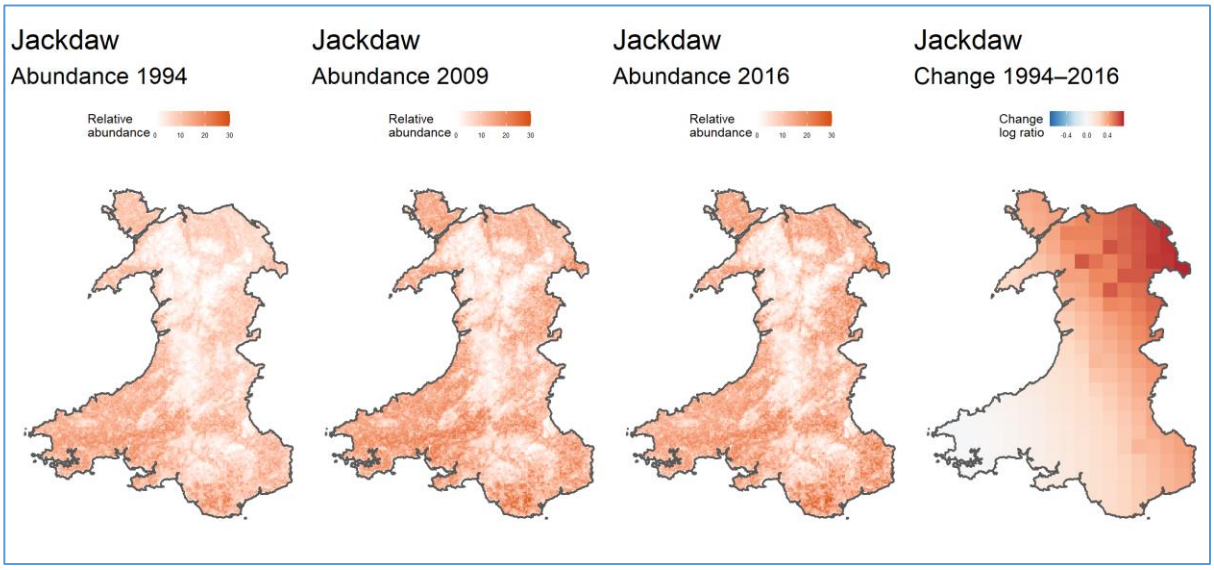


Figure 26. Maps of jackdaw relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 9.9% and 13.1% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 117,624 to 161,999 pairs (Table 6). The recommended population estimate based on the mean value of the four best apportioning approaches, (excluding the approach using distribution data and the method matching 2016 BBS relative abundance to the APEP4 estimates) is 138,348 pairs. Method 2 using distance sampling provides a figure of 327,802 individuals (Table 6), which divided by two yields an estimate of ca 163,901 pairs, slightly above the range of estimates obtained by apportioning. Distance sampling methods have a number of assumptions and the number of individuals seen may not reflect the number of pairs if some birds are cryptic or not detected, so we did not consider this to be a better estimate.

Table 6. Jackdaw population estimates (in pairs unless otherwise indicated) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	1291056
		Lower confidence limit	1133165
		Upper confidence limit	1448947
		Period	2009
	APEP 4 population estimate	Point estimate	1450000
		Lower confidence limit	1300000
		Upper confidence limit	1650000
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	11.9
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	13.1
		Lower confidence limit	12.5
		Upper confidence limit	13.7
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	9.9
	BBS (% of modelled density 2009)	Estimate	11.1
	BBS (% of modelled relative abundance 2009)	Estimate	12.6
	BBS (% of modelled relative abundance 2016)	Estimate	10.9
Welsh population change measures	Smoothed index 2009	Index value	125.0
	Smoothed index 2016	Index value	112.1
	Smoothed index 2018	Index value	114.6
	Trend 2016-2018	Proportional change	1.02
	Trend 2009-2018	Proportional change	0.92
	Sample size (last 12 yrs)	Number of squares	182
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	153636
		2009 estimate using Atlas TTV abundance	169451
		2009 estimate using Atlas modelled abundance	128328
		2009 estimate using BBS modelled densities	143356
		2009 estimate using BBS modelled relative abundance	162619
		2018 estimate using Atlas range	**140821**
		2018 estimate using Atlas TTV abundance	**155317**
		2018 estimate using Atlas modelled abundance	**117624**
		2018 estimate using BBS modelled densities	**131399**
		2018 estimate using BBS modelled relative abundance	**149055**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (to match APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	158379
		2018 estimate using BBS% of modelled relative abundance 2016	**161999**
	Method 2 - totals from BBS density maps	2009 total individuals	357632

		2018 total individuals	327802

(g) Rook *Corvus frugilegus*

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 27). Rook was recorded with breeding evidence in 257 10-km squares (89 % of squares in Wales) and during winter in 257 10-km squares (89 %).

Figure 27. Maps of rook breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

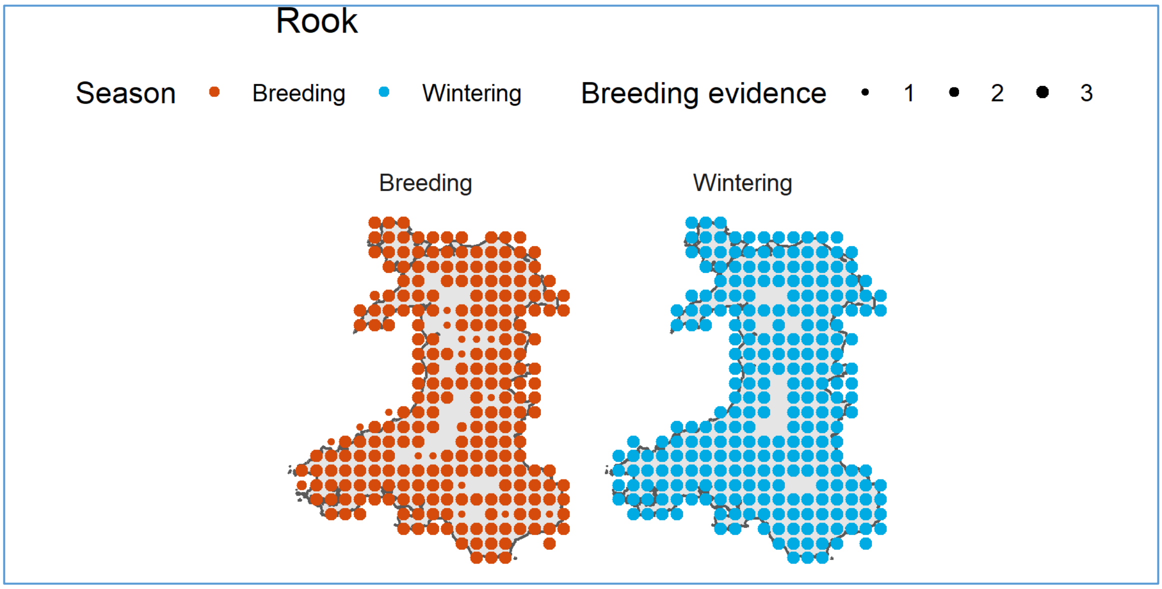


Figure 28. Maps of rook breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change. Based on a 20-km square resolution.

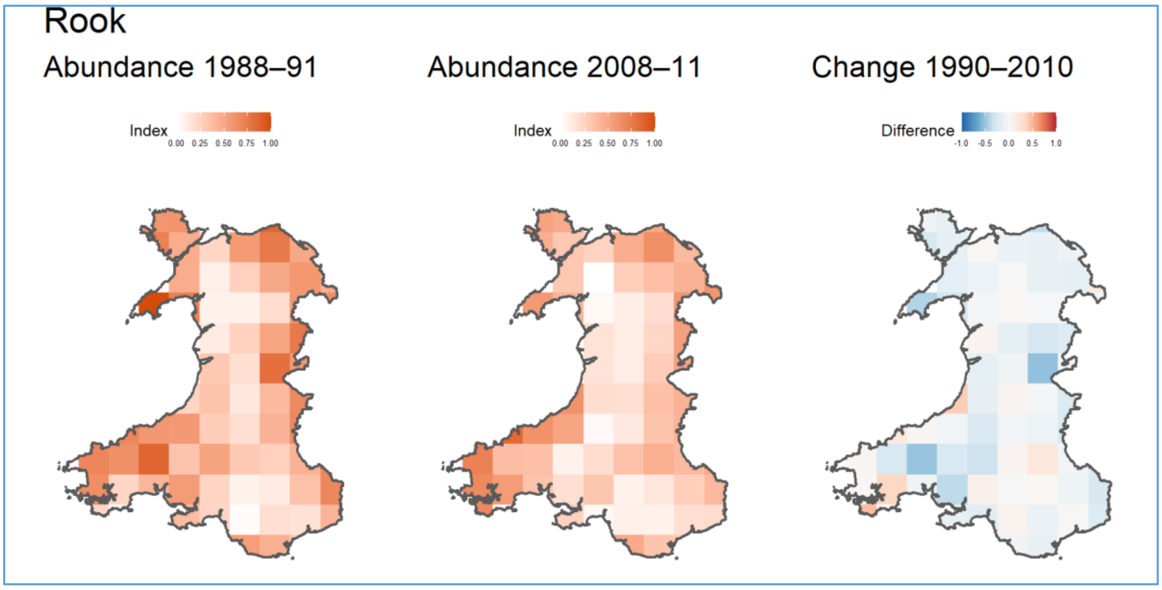


Figure 29. Map of rook fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution (tetrad).

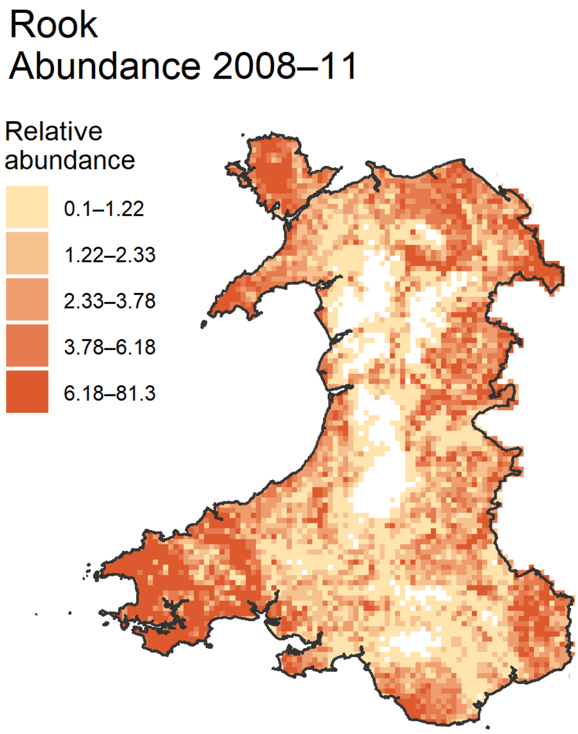


Figure 30. Maps of rook density for two periods, based on statistical models of BBS data, and change in density between those periods (from Massimino *et al.,* 2015).

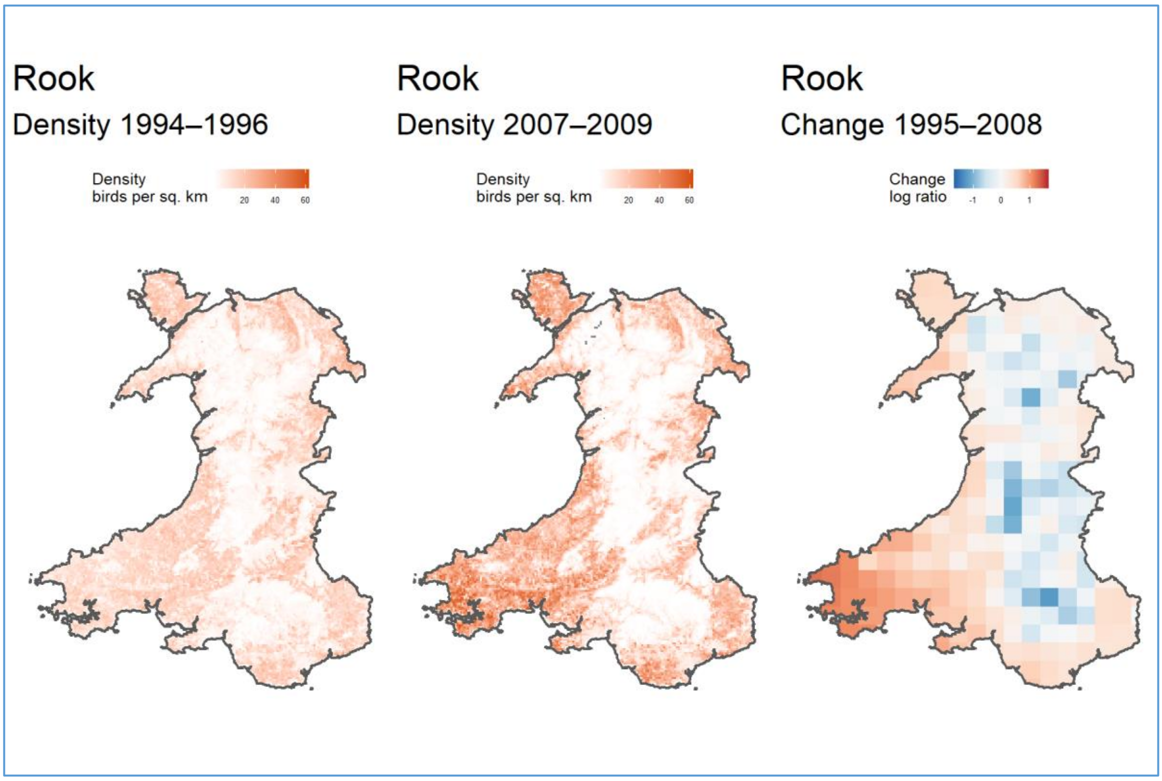
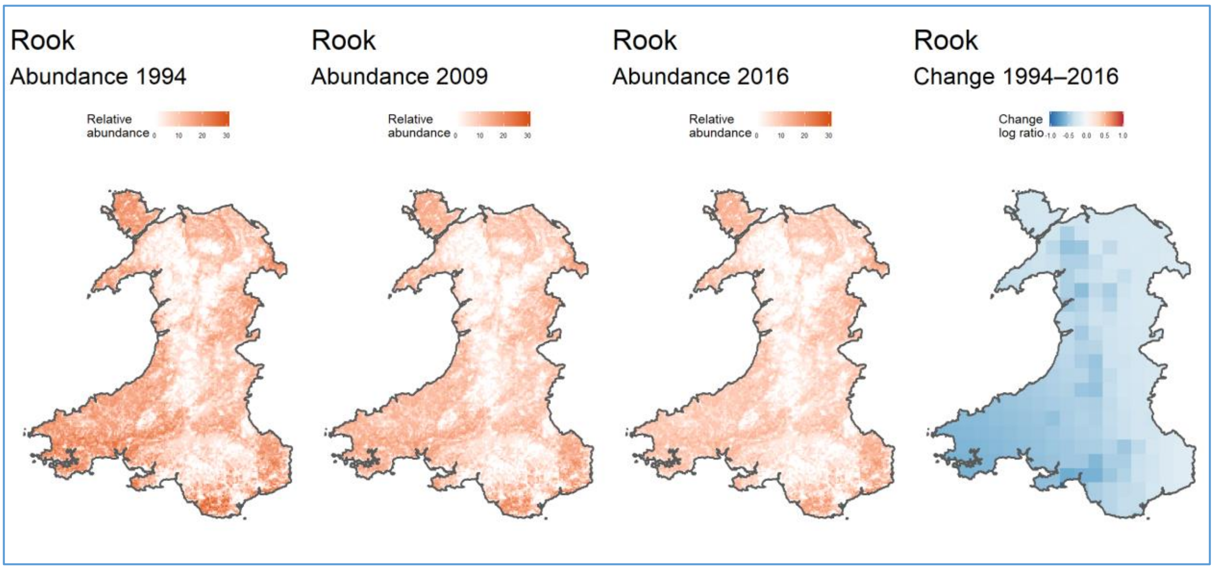


Figure 31. Maps of rook relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 4.8% and 8.9% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 23,295 to 49,413 pairs (Table 7). The recommended population estimate based on the mean value of the four best apportioning approaches, (excluding the approach using distribution data and the method matching 2016 BBS relative abundance to the APEP4 estimates) is 32,373 pairs. Method 2 using distance sampling provides a figure of 125,868 individuals (Table 7), which divided by two yields an estimate of ca 62,934 pairs, higher than the range of estimates obtained by apportioning. Distance sampling methods have a number of assumptions and the number of individuals seen may not reflect the number of pairs if some birds seen are non-breeders so we did not consider this to be a better estimate.

Table 7. Rook population estimates (in pairs unless otherwise indicated) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	986178
		Lower confidence limit	862689
		Upper confidence limit	1131254
		Period	2009
	APEP 4 population estimate	Point estimate	885000
		Lower confidence limit	775000
		Upper confidence limit	1000000
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	11.9
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	6.7
		Lower confidence limit	6.2
		Upper confidence limit	7.2
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	4.8
	BBS (% of modelled density 2009)	Estimate	8.9
	BBS (% of modelled relative abundance 2009)	Estimate	6.4
	BBS (% of modelled relative abundance 2016)	Estimate	6.0
Welsh population change measures	Smoothed index 2009	Index value	95.0
	Smoothed index 2016	Index value	49.9
	Smoothed index 2018	Index value	46.5
	Trend 2016-2018	Proportional change	0.93
	Trend 2009-2018	Proportional change	0.49
	Sample size (last 12 yrs)	Number of squares	89
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	117355
		2009 estimate using Atlas TTV abundance	66409
		2009 estimate using Atlas modelled abundance	47553
		2009 estimate using BBS modelled densities	87402
		2009 estimate using BBS modelled relative abundance	62975
		2018 estimate using Atlas range	**57489**
		2018 estimate using Atlas TTV abundance	**32532**
		2018 estimate using Atlas modelled abundance	**23295**
		2018 estimate using BBS modelled densities	**42816**
		2018 estimate using BBS modelled relative abundance	**30850**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	52937
		2018 estimate using BBS% of modelled relative abundance 2016	**49413**
	Method 2 - totals from BBS density maps	2009 total individuals	256942
		2018 total individuals	125868

(h) Carrion crow Corvus corone

Breeding distribution map were compiled by determining the highest breeding code (ie the strongest breeding evidence) for each 10-km square, from among possible probable and confirmed (Figure 32). Carrion crow was recorded with breeding evidence in 285 10-km squares (99 % of squares in Wales) and during winter in 285 10-km squares (99 %).

Figure 32. Maps of carrion crow breeding and wintering distribution based on data from Bird Atlas 2007–11 (Balmer *et al*., 2013). Based on 10-km square resolution with breeding evidence of 1 (possible), 2 (probable) and 3 (confirmed).

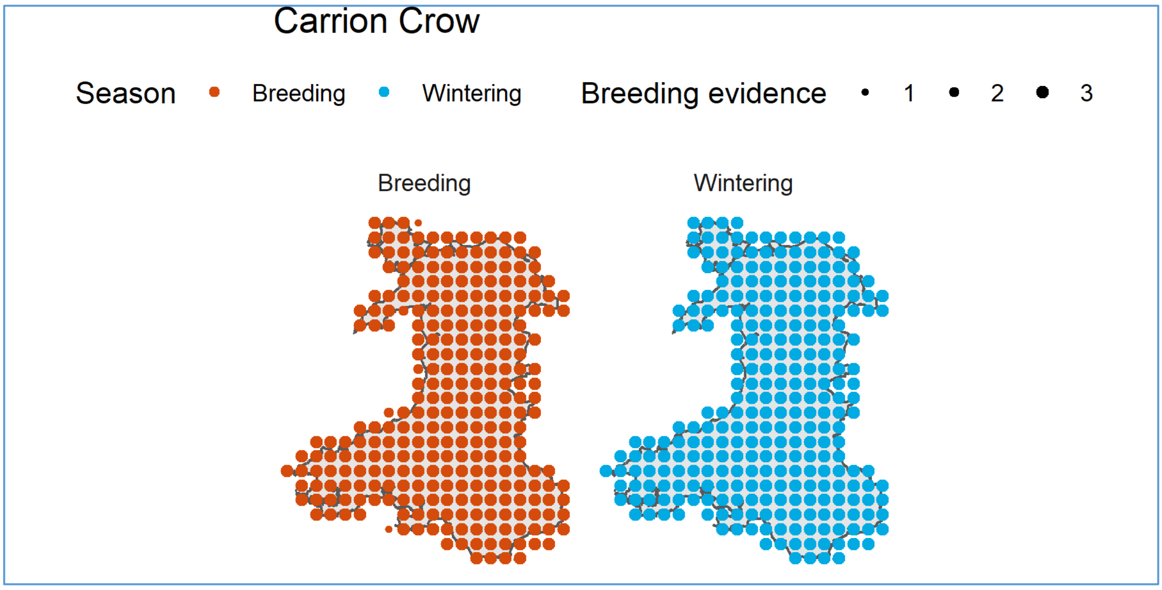


Figure 33. Maps of carrion crow breeding season relative abundance for 1988–91 and 2008–11, and the difference between these as an indication of abundance change. Based on a 20-km square resolution.

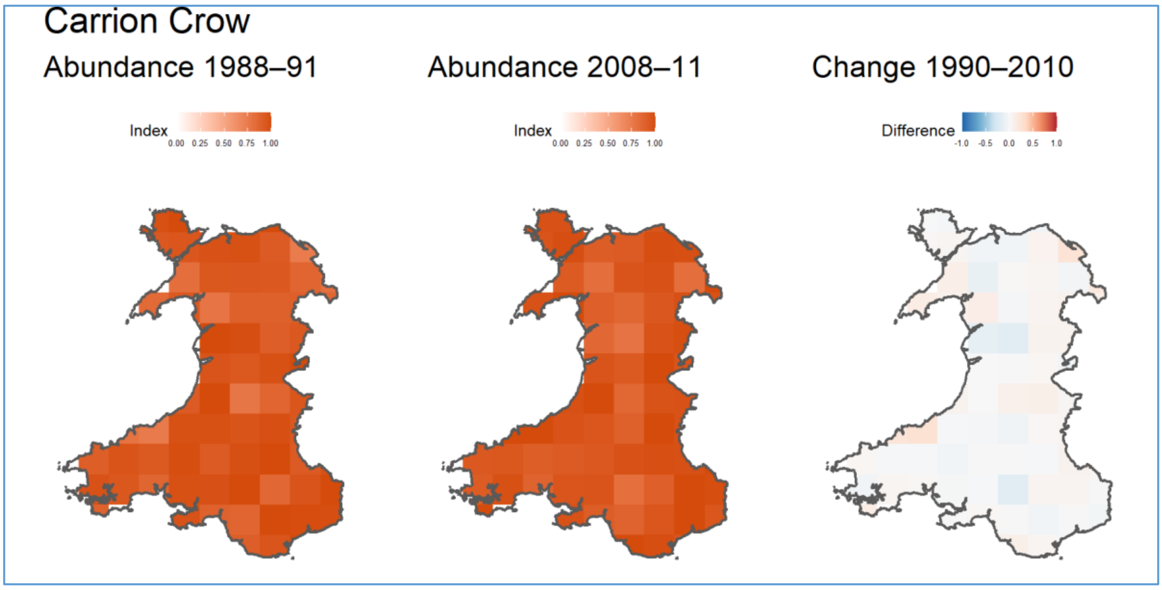


Figure 34. Maps of carrion crow fine-scale relative abundance based on statistical modelling of Bird Atlas 2007–11 Timed Tetrad Visit data. Based on a 2-km square resolution (tetrad).

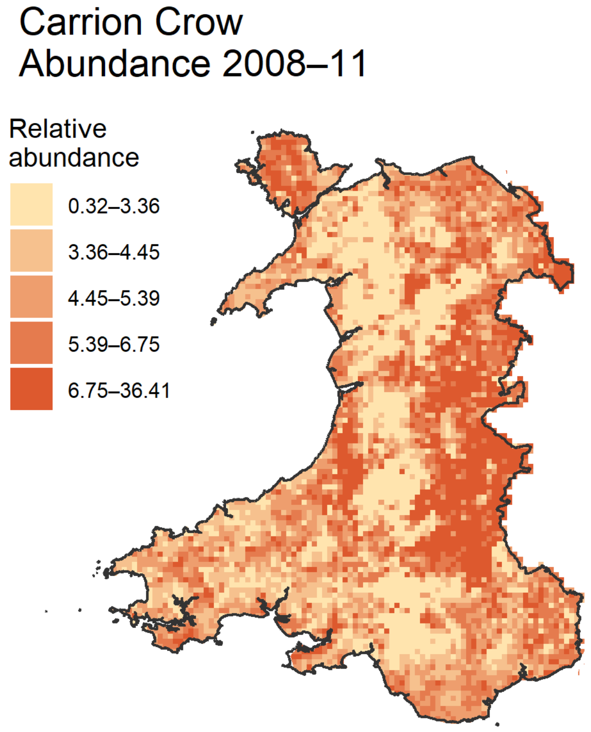


Figure 35. Maps of carrion crow density for two periods, based on statistical models of BBS data, and change in density between those periods (from Massimino *et al.,* 2015).

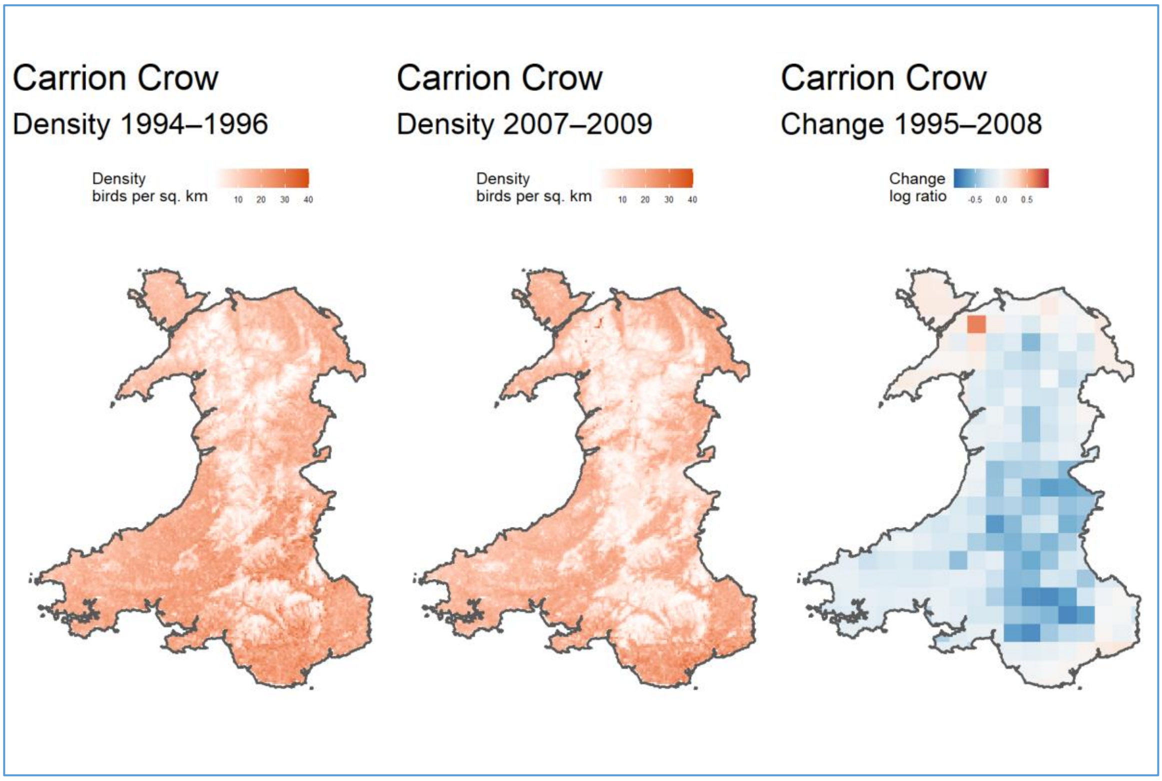
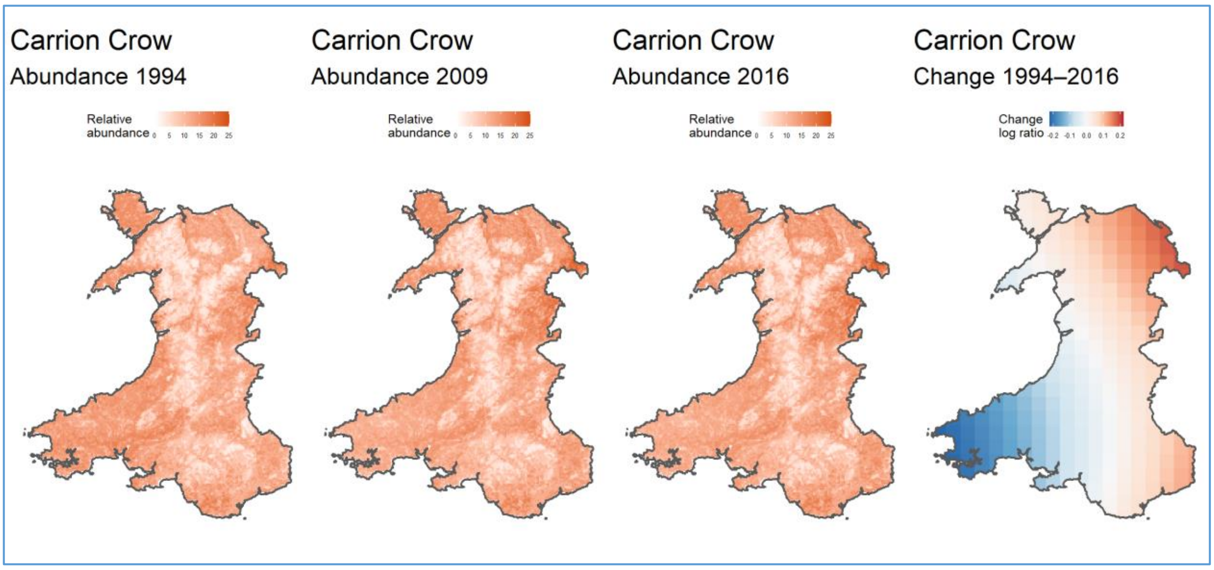


Figure 36. Maps of carrion crow relative abundance for three years, based on statistical models of BBS data, and change in abundance between1994 and 2016 (from Border and Gillings 2020).



We estimate that between 9.6% and 16.1% of GB abundance is associated with Wales, yielding population estimates for 2018 in the range 93,661 to 157,822 pairs (Table 8). The recommended population estimate based on the mean value of the four best apportioning approaches, (excluding the approach using distribution data and the method matching 2016 BBS relative abundance to the APEP4 estimates) is 121,057 pairs. Method 2 using distance sampling provides a figure of 232,683 individuals (Table 8), which divided by two yields an estimate of ca 116,341 pairs, very similar to the estimates obtained by apportioning. Distance sampling methods have a number of assumptions and the number of individuals seen, particularly for a flocking species like crow, may not accurately reflect the number of pairs, so we did not consider this to be a better estimate.

Table 8. Carrion crow population estimates (individual birds) and source metrics used in their derivation. Cells shaded orange indicate a derived population estimate for 2018.

Parameter	Source	Measure	Estimate
GB population estimates	APEP3 population estimate	Point estimate	1038108
		Lower confidence limit	
		Upper confidence limit	
		Period	2009
	APEP 4 population estimate	Point estimate	1050000
		Lower confidence limit	
		Upper confidence limit	
		Period	2016
Estimates of Welsh abundance as % of Great Britain abundance	BirdAtlas 2007–11 (% of range)	Estimate	11.8
	BirdAtlas 2007–11 (% of TTV abundance)	Point estimate	16.1
		Lower confidence limit	15.5
		Upper confidence limit	16.6
	BirdAtlas 2007–11 (% of modelled abundance)	Estimate	11.8
	BBS (% of modelled density 2009)	Estimate	9.6
	BBS (% of modelled relative abundance 2009)	Estimate	12.0
	BBS (% of modelled relative abundance 2016)	Estimate	11.6
Welsh population change measures	Smoothed index 2009	Index value	115.6
	Smoothed index 2016	Index value	113.9
	Smoothed index 2018	Index value	109.0
	Trend 2016-2018	Proportional change	0.96
	Trend 2009-2018	Proportional change	0.94
	Sample size (last 12 yrs)	Number of squares	266
Wales population estimates	Method 1 - 2009 GB estimate apportioned to Wales, adjusted to 2018 by trend	2009 estimate using Atlas range	122497
		2009 estimate using Atlas TTV abundance	167447
		2009 estimate using Atlas modelled abundance	122823
		2009 estimate using BBS modelled densities	99372
		2009 estimate using BBS modelled relative abundance	124117
		2018 estimate using Atlas range	**115456**
		2018 estimate using Atlas TTV abundance	**157822**
		2018 estimate using Atlas modelled abundance	**115763**
		2018 estimate using BBS modelled densities	**93661**
		2018 estimate using BBS modelled relative abundance	**116983**
	Method 1 - BBS relative abundance method as above but calculated for 2016 (APEP4) and updated to 2018 with the 2016-2018 BBS trend	2016 estimate using BBS% of modelled relative abundance 2016	121722
		2018 estimate using BBS% of modelled relative abundance 2016	**116433**
	Method 2 - totals from BBS density maps	2009 total individuals	246873
		2018 total individuals	232683

5. Interpretation

All methods of estimating the population sizes of the target species in Wales are subject to caveats related to the metric used, the reliability of each method and their inherent assumptions. This is reflected in the differences in the derived estimates. In the following table, we provide a recommendation of the best population estimate to use, and the reasoning behind that recommendation.

Table 9. Recommended population estimates for each species and reasons for that judgement.

	Best population estimate(s)	Reason for recommendation
Canada goose	**8,842 pairs** (8,800 when rounded)	The recommended population estimate of 8,842 pairs is based on the apportioning of GB estimate in APEP3 to Wales using the spatial patterns from modelling TTV counts. The estimate of finer scale estimate of 6,051 breeding pairs using finer-scale modelling and environmental variables was thought to be less likely to be as robust for a species in a colonising phase and not at equilibrium. This is exactly comparable to the estimate in Hughes *et al*. (2020) using the same method but rounded to nearest 50 (i.e. 8,850 pairs).
Feral pigeon	**31,213 pairs** (31,200 pairs when rounded)	The recommended population estimate of 31,213 pairs in 2018 is the mean of the best three relative abundance methods (two atlas-based and one BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS population change to account for change in abundance between 2009 and 2018. There was relatively some accordance (+/-30%) among the three best estimates (24,450 to 41,245 pairs see Table 2). There is no comparable independent estimate using distance sampling with BBS data, as that has not proved possible for this highly flocking species. The BBS relative abundance method of apportioning the GB component to Wales with and applying this to the APEP4 estimate yielded a similar estimate (35,527 pairs) within the rage above. The estimate published in Hughes *et al*. (2020) is the same as the Method 1 approach using Atlas TTVs (see Table 2) but their estimate was rounded from 41,245 to 41,000 pairs.

Woodpigeon	**222,450 pairs** (222,000 pairs when rounded)	The recommended population estimate of 222,450 pairs in 2018 is the mean of the best four methods (two atlas-based and two BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS population change to account for change in abundance between 2009 and 2018. There was a range of +/- 30% among the four estimates (179,886 to 295,385 pairs, Table 3), but the independent estimate of pairs (individuals/2) based on BBS distance analyses (229,488) was within this range and very close to the recommended mean. The method apportioning the APEP4 GB estimate using BBS relative abundance, and brought up to date with the BBS 2016-18 change was also remarkably similar (229,973) to the mean and the independent BBS density-based estimate, so the confidence in this estimate is high. The value published in Hughes *et al.* (2020) is the same as our Method 1 approach using Atlas TTVs, the higher end of our range (see Table 3), but their estimate was rounded from 295,385 to 295,000 breeding pairs.
Jay	**27,353 pairs** (27,400 when rounded)	The recommended population estimate of 27,353 pairs in 2018 is the mean of the best four methods (two atlas-based and two BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS population change to account for change in abundance between 2009 and 2018. There was relatively high accordance (+/- 25%) among the four estimates (20,431 to 35,422 pairs, Table 4), but the independent estimate of pairs (individuals/2) based on BBS distance analyses (16,047) fell outside this range, which could be attributed to fewer sightings of both individuals of breeding pairs during BBS visits. The method using the APEP4 estimate and updated with the BBS 2016-18 change was also very similar (26,305). The estimate published in Hughes *et al*. (2020) is the same as our Method 1 approach using Atlas TTVs (see Table 4) but their estimate was rounded from 35,422 to 35,500 pairs.
Magpie	**61,672 pairs** (61,700 pairs when rounded)	The recommended population estimate of 61,672 pairs in 2018 is the mean of the best four methods (two atlas-based and two BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS

		population change to account for change in abundance between 2009 and 2018. There was relatively high accordance among the four estimates (52,888 to 79,329 pairs, Table 5), and the independent estimate of pairs (individuals/2) based on BBS distance analyses fell within this range (76,164). The method using the APEP4 estimate and updated with the BBS 2016-18 change was also very similar (62,267). The estimate published in Hughes *et al*. (2020) is the same as our Method 1 approach using Atlas TTVs (see Table 5), but their estimate was rounded from 79,329 to 79,500 pairs.
Jackdaw	**138,348 pairs** (138,000 pairs when rounded)	The recommended population estimate of 138,348 pairs in 2018 is the mean of the best four methods (two atlas-based and two BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS population change to account for change in abundance between 2009 and 2018. There was relatively high accordance (+/ 20%) among the four estimates (117,624 to 155,317 pairs, Table 6), but the independent estimate of pairs (individuals/2) based on BBS distance analyses (163,901) fell outside this range. This might be attributed to non-breeders among populations of this semi-colonial species. The method using the APEP4 estimate and updated with the BBS 2016-18 change (161,999) was outside the range, reflecting the fact that UK numbers have increased more strongly than in Wales. The recommended estimates using Wales-specific population trends to adjust older UK population estimates avoid this issue. The estimate published in Hughes *et al*. (2020) is the same as our Method 1 approach using Atlas TTVs (see Table 6), but their estimate was rounded from 155,317 to 155,000 pairs.
Rook	**32,373 pairs** (32,400 pairs when rounded)	The recommended population estimate of 32,373 pairs in 2018 is the mean of the best four methods (two atlas-based and two BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS population change to account for change in abundance between 2009 and 2018. There was some accordance among the four estimates (23,295 to 42,816 pairs, Table 7), but the independent estimate of pairs (individuals/2) based on BBS distance analyses fell outside this

		range (62,934). This higher estimate may reflect failed or non-breeders in this colonial-nesting species. The method using the APEP4 estimate and updated with the BBS 2016-18 change (49,413) was higher, reflecting the fact that Rooks have declined less severely in the UK overall than in Wales, and hence why we recommend calculating change with Wales-specific trends from the earlier APEP3-based GB estimates. The estimate published in Hughes *et al*. (2020) is the same as our Method 1 approach using Atlas TTVs (see Table 7), but their estimate was erroneously rounded from 32,532 to 35,500 pairs.
Carrion crow	**121,057 pairs** (121,000 pairs when rounded)	The recommended population estimate of 121,057 pairs in 2018 is the mean of the best four methods (two atlas-based and two BBS-based) of apportioning the Wales component of the UK population estimate in 2009, each subsequently adjusted using the smoothed Wales-specific BBS population change to account for change in abundance between 2009 and 2018. Accordance among the four estimates was not particularly high (93,661 to 157,822 pairs, Table 8) but the independent estimate of pairs (individuals/2) based on BBS distance analyses (116,341 pairs) fell within the range and close to the mean estimate. The method using the APEP4 estimate and updated with the BBS 2016-18 change (116,433) was also within 5% of the mean provided here. The estimate published in Hughes *et al*. (2020) is the same as our Method 1 approach using Atlas TTVs (see Table 8), but their estimate was rounded from 157,822 to 160,00 pairs.

Since all of the **Method 1** approaches rely on the Avian Population Estimates Panel (APEP) figures (APEP3 Musgrove *et al*., 2013; APEP 4 Woodward *et al.,* 2020), it is important to understand that numbers of breeding pairs reported in APEP for many of the terrestrial species (i.e. all except Canada goose) are based ultimately on either (i) territory mapping estimates of territory densities in farmland, woodland and other Common Bird Census (CBC) plots in 1989, i.e. at the start of field data collection for the second Britain and Ireland Breeding Bird Atlas (Gibbons *et al.,* 1993), scaled up to calculate national population sizes, or (ii) calculations of densities and population sizes using distance sampling of 2006 BBS data. The CBC was phased out in the early 2000s and hence new density estimates were not recalculated, so the population estimates for those terrestrial species in APEP3 and APEP4 were adjusted from those in Gibbons *et al*. (1993) by a measure of change in the UK trend since the publication of that atlas to the latest year of data used in each APEP (to 2009 for APEP3 and to 2016 for APEP4). The distance-sampling based estimates in 2006 used in APEP3 for GB population sizes of jackdaw, feral pigeon and woodpigeon were similarly updated to 2016 using UK population trends.

For most of the corvids, the different methods of assessing the proportion of the GB population in Wales yielded similar estimates of the proportion of the population in Wales (broadly ca 10-15%), largely reflecting the distribution of these widespread species of open and woodland with quite generalist habitat requirements. As context, Wales accounts for approximately 8.5% of the landmass of Britain. The proportions of rook, feral pigeon and woodpigeon in Wales are lower, reflecting their greater preference for urban and lowland farmland, these habitats found in greater proportion outside Wales. The proportion of Canada geese in Wales was similar to that for most corvids.

Method 2 uses a completely different method to estimate numbers of species, being based on the summed BBS modelled densities in each 1 km square in Wales. We used recent distance analysis of BBS counts in distance bands along transects to determine detectability and subsequently densities and then modelled these in relation to land use and other factors to produce maps of estimated densities for every 1-km square in Wales. There is therefore no link with the historical territory mapping estimates in Gibbons *et al*. (1993) which were carried forward into APEP3 and APEP4. However, this method estimates number of individuals in the BBS square so needs to be converted to number of breeding pairs. In the absence of any other information on the relationship between numbers of individuals seen on BBS transects and numbers of breeding pairs, the most parsimonious solution is to divide the number of individuals by two to yield an estimate of breeding pairs. This assumption will be broadly true for species where both members of the pair are equally likely to be detected and where the majority of individuals seen during the BBS period (April to June) are breeding.

Each population estimate relies on certain assumptions and comes with caveats. For all of the Method 1 approaches, the first assumption is that the historical population estimates based mostly on territory mapping and published in Gibbons *et al*. (1993) are robust. The second consideration is the selection of approach to calculating the percentage of the GB population in Wales. The most straightforward method is using the number of occupied 10-km squares inside and outside Wales from Bird Atlas 2007-11. But this is the % range, not necessarily population size and this calculation is likely to be only valid for species that occur at the same density across the whole of Britain. Bird Atlas 2007- 11 shows that species generally have substantial spatial variation in abundance and this method would, for example, under-estimate the population size of any species that tends to occur at a higher density in Wales than in other parts of its British range.

Thirdly, a number of approaches under Method 1 that take into account difference in density between Wales and the rest of GB in 2007-11 are still based on APEP4 estimates for GB in 2016, and use long-term population trends (Common Birds Census and BBS; Massimino *et al.,* 2019) to adjust upwards or downwards older population estimates to reflect recent UK-level trends. If population trends differed markedly between Wales and the rest of GB in the intervening period (i.e. 1990 to 2016), estimates of the proportion of the GB population in Wales by this method may be wrong, leading to errors in our derived Welsh population estimates.

To overcome this problem, we developed a two-step method that used the same TTV data from Bird Atlas 2007-11 but with population estimates from APEP3 (Musgrove *et al.,* 2013). These were derived for 2009, coincident with the atlas fieldwork so do not suffer from the mismatch described above. The first step of this method involved multiplying the 2009 GB population estimate by the proportion of abundance in Wales from the Bird Atlas data, giving a Welsh population estimate for 2009. The second step was to update these figures to 2018 using the population trends for Wales from BBS (Harris *et al.,* 2020). Specifically, the ratio of change in the smoothed index value for 2009 and 2018 was multiplied by the 2009 Wales estimate to give a 2018 Wales estimate. This method is only possible for species with a robust population trend in Wales. For this purpose, we used trends for species that occurred in 30 or more BBS squares during that period. The criterion of 30 was adopted as that is the number of squares with data used to generate an annual population index for Wales (e.g. Harris *et al.,* 2020).

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