Game & Wildlife
CONSERVATION TRUST

Research Report

Trends and Distribution of Hedgehogs Reported to GWCT's National Gamebag Census from 1981 to 2019

A report to the People's Trust for Endangered Species

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Summary

1. The National Gamebag Census (NGC) was established in 1961 by the predecessor of the Game & Wildlife Conservation Trust (GWCT). Its aim was to provide a central repository of records from shooting estates across the UK, by documenting the numbers of quarry species and predators that have been shot or trapped ('bag data') as permitted by legislation.

2. In June 2021, the People's Trust for Endangered Species (PTES) commissioned GWCT to analyse NGC records of European hedgehog *Erinaceus europaeus*, submitted between 1981 and 2019, in order to determine trends in bag indices, quantify changes for the full period and the most recent 25 and 10 years, and produce relative abundance maps for the periods 1985-89 and 2015-19 to complement those already existing for 1995-99 and 2005-09.

3. Annual NGC indices were estimated using generalised linear models with Poisson error, logarithmic link function, ln(area) as offset and year and site as factors. To allow comparisons between years and sites, the numbers reported to NGC were standardised to unit area. Percentage changes were evaluated after smoothing out annual fluctuations using generalised additive models. Confidence intervals (95%) of the estimated changes were obtained by bootstrapping. Decadal maps of relative abundance and change at a 10x10-km resolution were derived by smoothing and categorising values into contour bands based on percentiles, following the approach of Noble *et al.* (2012).

4. Overall, the density of hedgehogs reported to the NGC has declined by around half across Britain over the 1981-2019 period. The change seemed to start in the west and spread eastward, but by the end of the 2010s was widespread throughout. Too few sites were available to calculate trends in Wales and in the North East England government region, and the NGC index had to be truncated before 2019 for four other government regions as the number of estates reporting hedgehogs had fallen too low for reliable calculation.

5. The distribution maps showed that in the 1980s, the density of hedgehogs reported to the NGC was high across most of Great Britain. By the 1990s, the distribution had become patchy, and many sites in south-west England and Wales had stopped reporting hedgehogs. In the 2000s, the patches of high-density hedgehog reports shrank further, while areas with no hedgehogs reported expanded eastwards from the south-west. The trend continued into the 2010s, resulting in widespread declines over four decades across the whole of Britain.

6. The observed decline in numbers of hedgehogs reported to the NGC may indicate a genuine decline in numbers of live hedgehogs, but may also arise through increased awareness of hedgehog conservation status, a decline in numbers of traps set or in length of time they are set, implementation of measures to avoid catching hedgehogs in traps, an increased reluctance to report hedgehogs or through any combination of these factors. There is no information available to separate out these effects.

7. Nevertheless, the decline observed in NGC data coincides with an increase in numbers of badgers, a predator of hedgehogs that has been shown to limit hedgehog distribution. Other possible reasons for decline also include agricultural intensification (reducing food resources and number of habitat refuges), habitat fragmentation, population isolation and mortality associated with road traffic collisions. If the decline in numbers of hedgehogs reported to the NGC reflects a genuine change in the live hedgehog population, there is a range of plausible ecological explanations for the change.

1. Introduction

The National Gamebag Census (NGC) is a voluntary scheme established in 1961 by the Game Research Association, the predecessor of the Game & Wildlife Conservation Trust (GWCT). The aim was to provide a central repository of records from shooting estates in England, Wales, Scotland and Northern Ireland. At the end of each shooting season, participating estates return a questionnaire requesting information from shooting and gamekeeping activities on the numbers of quarry species and predators that have been shot or trapped ('bag data') as permitted by legislation.

Because a substantial proportion of the countryside is managed for shooting, the NGC data potentially reflect trends in national and regional abundance for a wide range of species. Several of these, such as European hedgehog *Erinaceus europaeus*, are poorly monitored by government schemes. When expressed as the numbers of animals recorded per unit area, the data can be used to evaluate temporal and regional trends (Tapper 1992; Aebischer & Baines 2008, Aebischer 2019). It is, however, important to realise that the numbers returned to the NGC reflect catch effort as well as abundance, so the interpretation of trends is not necessarily straightforward.

The hedgehog benefits from partial protection under the Wildlife & Countryside Act (1981), in that it is unlawful to kill the species deliberately, or to set a trap with the intention of catching hedgehogs. Hedgehogs may, however, be trapped or killed accidentally in traps set for other species in the context of legitimate control of small mammalian pests (brown rat *Rattus norvegicus*, grey squirrel *Sciurus carolinensis*) and predators (stoat *Mustela erminea*, weasel *Mustela nivalis*) using spring kill traps or, less commonly, live traps. Since 1981, the numbers reported to the NGC are the result of by-catch taken in tunnel traps set for rats, stoats or weasels.

In June 2021, the People's Trust for Endangered Species (PTES) commissioned GWCT to analyse NGC records of European hedgehog *Erinaceus europaeus*, submitted between 1981 and 2019. The analyses were agreed as follows:

1. Produce trends in bag indices for UK, England, Scotland and, if possible, Wales from 1981 to 2019 following the methodology described in Aebischer (2019).

2. Produce estimates of percentage change (plus 95% confidence intervals) for the periods 1981-2019 (38 years), 1994-2019 (25 years) and 2009-19 (10 years) based on GAM smooths of the annual indices as per Aebischer (2019).

3. Produce relative abundance maps for the periods 1985-89 and 2015-19 consistent with and complementing those for 1995-99 and 2005-09 contained in the BTO/GWCT report to JNCC (Noble *et al.* 2012).

4. Explore whether there are sufficient data to produce trends in bag indices and estimates of percentage change for English government regions, as described under (1) and (2) for countries.

2. Statistical methods

Calculation of trends and change

Statistical analysis followed the approach of Aebischer (2019). A minimum of two years' data from the same site is needed to measure within-site change, so sites contributing only one year's data were omitted. Analysis was based on all annual returns reporting one or more hedgehogs. Numbers of hedgehogs were analysed using a generalised linear model (McCulloch & Nelder 1996) with a Poisson error distribution and logarithmic link function. Numbers reported increase with the size of a site, so they were standardised to densities by specifying the logarithm of site area as an offset; site and year were included as factors. In most cases the data spanned the period from 1981 to 2019, but for some regional analyses the end year had to be moved back because of insufficient sites in recent years (three contributing sites in any one year was a minimum requirement unless a lower number was a one-off). The estimated coefficients were used to predict values for each combination of year and site on the logarithmic scale; these values were then averaged across all sites to give logarithmic annual indices. The index series was exponentiated to give annual indices on the arithmetic scale, and a generalized additive model (GAM, Hastie and Tibshirani 1990) was fitted with one degree of freedom per decade or part-decade to smooth out annual variation. The smoothed values were used to evaluate the percentage change over the full series 38 years (1981–2019), 25 years (1994–2019) and 10 years (2009–2019).

The 95% confidence intervals around the annual index values were obtained by bootstrapping at the shoot level: for each of 999 bootstrap runs, shoots equal in number to the original sample were selected at random with replacement and a new set of indices obtained as described above. For each year, the 95% confidence limits were taken as the lower and upper 95th percentiles of the distribution of all 1000 index values. The original arithmetic index series and its confidence limits were standardised by dividing all values by the index value for the start year, so that the index value of the start year equalled 1 and subsequent index values were relative to the start year. Likewise, the 95% confidence limits of percentage change values were obtained by fitting GAMs to each bootstrap sample, calculating the percentage change, and selecting the lower and upper 95th percentiles of the 1000 values that resulted. If the 95% confidence interval did not include zero, the percentage change was declared significant at $P<0.05$.

Calculation of relative abundance maps

The report by Noble *et al.* (2012) contains synoptic maps showing smoothed densities of hedgehogs reported to the NGC for the two periods 1995-1999 and 2006-2009; maps were produced at a resolution of 10x10 km based on the standard Ordnance Survey grid system. Using the methodology of Noble *et al.* (2012), we produced comparable maps for the periods 1985-1989 and 2015-2019 as follows. First, the number of hedgehogs reported at each site and year was standardised by dividing by site area before smoothing to give a density; sites of unknown area or with an area less than 1 km^2 were excluded from analysis. For each of the two new periods, we calculated a mean value for each NGC site contributing data within the period, then applied a simple spatial smooth based on averaging all site values within a 35-km radius around the centre of each 10x10-km square. Data from 619 sites were including in the mapping for the period 1985-1989, whilst 788 sites were included in the mapping for 2015-2019. For display purposes, the smoothed data were categorised into six contour bands, using the same cut points as in Noble *et al.* (2012) for comparability (the original bands corresponded to 0, 0-20%, 20-40%, 40-60%, 60-80% and 80-100% percentiles).

For pairs of maps corresponding to consecutive periods, e.g. 1985-1989 and 1995-1999, we produced a change map in two steps. First, at each OS grid point, we subtracted the smoothed value for 1985-1989 from the smoothed value for 1995-1999. Where there had been increases this resulted in a positive difference, and where there had been declines it produced a negative difference. The second step was to determine contour levels of change from the difference values. This was done by ranking the difference values by absolute magnitude (i.e. ignoring the sign of the difference) and calculating 10th, 40th and 70th percentiles. These allowed us to define a central band containing the 10% of values closest to 0 (the band of no change, denoted -10 to 10%). The remaining values were split according to the 40th and 70th percentiles and cast into three "decline" bands if negative, and three "increase" bands if positive (denoted -100 to -70%, -70 to -40%, -40 to -10% and 10 to 40%, 40 to 70% and 70 to 100% respectively). The same procedure was carried out for the pair of maps from the first and last decades, to highlight the spatial changes that took place between the start and the end of the full 1981-2019 period.

3. Trends in numbers of hedgehogs reported to NGC

Sample sizes

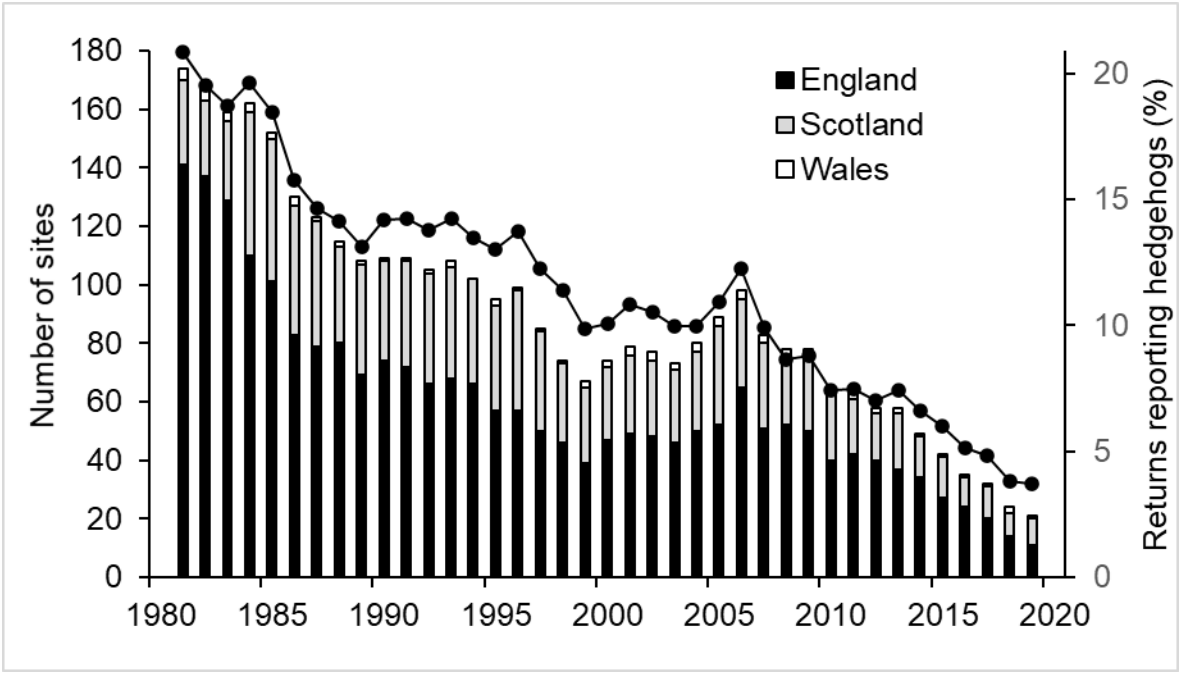
There were no NGC records of hedgehogs from Northern Ireland, so the analysis for the United Kingdom is in fact an analysis for Great Britain, and is reported as such.

Overall, the number of sites that reported at least one hedgehog to the NGC in their annual return fell from 174 in 1981 to 21 in 2019, a drop of 88% over 39 years (Table 3.1, Figure 3.1). The fall was greater in England (141 to 11 sites, drop of 92%) than in Scotland (29 to 9, drop of 69%). As a result, the original preponderance of English sites fell from around four-fifths of all sites that reported hedgehogs initially to just over half in 2019. The number of Welsh sites reporting hedgehogs between 1981 and 2019 was always small, remaining between 1 and 4. These changes did not arise through a reduction in the overall annual number of returns received by the NGC, but mirrored the annual percentage of NGC returns that reported hedgehogs (Figure 3.1).

Table 3.1. Average, minimum and maximum annual number of sites reporting hedgehogs to the NGC over the period 1981-2019, for Great Britain, England, Scotland and Wales.

Country	Sites reporting hedgehogs annually		
	Average	Minimum	Maximum
Great Britain	90	21	174
England	60	11	141
Scotland	28	8	49
Wales	2	0	4

Figure 3.1. Number of sites reporting hedgehogs to the NGC annually between 1981 and 2019, for England, Scotland and Wales (stacked bars, left-hand axis). The change mirrored the change in the annual percentage of NGC returns that reported hedgehogs (solid line, right-hand axis).



Great Britain

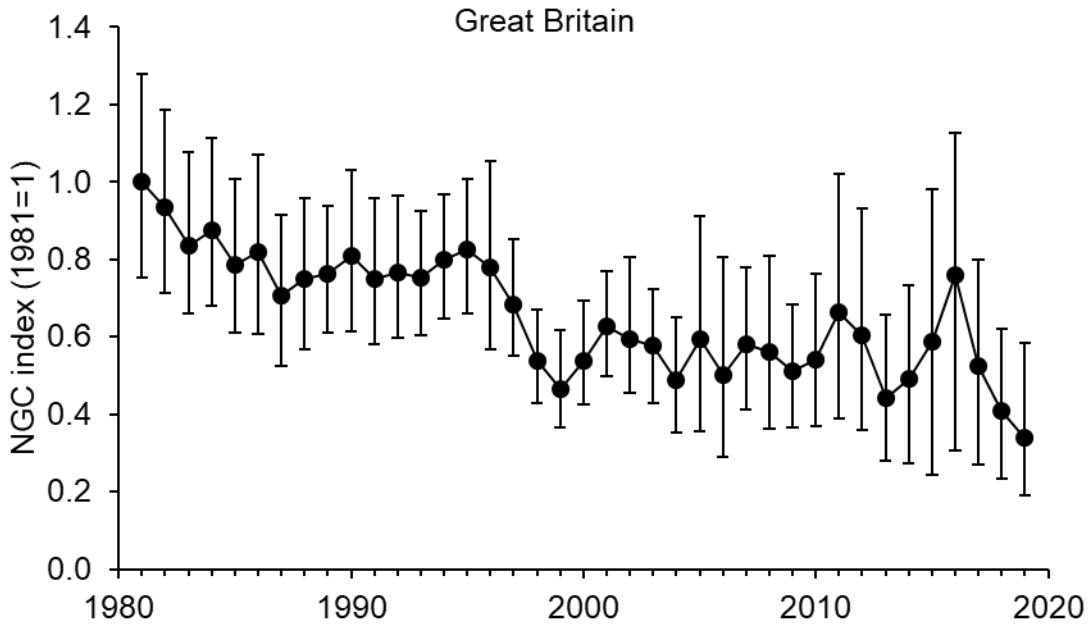
The NGC index declined by half over the full 1981-2019 period. Over shorter periods, although the values for percentage change were negative, their 95% confidence limits included zero, so the apparent declines are not statistically distinguishable from no change.

Table 3.2. Great Britain: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
Great Britain	418	1981	2019	-49.8* -78.2 to -13.2	-35.2 -69.0 to 0.1	-16.3 -42.9 to 18.8

* significant at $P < 0.05$

Figure 3.2. Great Britain: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2019. Indices are relative to 1981, which has a value of 1.



England

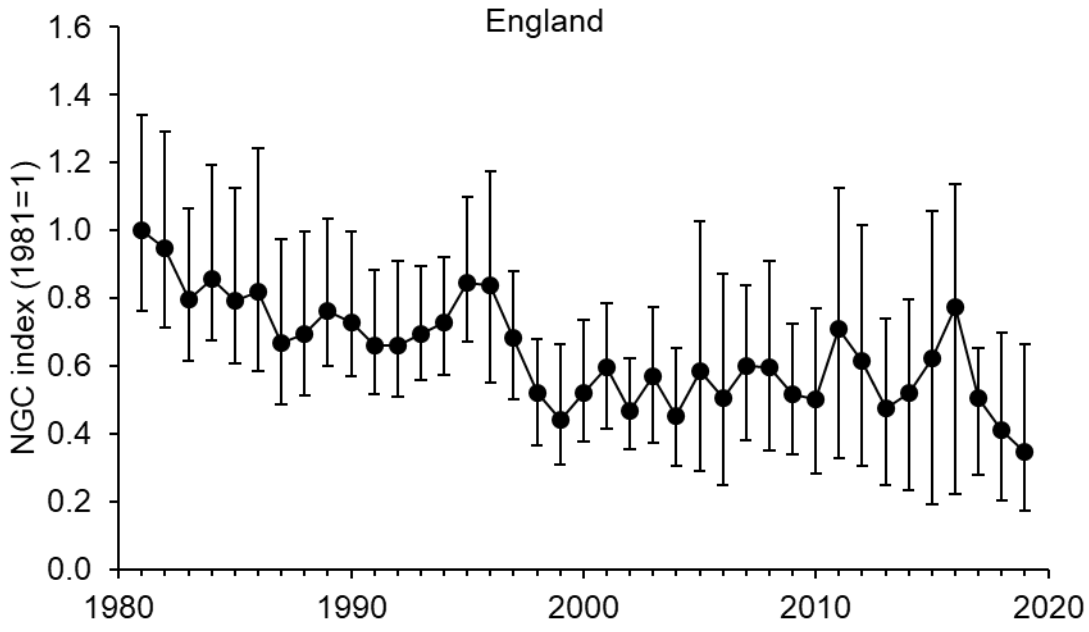
The NGC index declined by almost half over the full 1981-2019 period. Over shorter periods, although the values for percentage change were negative, their 95% confidence limits included zero, so the apparent declines are not statistically distinguishable from no change

Table 3.3. England: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
England	287	1981	2019	-48.8* -81.9 to -10.0	-30.3 -72.0 to 5.3	-15.6 -44.7 to 14.0

* significant at $P < 0.05$

Figure 3.3. England: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2019. Indices are relative to 1981, which has a value of 1.



Scotland

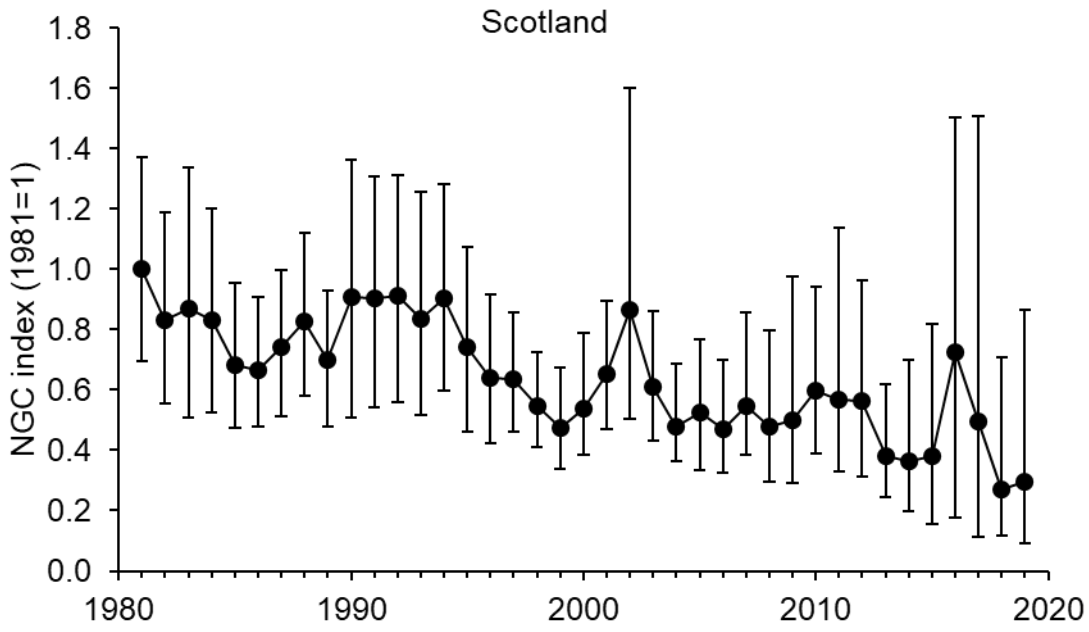
The pattern of changes in the NGC index for Scotland was very similar to those from the UK and England, although in all cases the 95% confidence limits included zero. Given the similarity with UK and England, it is possible that the smaller sample size is the reason for the lack of significance over the full period, but apparent declines in later periods are not statistically distinguishable from no change.

Table 3.4. Scotland: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
Scotland	123	1981	2019	-57.6 -90.3 to 18.3	-50.6 -88.7 to 44.0	-28.6 -80.2 to 67.4

* significant at $P < 0.05$

Figure 3.4. Scotland: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2019. Indices are relative to 1981, which has a value of 1.



Wales

With only 8 sites contributing hedgehog records between 1981 and 2019, there were too few annual reports of hedgehogs to carry out a trend analysis.

Summary

The pattern of change was broadly similar in all three cases, with NGC hedgehog record density approximately halving over the 38-year period 1981-2019. The changes were significant for the UK and England, but not for Scotland, probably because the smaller sample size led to a wider confidence interval that included zero. Similarly, changes for the most recent 25-year and 10-year periods were negative in all cases, but none differed significantly from zero,

Table 3.5. Summary by country of percentage changes (with 95% confidence limits) in NGC hedgehog index over three time periods, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
United Kingdom	418	1981	2019	-49.8* -78.2 to -13.2	-35.2 -69.0 to 0.1	-16.3 -42.9 to 18.8
England	287	1981	2019	-48.8* -81.9 to -10.0	-30.3 -72.0 to 5.3	-15.6 -44.7 to 14.0
Scotland	123	1981	2019	-57.6 -90.3 to 18.3	-50.6 -88.7 to 44.0	-28.6 -80.2 to 67.4
Wales	8	Insufficient data				

* significant at $P < 0.05$

4. Government region trends in numbers of hedgehogs reported to NGC

There are eight government regions of England, as per the map shown below:

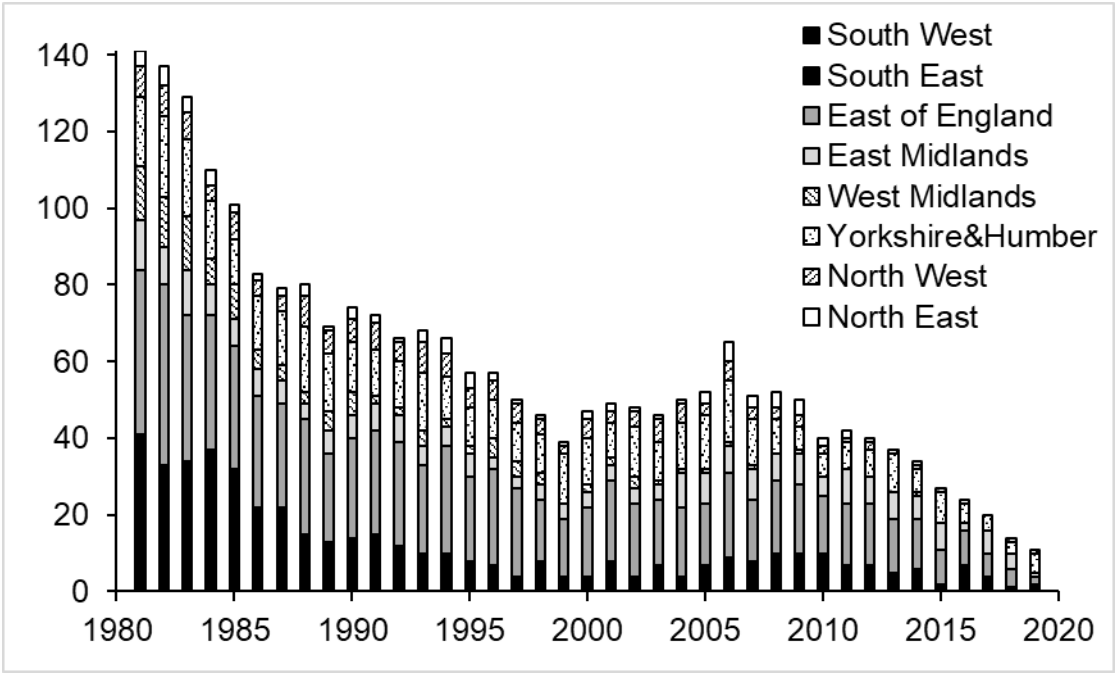
Sample sizes

When England was broken down into government regions, the regions with the highest average annual number of sites reporting hedgehogs to the NGC were the East of England and Yorkshire & Humber. Those with the lowest average annual number were the South West, West Midlands, North West and North East. The fall in number of sites observed at the England level was also apparent within each of the government regions, with no site reporting hedgehogs in 2019 for the South West, East Midlands, and North East, and only one site doing so for the West Midlands and North West.

Table 4.1. Average, minimum and maximum annual number of sites reporting hedgehogs to the NGC over the period 1981-2019, for Great Britain, England, Scotland and Wales.

Government region	Sites reporting hedgehogs annually		
	Average	Minimum	Maximum
South West England	3	0	17
South East England	9	1	24
East of England	21	2	47
East Midlands	6	0	13
West Midlands	3	0	14
Yorkshire & Humber	11	3	21
North West England	4	0	8
North East England	2	0	5

Figure 4.1. Number of sites reporting hedgehogs to the NGC annually between 1981 and 2019 for the eight government regions of England.



South West England

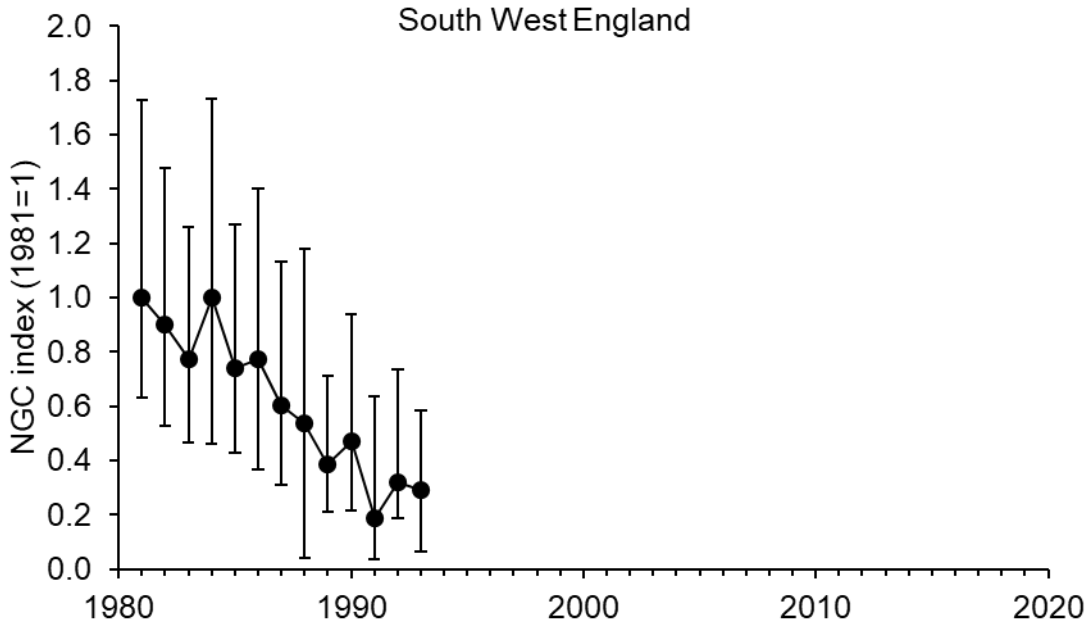
Too few data were available to calculate indices beyond 1993. The NGC index declined by three-quarters over the 1981-1993 period.

Table 4.2. United Kingdom: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-1993	% change 1994-2019	% change 2009-2019
South West England	20	1981	1993	-77.2* -89.1 to -50.1	n/a	n/a

* significant at $P < 0.05$

Figure 4.2. South West England: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-1993. Indices are relative to 1981, which has a value of 1.



South East England

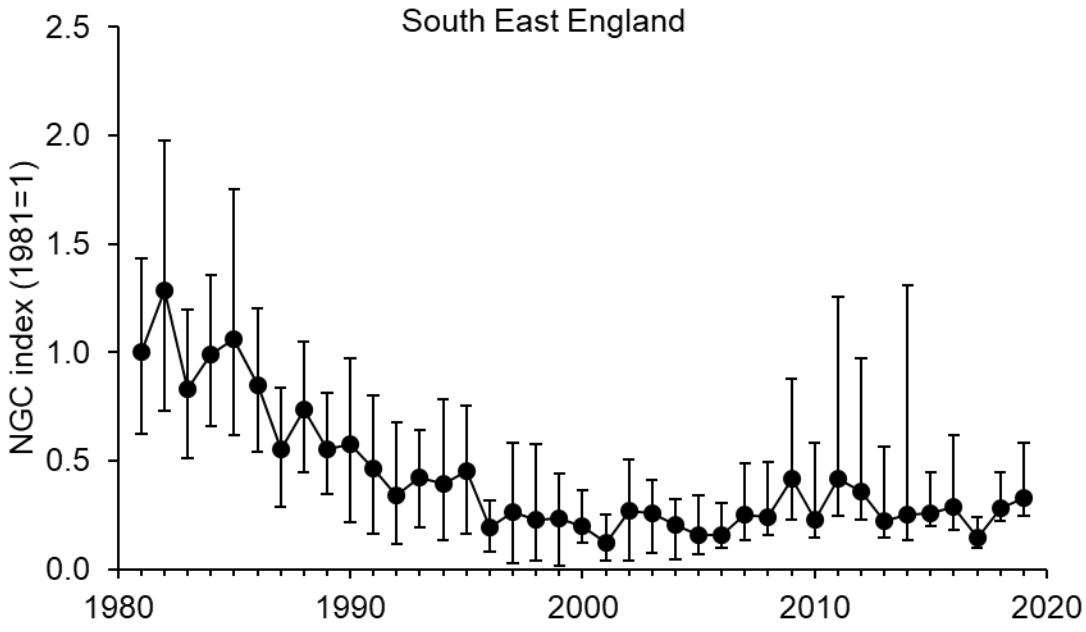
The NGC index declined by three-quarters over the full 1981-2019 period. Over shorter periods, although the values for percentage change were negative, their 95% confidence limits included zero, so the apparent declines are not statistically distinguishable from no change.

Table 4.3. South East England: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
South East England	48	1981	2019	-75.7* -82.3 to -49.1	-25.1 -50.4 to 167.9	4.4 -21.2 to 46.0

* significant at $P < 0.05$

Figure 4.3. South East England: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2019. Indices are relative to 1981, which has a value of 1.



East of England

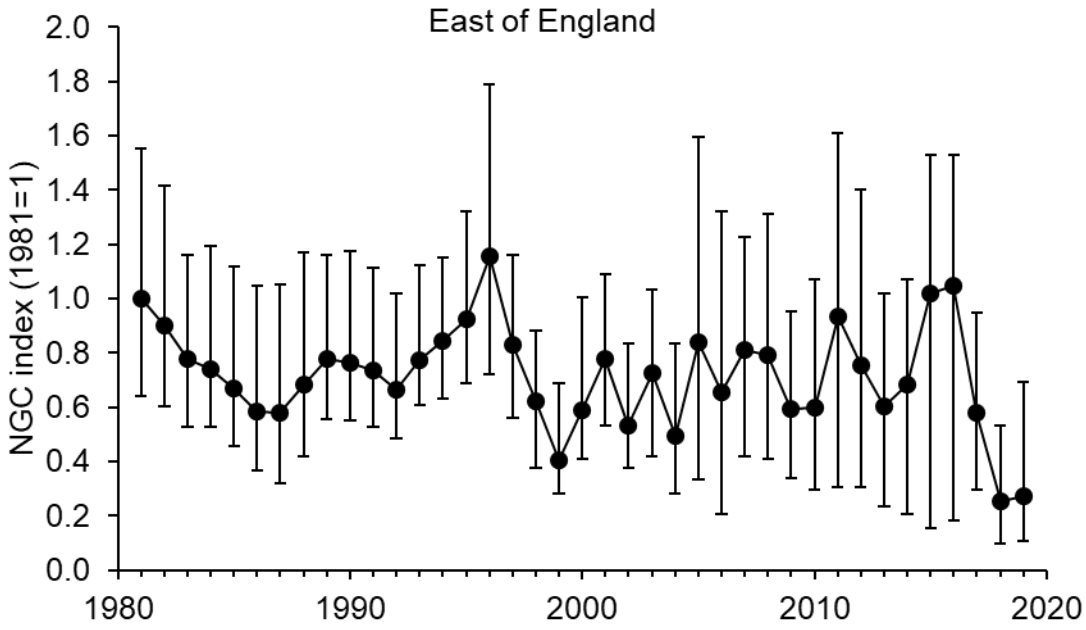
The NGC index declined by around a third over the last 25 years. Over the full 1981-2019 period and over the last 10 years, the values for percentage change were similar to the change over 25 years, but their 95% confidence limits included zero so the apparent declines are not statistically distinguishable from no change

Table 4.4. East of England: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
East of England	89	1981	2019	-41.9 -89.6 to 22.9	-35.2* -85.4 to -2.2	-32.7 -73.6 to 13.2

* significant at $P < 0.05$

Figure 4.4. East of England: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2019. Indices are relative to 1981, which has a value of 1.



East Midlands

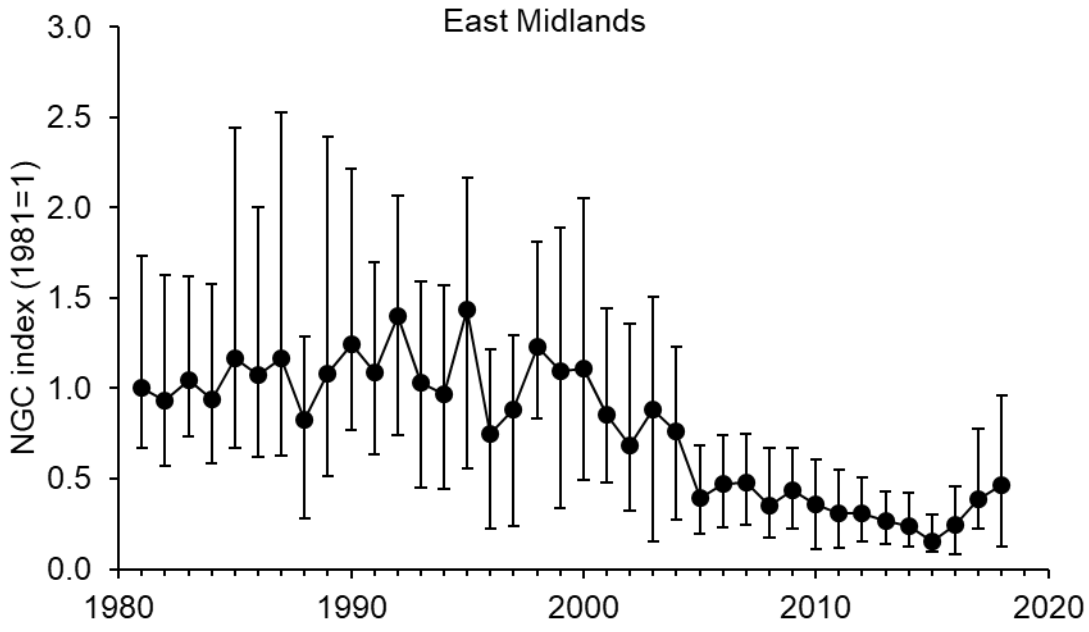
Too few data were available to calculate an NGC index value for 2019, so 2018 was the last year to be indexed. The index series declined by almost three-quarters over the full 1981-2018 period, and over the last 25 years. Over the last 10 years, there was no evidence of change.

Table 4.5. East Midlands: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2018	% change 1994-2018	% change 2009-2018
East Midlands	27	1981	2018	-70.1* -86.5 to -38.2	-73.6* -82.9 to -33.7	-26.9 -40.1 to 66.2

* significant at $P < 0.05$

Figure 4.5. East Midlands: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2018. Indices are relative to 1981, which has a value of 1.



West Midlands

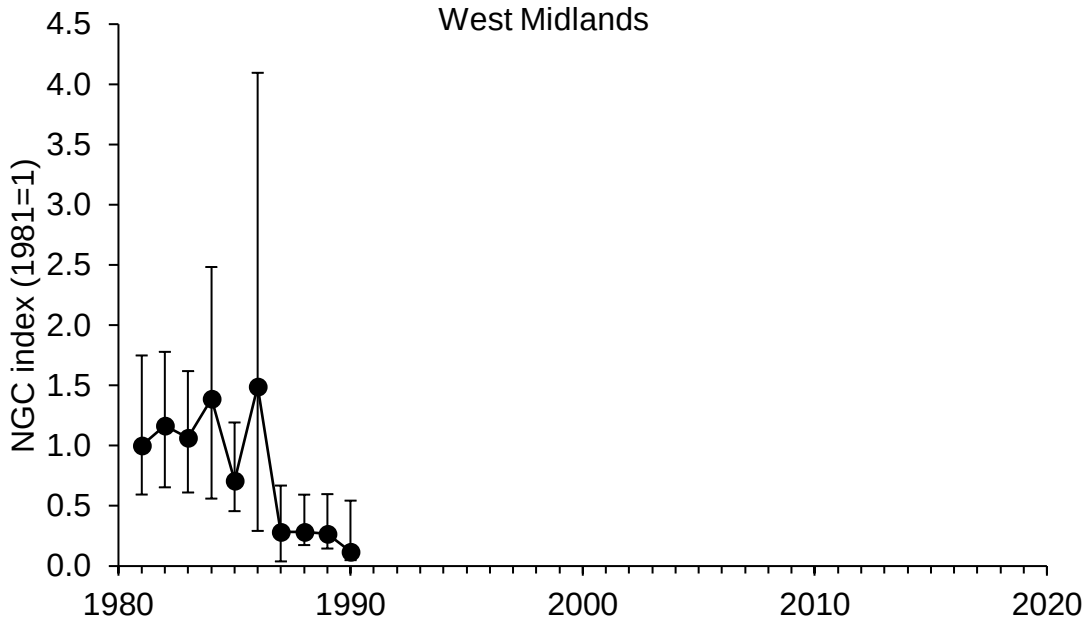
Too few data were available to calculate indices beyond 1990. The NGC index declined by over four-fifths over the 1981-1990 period.

Table 4.6. West Midlands: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-1990	% change 1994-2019	% change 2009-2019
West Midlands	19	1981	1990	-84.0* -99.9 to -39.3	n/a	n/a

* significant at $P < 0.05$

Figure 4.6. West Midlands: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-1990. Indices are relative to 1981, which has a value of 1.



Yorkshire and the Humber

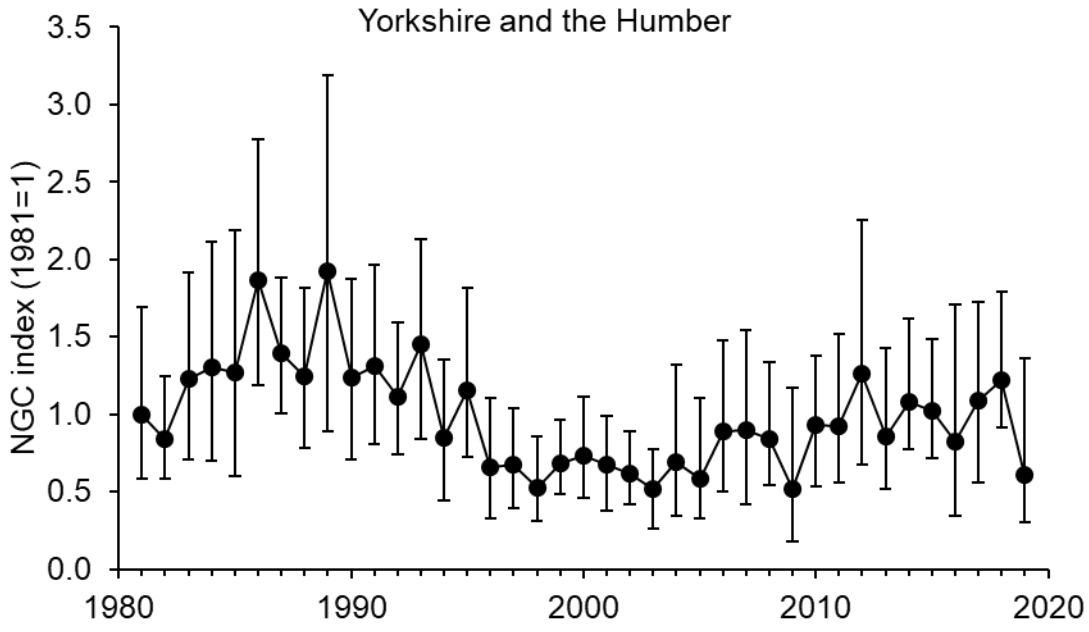
The NGC index did not change detectably over either the full 1981-2019 period or the shorter periods.

Table 4.7. Yorkshire and the Humber: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2019	% change 1994-2019	% change 2009-2019
Yorkshire and the Humber	46	1981	2019	-14.4 -48.2 to 51.6	-7.2 -32.4 to 39.9	17.7 -7.7 to 56.4

* significant at $P < 0.05$

Figure 4.7. Yorkshire and the Humber: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2019. Indices are relative to 1981, which has a value of 1.



North West England

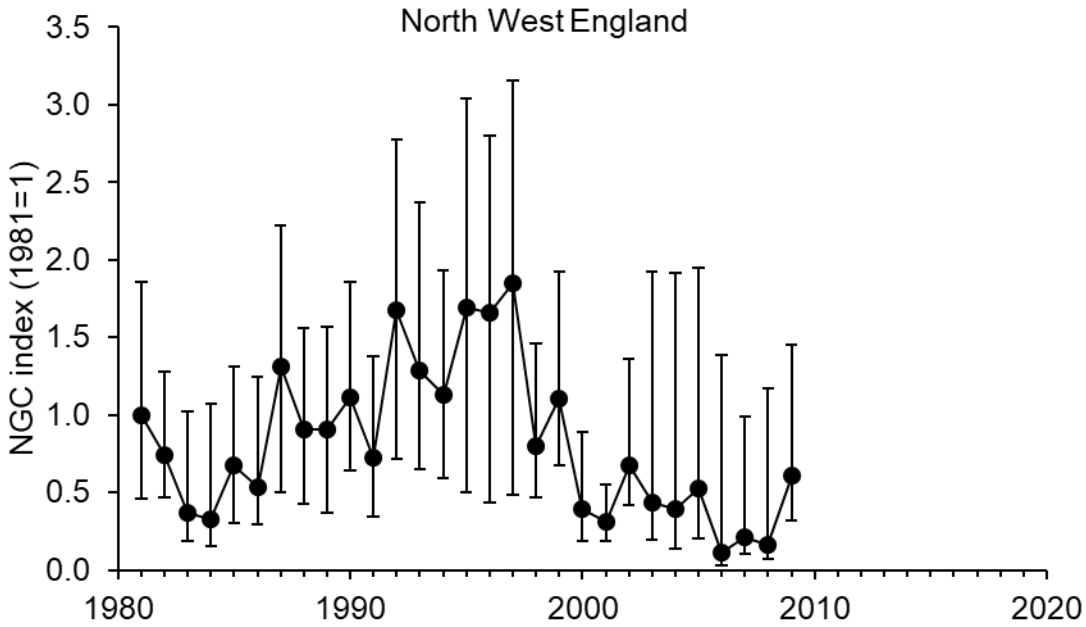
Too few data were available to calculate indices beyond 2009. Although the values for percentage change were negative, their 95% confidence limits included zero, so the apparent declines are not statistically distinguishable from no change.

Table 4.8. North West England: change in NGC hedgehog index over three time periods, with 95% confidence limits, together with number of participating sites and start/end years of the time series.

Country	Sites	Start year	End year	% change 1981-2009	% change 1994-2009	% change 2009-2019
North West England	19	1981	2009	-66.8 -94.4 to 62.0	-84.1 -97.6 to 6.3	n/a

* significant at $P < 0.05$

Figure 4.8. North West England: annual indices (with 95% confidence limits) of hedgehogs reported to NGC, 1981-2009. Indices are relative to 1981, which has a value of 1.



North East England

With only 14 sites contributing hedgehog records between 1981 and 2019, there were too few annual reports of hedgehogs to carry out a trend analysis.

Summary

Too few data were available to carry out a trend analysis for North East England, and for several other regions the analysis had to be truncated before 2019 because too few NGC sites reported hedgehog records in later years. Most regions recorded declines over the full 1981-2019 period or over the last 25 years (or both), but there was little apparent change in Yorkshire & Humber, and apparent declines were not significant for North West England.

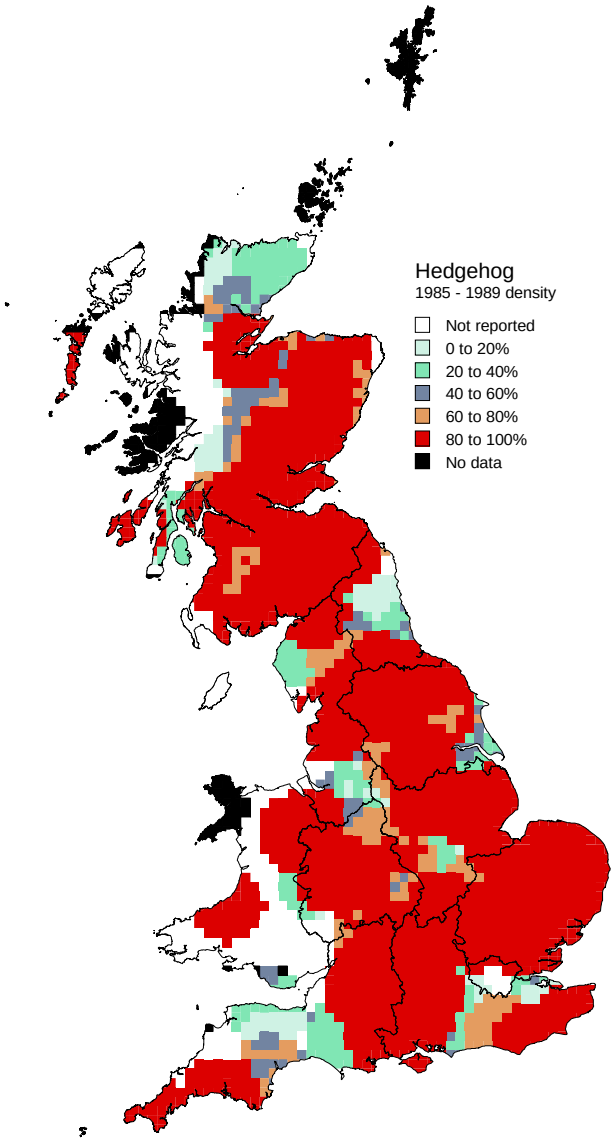
Table 4.9. Summary by English government region of percentage changes (with 95% confidence limits) in NGC hedgehog index over three time periods, together with number of participating sites and start/end years of the time series.

Government region	Sites	Start year	End year	% change 1981-end	% change 1994-end	% change 2009-end
South West England	20	1981	1993	-77.2* -89.1 to -50.1	n/a	n/a
South East England	48	1981	2019	-75.7* -82.3 to -49.1	-25.1 -50.4 to 167.9	4.4 -21.2 to 46.0
East of England	89	1981	2019	-41.9 -89.6 to 22.9	-35.2* -85.4 to -2.2	-32.7 -73.6 to 13.2
East Midlands	27	1981	2018	-70.1* -86.5 to -38.2	-73.6* -82.9 to -33.7	-26.9 -40.1 to 66.2
West Midlands	19	1981	1990	-84.0* -99.9 to -39.3	n/a	n/a
Yorkshire & Humber	46	1981	2019	-14.4 -48.2 to 51.6	-7.2 -32.4 to 39.9	17.7 -7.7 to 56.4
North West England	19	1981	2009	-66.8 -94.4 to 62.0	-84.1 -97.6 to 6.3	n/a
North East England	14	Insufficient data				

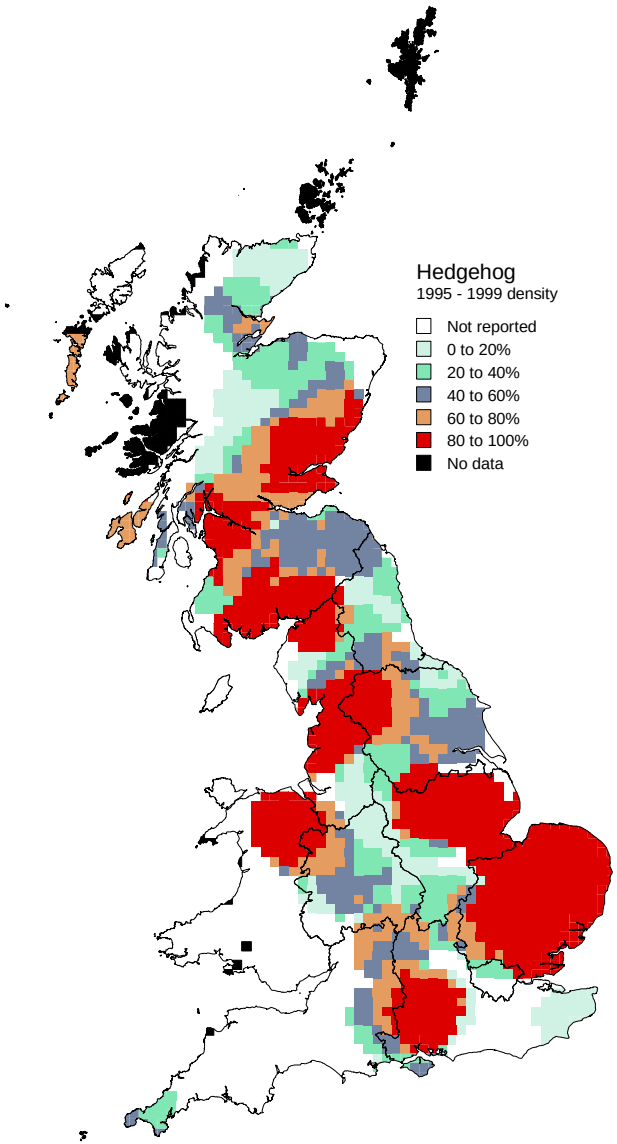
* significant at $P < 0.05$

5. Maps of relative abundance of hedgehogs reported to NGC

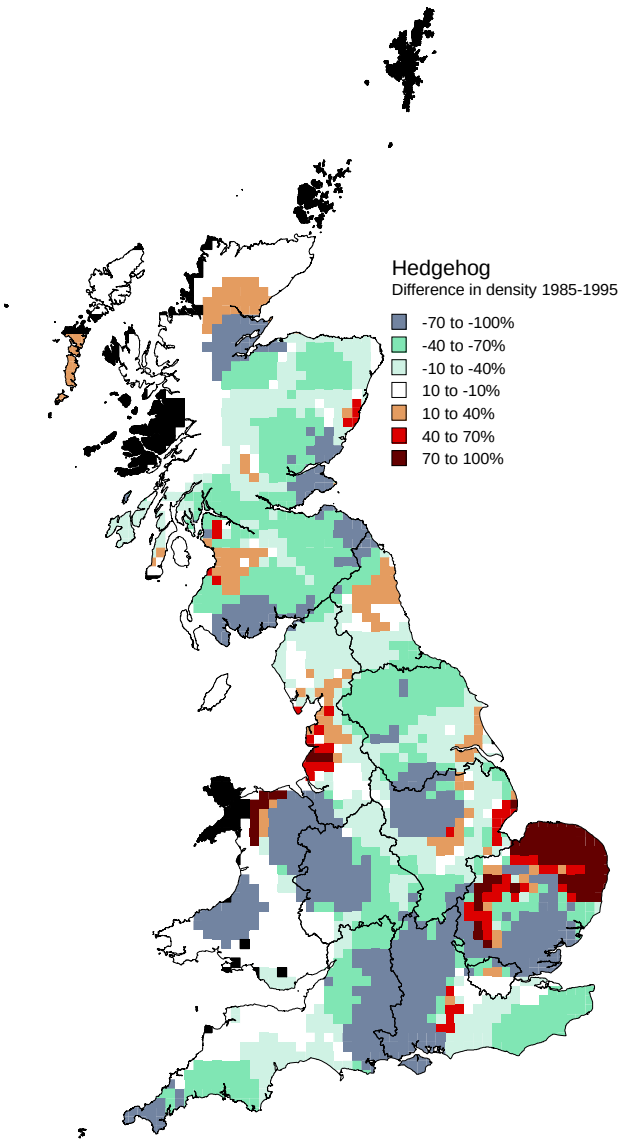
1985-1989



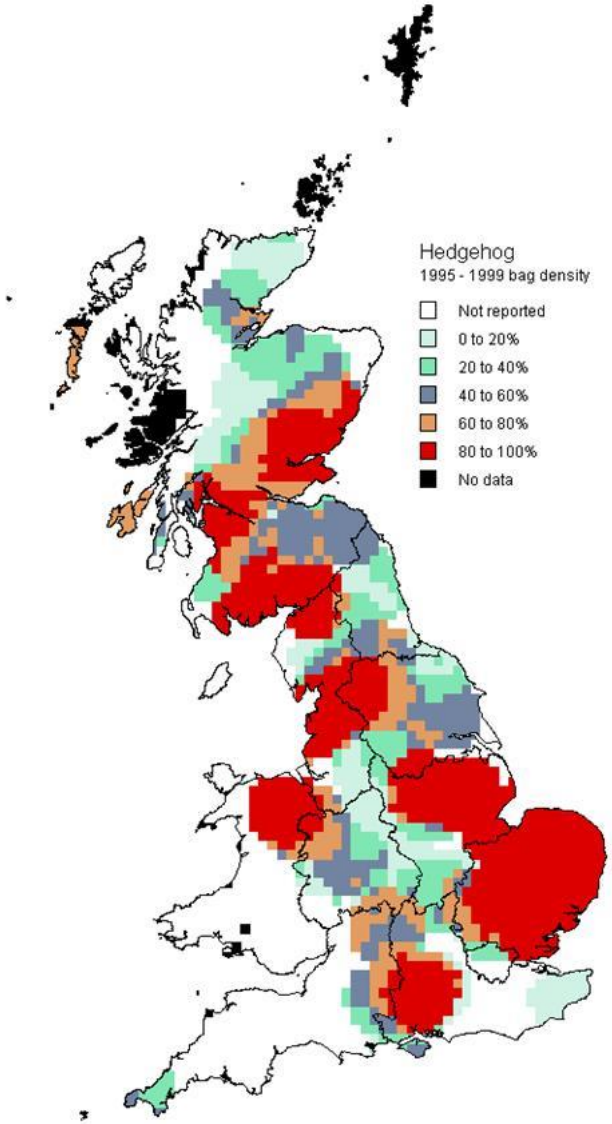
1995-1999



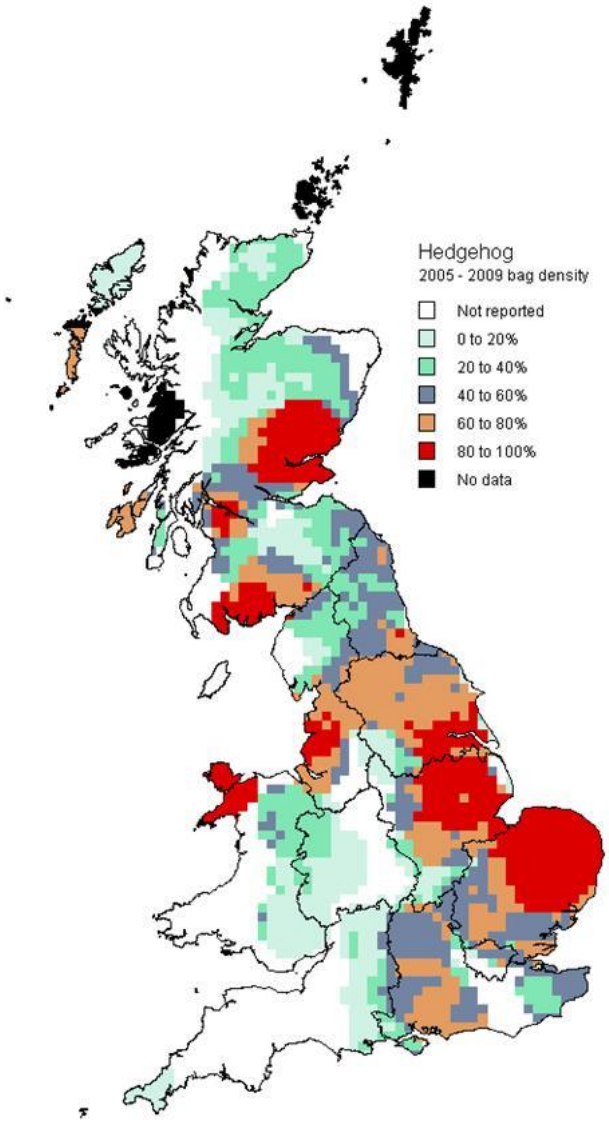
Change



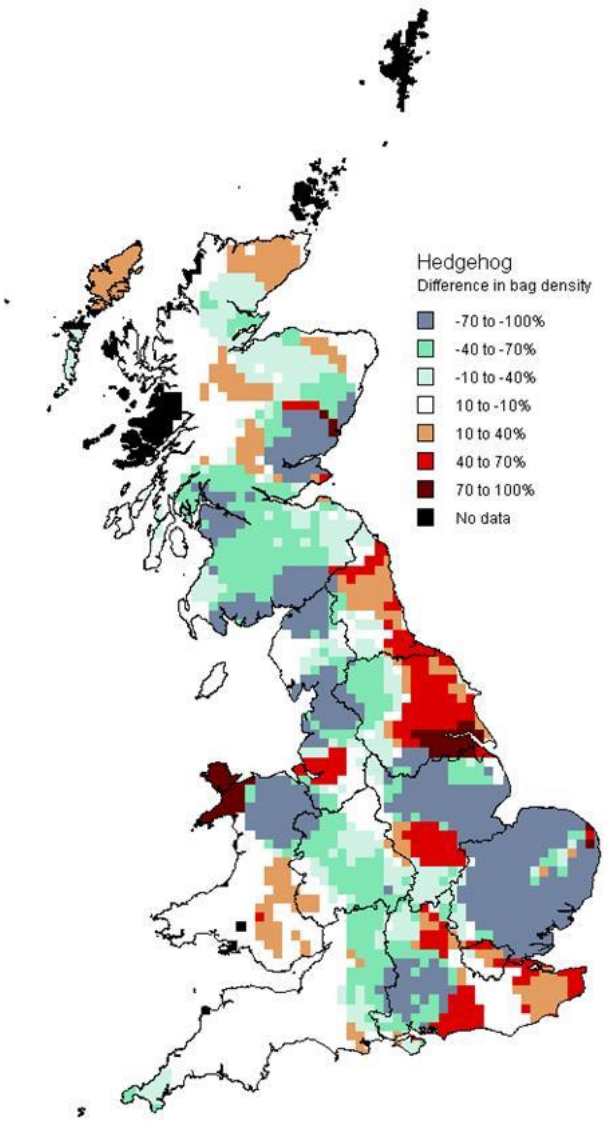
1995-1999



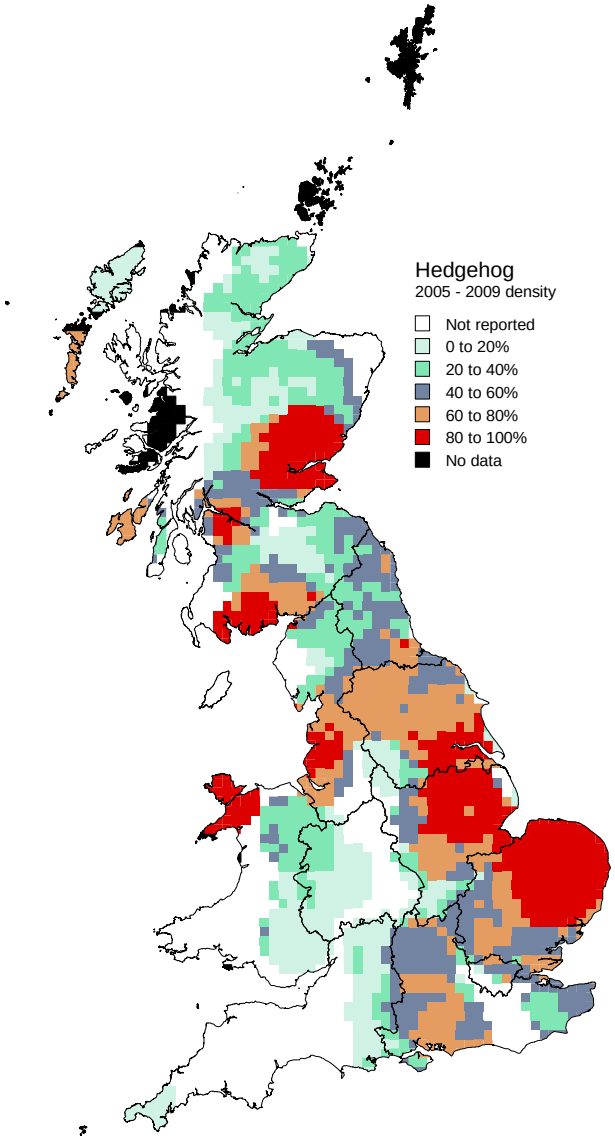
2005-2009



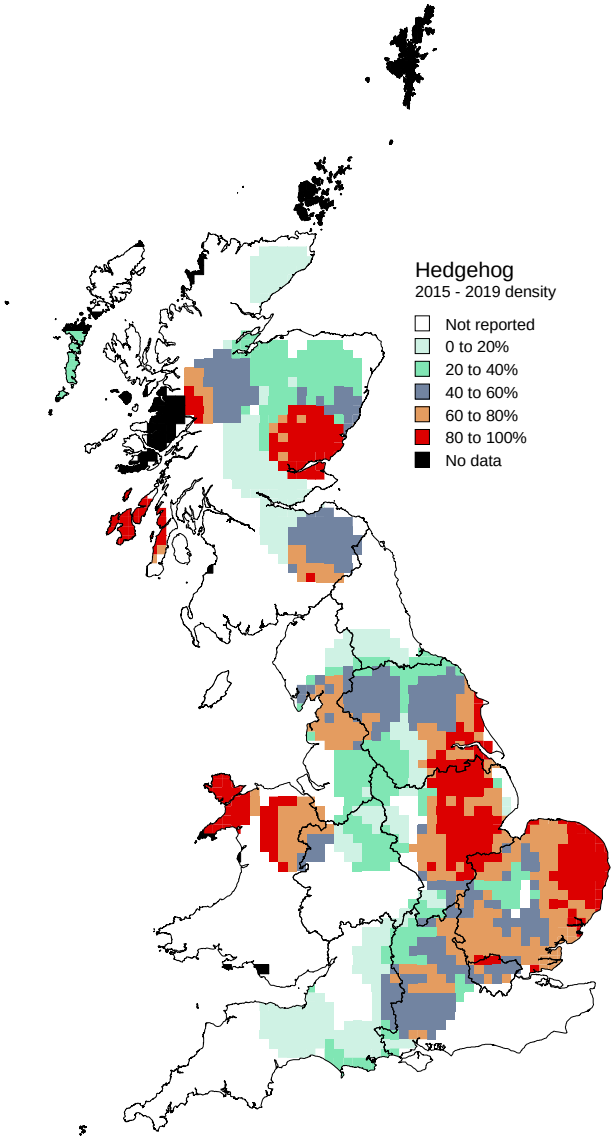
Change



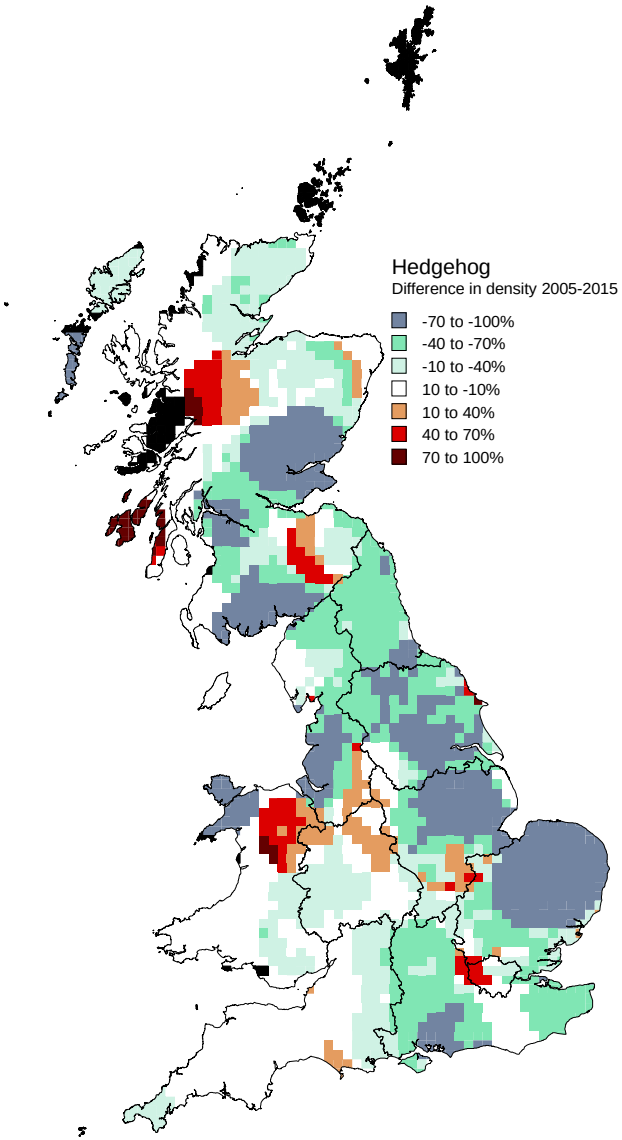
2005-2009



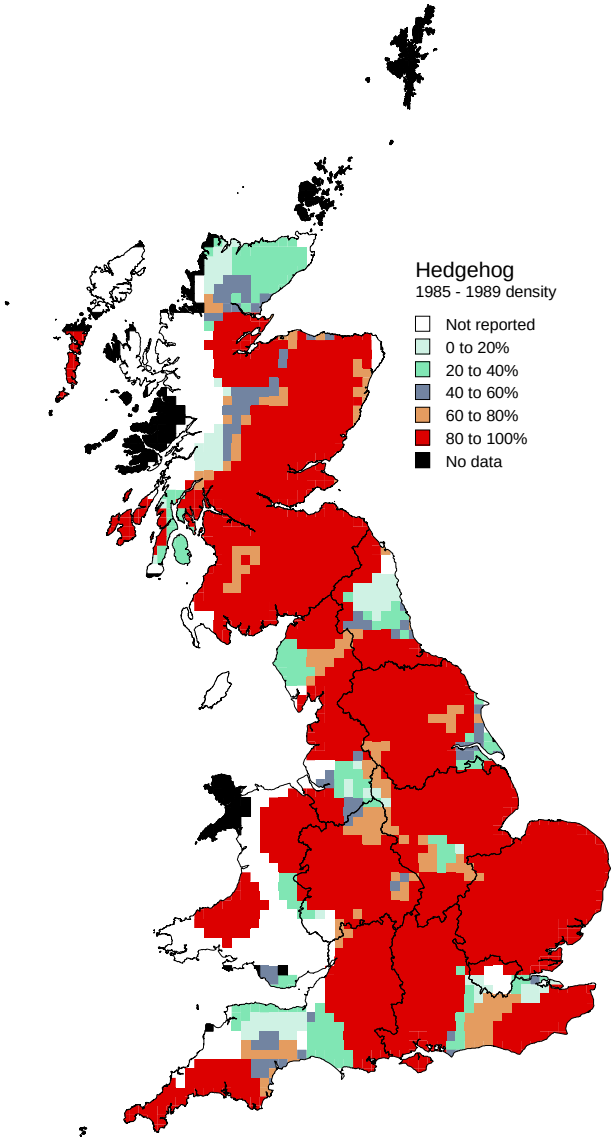
2015-2019



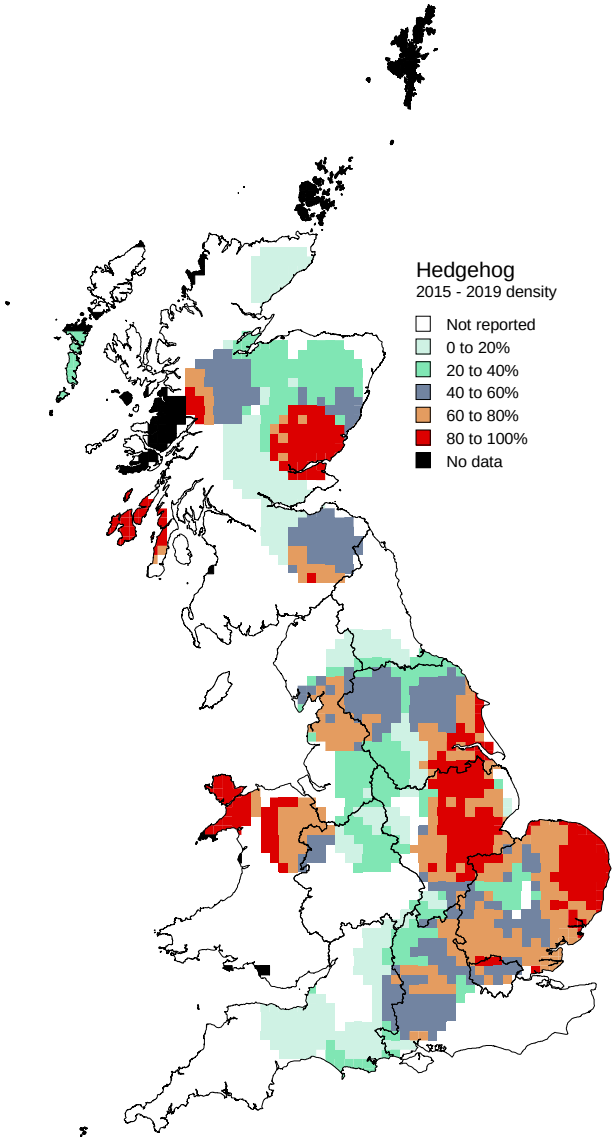
Change



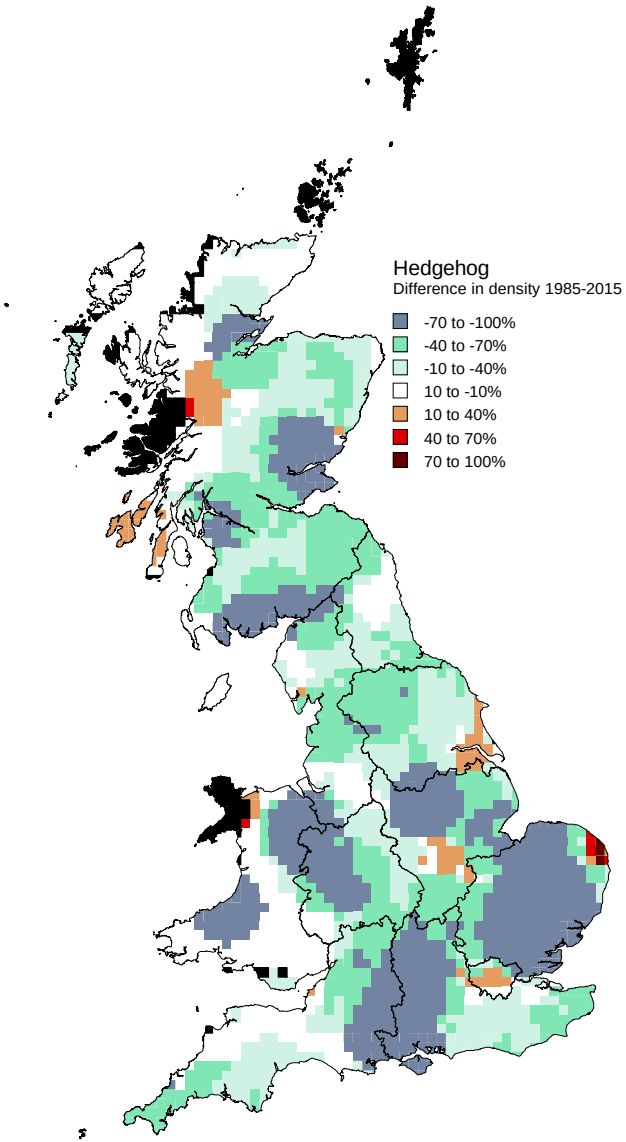
1985-1989



2015-2019



Change



Summary

In the 1980s, the density of hedgehogs reported to the NGC indicated that the prevalence of hedgehogs was high across most of Great Britain, and densities were large relative to those reported in the next decades. By the 1990s, the areas of high density had broken up into large patches located across the southern half of Scotland, in north-west, eastern and central southern England, and north Wales. Many sites in south-west England and Wales that had reported hedgehogs in the 1980s had stopped reporting them by the 1990s. In the 2000s, the high-density patches shrank further, while the areas with no hedgehog reporting expanded eastwards from the west coast. By the 2010s, high-density areas were restricted to south-east Scotland, north Wales and eastern England. Hedgehogs were no longer reported from most of western and northern Scotland (except on some large Hebridean islands). In England, they were no longer reported from the north, south-east, south-west and part of the West Midlands. Overall, from beginning to end of all four decades, the net result was widespread declines in reporting across almost the whole of Great Britain.

6. **Interpretation**

Overall, the density of hedgehogs reported to the NGC has declined by around half across Britain over the 1981-2019 period. The change seemed to start in the west and spread eastward, but by the end of the 2010s was widespread throughout. Too few sites were available to calculate trends in Wales and in the North East government region, and the NGC index had to be truncated before 2019 for four other government regions because the number of estates reporting hedgehogs had fallen too low for reliable calculation.

Because the trends summarised above derive from numbers of hedgehogs trapped during control of small mammalian pests and predators on shooting estates, interpretation is not straightforward. The number of hedgehogs reported to the NGC is the combined result of the abundance of live animals on the ground, of the amount of trapping effort on the shoot, of the susceptibility of hedgehogs to be captured and of the willingness of the operators to report what they have caught. The observed decline in numbers of hedgehogs reported to the NGC may therefore indicate a genuine decline in numbers of hedgehogs, but it may also arise through increased awareness of the conservation status of hedgehogs, a decline in numbers of traps set or the length of time they are set, implementation of measures to avoid catching hedgehogs in traps, increased reluctance to report hedgehogs (either through embarrasment or fear of consequences under the legislation) or any combination of these factors, even though the number of live animals may actually be stable over time.

Unfortunately, there is no information available on how the numbers of traps set or the length of time they are set has changed over time. Short & Reynolds (2001) demonstrated how it is possible to reduce the number of hedgehogs caught in tunnel traps set for other species through the use of excluders. This has been a standard recommendation for trap users for many years (see e.g. Anon 1994 and also https://www.gwct.org.uk/blogs/news/2020/april/all-change-to-lowland-trapping-from-april-2020/mustelids), but again there is no information available on whether growing awareness has led to increased use of excluders over time. The same applies to the willingness of operators to report numbers of trapped hedgehogs. In our maps, we made the assumption that if no hedgehogs were reported, none had been caught. Yet again, no information is available on how willingness to report has changed over time. However, the maps documenting the distribution and density of hedgehogs reported to the NGC show that non-

reporting began in the south-west and spread eastwards. Our expectation was that increasing harassment of gamekeepers on upland areas managed for driven grouse shooting (Denny *et al.* 2021) would result in widespread non-reporting of hedgehogs across the Pennines and Scottish uplands rather than starting in the south-west and moving east. This lack of coincidence suggests that deliberate withholding of information is generally of reduced importance, and that a lack of hedgehog reports likely stems from a genuine lack of hedgehog captures.

The best way to assess how much the NGC trends reflect changes in underlying hedgehog abundance would be by comparing them to trends obtained through systematic surveys of live animals, such as the BBS. The nocturnal behaviour of hedgehogs make the species a poor candidate for monitoring via BBS, however, and only binary presence/absence data are available. Trends in presence/absence are not directly comparable with trends obtained from the quantitative NGC data.

Another issue to be aware of is representativeness. Sites contributing records to the NGC are shoots, contributing data on a voluntary basis, so they cannot be assumed to represent a random sample of rural Britain. Landowners participating in field sports, such as fox hunting and gamebird shooting, maintain more established woodland and plant more new woodland and hedgerows than non-participants (Oldfield *et al.* 2003). In the uplands, moors managed for grouse shooting retain more heather than non-managed moors (Robertson *et al.* 2001). These management practices imply that NGC sites are likely to differ from random sites in the countryside as they usually offer good-quality habitat in terms of food resources, shelter and breeding requirements (cf. Yarnell & Pettett 2020) and carry out predator control. Nevertheless, any bias induced by non-randomness is probably reduced by the fact that the same sites contribute records over many years, and results from the same site are comparable between years (Toms *et al.* 1999). Toms *et al.* (1999) also emphasize the advantage of historical continuity in improving the precision of estimates of change, because it removes the component of error variance associated with site.

These caveats notwithstanding, it is notable that the decline in the density of hedgehogs reported to the NGC coincides with an increase in the numbers of badgers *Meles meles* across Britain (Sainsbury *et al.* 2019). This is relevant because the badger is an important predator of hedgehogs that has been shown to limit hedgehog distribution (Doncaster 1994, Trewby *et al.* 2014). In England between 1985-88 and 2011-13, the estimated number of badger social groups increased by 103% while that in Wales remained approximately constant (Judge *et al.* 2014). Moreover, 55% of the estimated badger population in England and Wales was in south-west England and south Wales (Judge *et al.* 2017), the areas that were among the first where hedgehogs ceased to be reported to the NGC, with a higher probability of hedgehog presence in eastern than in southern and western parts of England (Hof *et al.* 2020). Other possible reasons for decline exist as well, and should not be overlooked. Agricultural intensification has led to a loss of habitat complexity through the removal of hedgerows, increased field sizes, cultivation expansion and widespread pesticide use (Robinson & Sutherland 2002), reducing hedgehog food resources and foraging opportunities (Hof & Bright 2010a,b) as well as removing safe sites for day nests and hibernation (Haigh *et al.* 2012). In urban areas, lack of connectivity and habitat fragmentation was inversely related to hedgehog presence (Hof & Bright 2009). Mortality risk associated with road traffic collisions may also have increased owing to an increase in the density of road networks and associated traffic, with road casualties estimated to represent 10-20% of hedgehog annual mortality, contributing to population isolation (Wembridge *et al.* 2016, Moore *et al.* 2020). It seems therefore that if the decline in numbers of hedgehogs reported to the NGC reflects a genuine fall in the live hedgehog population, there is a range of plausible ecological explanations for the change.

7. References

Aebischer, N.J. (2019). Fifty-year trends in UK hunting bags of birds and mammals, and calibrated estimation of national bag size, using GWCT's National Gamebag Census. European Journal of Wildlife Research 65(64): 1-13.

Aebischer, N.J. & Baines, D. (2008). Monitoring gamebird abundance and productivity in the UK: the GWCT long-term datasets. Revista Catalana d'Ornitologia 24: 30-43.

Anon. (1994). Predator Control. Game Conservancy Ltd, Fordingbridge.

Denny, S., Latham-Green, T. & Hazenberg, R. (2021). Sustainable Driven Grouse Shooting? A Summary of the Evidence. Institute for Social Innovation and Impact, University of Northampton, Northampton.

Doncaster, C.P. (1994). Factors regulating local variations in abundance: field tests on hedgehogs, *Erinaceus europaeus*. Oikos 69: 182-192.

Haigh, A., O'Riordan, R.M. & Butler, F. (2012). Nesting behaviour and seasonal body mass changes in a rural Irish population of the Western hedgehog (*Erinaceus europaeus*). Acta Theriologica 57: 321-331.

Hastie, T.J. & Tibshirani, R.J. (1990). Generalized Additive Models. Chapman & Hall, London.

Hof, A.R., Allen, A.M. & Bright, P.W. (2020). Investigating the role of the Eurasian badger (Meles meles) in the nationwide distribution of the Western European hedgehog (Erinaceus europaeus) in England. Animals 9(759): 1-15.

Hof, A.R. & Bright, P.W. (2009). The value of green-spaces in built-up areas for western hedgehogs. Lutra 52: 69-82.

Hof, A.R. & Bright, P.W. (2010a). The value of agri-environment schemes for macro-invertebrate feeders: hedgehogs on arable farms in Britain. Animal Conservation 13: 467-473.

Hof, A.R. & Bright, P.W. (2010b). The impact of grassy field margins on macro-invertebrate abundance in adjacent arable fields. Agriculture, Ecosystems and Environment 139: 280-283.

Judge, J., Wilson, G.J., Macarthur, R., Delahay, R.J. & McDonald, R.A. (2014). Density and abundance of badger social groups in England and Wales in 2011–2013. Scientific Reports 4(3809): 1-8.

Judge, J., Wilson, G.J., Macarthur, R., McDonald, R.A. & Delahay, R.J. (2017). Abundance of badgers (*Meles meles*) in England and Wales. Scientific Reports 7(276): 1-8.

McCullagh, P. & Nelder, J.A. (1996). Generalized Linear Models, 3rd edn. Chapman & Hall, London.

Moore, L.J., Petrovan, S.O., Baker, P.J., Bates, A.J., Hicks, H.L., Perkins, S.E. & Yarnell, R.W. (2020). Impacts and potential mitigation of road mortality for hedgehogs in Europe. Animals 10(1523): 1-19.

Noble, D.G., Aebischer, N.J., Newson, S.E., Ewald, J.A. & Dadam, D. (2012) A comparison of trends and geographical variation in mammal abundance in the Breeding Bird Survey and the National Gamebag Census. JNCC Report No. 468, JNCC, Peterborough.

Oldfield, T.E.E., Smith, R.J., Harrop, S.R. & Leader-Williams, N. (2003). Field sports and conservation in the United Kingdom. Nature 423: 531-533.

Robertson, P.A., Park, K.J. & Barton, A.F. (2001). Loss of heather *Calluna vulgaris* moorland in the Scottish uplands: the role of red grouse *Lagopus lagopus scoticus* management. Wildlife Biology 7: 11-16.

Robinson, R.A. & Sutherland, W.J. (2002). Post-war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology 39: 157-176.

Sainsbury, K.A., Shore, R.F., Schofield, H., Croose, E., Campbell, R.D. & McDonald, R.A. (2019). Recent history, current status, conservation and management of native mammalian carnivore species in Great Britain. Mammal Review 49: 171-188.

Short, M.J. & Reynolds, J.C. (2001). Physical exclusion of non-target species in tunnel-trapping of mammalian pests. Biological Conservation 98: 139-147.

Tapper, S.C. (1992). Game Heritage: An Ecological Review from Shooting and Gamekeeping Records. Game Conservancy Ltd, Fordingbridge.

Toms, M.P., Siriwardena, G.M. & Greenwood, J.J.D.(1999). Developing a Mammal Monitoring Programme for the UK. British Trust for Ornithology, Thetford.

Trewby, I.D., Young, R.P., McDonald, R.A., Wilson, G.J., Davison, J., Walker, N., Robertson, A., Doncaster, C.P. & Delahay, R.J. (2014). Impacts of removing badgers on localised counts of hedgehogs. PLoS ONE 9(e95477): 1-4.

Wembridge, D.E., Newman, M.R., Bright, P.W. & Morris, P.A. (2016). An estimate of the annual number of hedgehog (*Erinaceus europaeus*) road casualties in Great Britain. Mammal Communications 2: 8-14.

Yarnell, R.W. & Pettett, C.E. (2020). Beneficial land management for hedgehogs (*Erinaceus europaeus*) in the United Kingdom. Animals 10(1566): 1-10.

8. **Acknowledgements**

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