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A comparison of trends and geographical variation in mammal abundance in the Breeding Bird Survey and the National Gamebag Census

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Acknowledgements

This work was funded under a variation in the BTO-JNCC contract and we would particularly like to thank Deborah Procter and Anna Robinson of the Joint Nature Conservation Committee (JNCC) for their support and advice on this work. Thanks are also due to Alison Johnston of BTO for statistical advice, Maria Knight for help in formatting the report, and all BBS surveyors and NGC contacts for collecting and providing all of the information on mammal numbers in those two schemes.

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Executive Summary

In the UK, monitoring schemes and surveys for mammals vary markedly in methodologies and geographical and temporal extent among species, mainly due to the specialised protocols required to detect and identify most species. In this report, we compare results from two very different current annual monitoring schemes – the BTO/JNCC/RSPB Breeding Bird Survey (BBS) and the GWCT National Gamebag Census (NGC). Both schemes cover the entire UK, have been running for at least 15 years, and provide quantitative measures of abundance for multiple species, with considerable but not complete overlap in species coverage. This makes it possible to compare both temporal and geographic patterns of abundance and to explore possibilities for combining results across the two schemes.

Of nine species (brown hare, mountain hare, rabbit, grey squirrel, fox, red deer, fallow deer, roe deer and Reeves muntjac) for which sufficiently reliable population trends could be generated for both schemes between 1995 and 2009, there were no significant differences in the population trend between schemes. Both schemes indicated a significant increase in grey squirrel. The BBS also revealed significant increases in three deer species (red, roe and muntjac) and a significant decline in rabbits over this period. With the exception of red deer, the changes in numbers from NGC over this period were similar but not significantly so. This provided justification for generating a joint trend for each of these nine species using data from both schemes that took into account the statistical variation within each scheme which varied among species. BBS and NGC differ in methodologies as well as in geographical coverage (although both cover the UK) and this provides a process for generating an agreed trend for consistent reporting, particularly in the context of statutory reporting requirements.

Spatial maps of relative abundance and change were produced for Great Britain only due to limited data coverage in Northern Ireland. They provide a useful visualisation of geographical patterns, and reveal concordance at very broad but not finer-scale resolutions. This is due to important differences in the design of the two schemes, the extent and distribution of the sampling sites, differences in coverage across the season, and differences in detectability despite using the same spatial modelling procedures. It is therefore not recommended to combine data from BBS and NGC in spatial maps using these spatial modelling approaches. Although clearly it would be possible to combine data without modelling - such as collating evidence of presence over particular time periods – this approach would not be able to make use of the predictive capacity of models needed for data based on a sampling design.

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1 Introduction

Mammals are an important component of biodiversity with significant impacts on ecosystems. They are themselves impacted by a range of environmental and anthropogenic factors. Mammals are also covered by international and national legislation and policy that requires that populations of many species (particularly species of conservation concern and invasive non-natives) are monitored. Owing to their biology, mammals can be difficult to monitor effectively and in the UK, a range of different initiatives are used for different species, including periodic national single-species surveys, national and regional surveys, and pilot surveys to develop new methods. Here, we report on two annual monitoring schemes for mammals, each reporting on a suite of mammal species that overlap in scheme coverage and allow patterns of temporal and spatial change to be compared. The aim is to produce an integrated overview of trends in abundance and in distribution of ca15 widespread UK mammal species monitored effectively by counts made during the BTO/JNCC/RSPB Breeding Bird Survey and bag totals from the GWCT National Gamebag Census. This work is an element of the addendum to the JNCC-BTO Monitoring of Birds and the Environment Contract 2010/11-2015/16 under Workstream 4: Analysis and Reporting of information on species and environmental change, and was undertaken through collaboration between BTO and GWCT.

2 Methods

2.1 Data sources

The **BTO/JNCC/RSPB Breeding Bird Survey (BBS)** is coordinated at BTO headquarters through a network of volunteer Regional Organisers, who are responsible for the volunteer observers in their region. Running since 1994, it employs a stratified random sampling design, with 1km squares from the National Grid assigned randomly within BTO regions (Risely *et al* 2010). A transect route through the allocated 1km square is determined comprising two roughly parallel lines, ideally ca500 m apart, divided into ten equal sections of 200m. The first BBS visit is made between April and mid-May and the second at least four weeks later between mid-May and the end of June. BBS visits are timed to start at between 0600 and 0700 hours and to last less than two hours. Visits during heavy rain, strong winds or poor visibility are discouraged. The majority (>80%) of data is inputted online by BBS observers www.bto.org/bbs, whilst the remaining data forms are returned to the BTO after the field season for input. Mammal recording has been carried out during the course of the bird surveys since 1995, during the two counting visits to each survey square per season. All mammals detected from the transect lines are recorded, but unlike the BBS bird data, data for mammals are recorded within a single distance category.

Although all mammal species can be recorded, records for only nine species encountered in sufficient numbers and reliably identified by BBS observers (mainly medium to large diurnal species) were suitable for trend analysis (rabbit *Oryctolagus cuniculus*, brown hare *Lepus europaeus*, mountain hare *Lepus timidus*, roe deer *Capreolus capreolus*, red deer *Cervus elaphus*, fallow deer *Dama dama*, muntjac *Muntiacus reevesi*, grey squirrel *Sciurus carolinensis*, fox *Vulpes vulpes*). Even among the species counted on a sufficiently large sample of squares, detection rates vary considerably from ca62% of squares for rabbit to 2-3 % for mountain hare, fallow deer and red deer. This resulted in mean annual sample sizes for the BBS population trends from 43 for mountain hare to 1,206 for rabbit as below. Although mean counts for the herding deer species and rabbits were larger (8-17), most mammals were detected in low numbers, of ca2 individuals.

Table 1. Sample parameters for mammal species monitored by the BBS.

BBS species	Sample size: mean annual # sites in the model	Mean number counted per site (2010)
Rabbit	1206	8.2
Brown Hare	601	3.3
Mountain Hare	43	2.8
Grey Squirrel	601	2.2
Red Fox	256	1.2
Red Deer	54	12.9
Fallow Deer	47	17.0
Roe Deer	313	2.2
Reeves Muntjac	69	1.4

The **National Gamebag Census (NGC)** was established in 1961 by the Game Research Association, which subsequently became the GWCT. It is a voluntary scheme that currently collects bag statistics from some 900 shooting estates annually in England, Wales, Scotland and Northern Ireland. Through the inclusion of data from historical game books, series for several species extend back to the 19th century. The GWCT believes that the NGC approach, which targets the estate rather than individual shooters, is the best way of assessing bags on driven shoots. The NGC statistics also include bags from rough shooting carried out on the same estates, as well as numbers of predatory species culled as part of legal pest control.

At the end of the shooting season, each participant completes an annual bag survey form detailing the numbers of each species shot or culled, numbers of shoot days, estate area and, in the case of upland estates, moorland area. Reminders are issued for non-returned forms and the return rate exceeds 90%. When expressed as the numbers of animals shot per unit area, the data provide temporal and regional trends in bags on shooting estates (Tapper 1992; Aebischer & Baines 2008). Overall, the NGC collates data on the shooting bags of 24 huntable species and 19 predator species. Of these, 19 species are mammals, namely rabbit *Oryctolagus cuniculus*, brown hare *Lepus europaeus*, mountain hare *Lepus timidus*, roe deer *Capreolus capreolus*, red deer *Cervus elaphus*, fallow deer *Dama dama*, muntjac *Muntiacus reevesi*, sika deer *Cervus nippon*, Chinese water deer *Hydropotes inermis*, wild boar *Sus scrofa*, hedgehog *Erinaceus europaeus*, grey squirrel *Sciurus carolinensis*, fox *Vulpes vulpes*, feral cat *Felis catus*, weasel *Mustela nivalis*, stoat *Mustela erminea*, polecat *Mustela putorius*, mink *Mustela vison* and brown rat *Rattus norvegicus*. All series are ongoing, with 2009 the last season included here (throughout this report, the year denotes the year in which a shooting season starts, e.g. 2009 refers to the 2009/10 season).

Trends derived from bags are unusual because the data analysed represent numbers of animals killed rather than counts of live animals. Nevertheless, they have been shown generally to provide a good index of population change where it has been possible to match up bag data with count data (e.g. red grouse: Cattadori *et al* 2003; fox: Jarnemo & Liberg 2005). Considerations in the interpretation of NGC trends are explored further on the GWCT website at:
www.gwct.org.uk/research__surveys/wildlife_surveys_and_ngc/national_gamebag_census_ngc/3001.asp.

Table 2. Sample parameters for mammal species monitored by the NGC.

NGC species	Sample size: total number of sites contributing to the long-term dataset. The annual sample size for any mammal data is ca 650 sites
Rabbit	1336
Brown Hare	1174
Mountain Hare	194
Grey Squirrel	917
Red Fox	1118
Red Deer	237
Fallow Deer	138
Roe Deer	525
Reeves Muntjac	152

2.2 Analysis and comparison of temporal trends

Population trends from the BBS data between 1995 and 2009 were produced using established methods for birds (Freeman *et al* 2007; Risely *et al* 2010) using the maximum count recorded over the two visits (early and late) for each 1km square in each year as the basic measure. Survey work was severely affected by foot and mouth restrictions in 2001, resulting in a heavy bias towards particular areas of the country. For this reason, we exclude survey data for 2001 from all analyses. Generalised linear models (GLMs) with Poisson error terms were used to model counts of each species for the UK using PROC GENMOD in SAS, with site and year effects (McCullagh & Nelder 1996) where the year effect is an index of the change in numbers relative to the first year 1995, which is set to an arbitrary index value of one. Corrections for over-dispersion where the deviance divided by the degrees of freedom was >3, were made using the DSCALE option in SAS (SAS Institute 2008). Red deer and fallow deer counts were particularly over-dispersed due to herding, so trends were produced using GLMs with negative binomial rather than Poisson error terms. Confidence intervals were calculated as the exponential of the estimate plus or minus (upper and lower confidence level) the standard error multiplied by 1.96. Deer parks were further excluded from the analyses for red and fallow deer. As with many long-term surveys these data include missing values, where a particular site was not surveyed in a particular year. The model is estimated using the observed counts to predict the missing counts and calculate the indices from a full data set, including the observed and predicted counts. The model requires that two points in the time series are available to estimate parameters, so squares counted in only one year are excluded. Because the stratified random sampling design results in unequal representation of regions across the UK, annual counts are weighted by the inverse of the proportion of each region that is surveyed in that year. The significance of the change in abundance between the first and last years of the time series was assessed using the 95% confidence intervals of the measure of change, whereby changes with confidence intervals that did not overlap were considered significant. Only results for species occurring on a mean of 35 or more squares in two or more years over the fourteen years for which survey data are available are presented, because of the low precision associated with small sample sizes (Joys *et al* 2004).

Population trends from the NGC bag data were produced using a very similar approach. For each species, analysis was based on all annual shoot returns greater than zero. Shoots contributing only one year's data were omitted. Statistical analysis followed the approach adopted by Whitlock *et al* (2003) and was carried out using GenStat 14 (Lawes Agricultural Trust, Rothamsted). For each species, bag data were analysed using a generalised linear model (McCulloch & Nelder 1996) with a Poisson error distribution and logarithmic link function, with shoot and year as factors and the logarithm of shoot area as an offset variable. For most species, the bag data spanned the period from 1961 to 2009 but for several species the start year had to be moved forward because of insufficient sites in early years (five contributing sites in any one year was a minimum requirement). The year coefficients were exponentiated to give an index of bag size on the arithmetic scale. All index values were relative to the start year, which had a value of 1. To obtain index values for the standard Tracking Mammals Partnership period of 1995-2009, the index values from the full analysis were recalibrated by dividing by the 1995 value. The 95% confidence intervals around the index values were obtained by bootstrapping at the shoot level: for each of 199 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 200 index values.

For each species in common between the BBS and the NGC, a statistical comparison of the two index series was carried out using a Wald test (Sauer & Williams 1989). If no significant difference was detected, the two series were combined into one as follows. For a given species, the combined index value and variance for each year are calculated as a weighted mean of the (log-transformed) annual indices of the two separate surveys. The weights are the reciprocal of the variance of the annual index for each survey. Therefore the mean index is weighted by the precision of each of the individual indices. If BBS has higher precision than NGC in a given year, then it will carry a greater weight in the averaged index for that year. The combined population trends show the joint mean of BBS and NGC indices for each year excluding 2001 (see above).

2.3 Mapping relative abundance (or presence) and change using BBS and NGC

Maps were produced for 15 species recorded on BBS sites, and 19 species recorded on NGC sites. To allow data to express themselves as far as possible, we chose a simple spatial smoothing approach based on an average value within a given radius around each point of the 10km OS grid across Great Britain (Northern Ireland was excluded due to low coverage of records). This is the same grid as used for mapping BTO Atlas data. In most cases, the average at a grid point represented the average count across all records within a specified radius of the grid point, but for 6 of 15 BBS species (brown rat, mole, hedgehog, badger, stoat and weasel) only presence/absence data were available (1 or 0 based on signs or other information relating to species presence), and the average at a grid point represented the probability of presence within a given radius.

To maximise the use of the data and to remove the possibility of a single year influencing the maps, we pooled annual records within each of two five-year time periods (1995-1999 and 2005-2009) prior to mapping. In terms of the units of measurement, BBS data were based on standard 1km squares, so the smoothed grid-point values were per km^2. For the NGC, where data were obtained from sites of diverse areas, each site-year value was standardised by dividing by area before smoothing so represented bags per km^2; sites of unknown area and with an areas less then $1km^2$ were excluded from the analysis. Annual records from 619 NGC sites and 2,624 BBS squares were included in the mapping for the period 1995-1999, whilst 788 NGC and 3,836 BBS squares contributed annual records for mapping the 2005-2009 period. Importantly the radius is a compromise between obtaining maximum spatial resolution and gathering an adequate sample size of annual records to produce a reliable reflexion of abundance or presence at a grid point. Wanting to standardise mapping as far as possible across species, following tests with radius set to 35km and 60km, we based all our maps on a radius of 35km, i.e. we calculated the mean count / presence (including zeros) within a 35km radius around each 10km grid point, which seemed to work well across surveys/species.

For maximum comparability of BBS and NGC maps, we adopted a standardised approach based on six percentile subdivisions (contour bands) of the smoothed values at the grid points. These corresponded to 0 (not recorded) and 0-20%, 20-40%, 40-60%, 60-80% and 80-100% percentiles of the smoothed values above zero. In all cases the 2005-2009 map for a species and survey was used to identify cut-points for the five percentile categories. We then applied these to the smoothed values for the corresponding 1995-1999 map, to ensure that the levels were directly comparable between periods. In terms of comparing maps between BBS and NGC, this meant that despite the differences in numerical scale between the two surveys for a given species, each contour band for the 2005-2009 map contains matching proportions of non-zero grid-point values so that the relative scales are the same: for both surveys, the top band (for instance) contains the grid points with the highest 20% of non-zero smoothed values.

To produce a change map, we proceeded in two steps. First, at each OS grid point, we subtracted the smoothed value for 1995-1999 from the smoothed value for 2005-2009. 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. We felt that it was important to produce a map showing a contour band representing no change, contour bands representing different rates of increase, and ones representing different rates of decline. The bandings for rates of increase also needed to match those for rates of decline. To achieve this, we ranked the difference values by absolute magnitude (i.e. ignoring the sign of the difference) and calculated 10%, 40% and 70% percentiles. These allowed us to define a central band containing the 10% of values closest to 0, which we considered to be 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.

3 Results

3.1 Temporal trends

The trends produced by the NGC and the BBS were not significantly different for any of the 9 species analysed (see Table 3). This is consistent with the patterns of overall change between 1995 and 2009, and their levels of significance, revealed by the two surveys. The BBS results indicated significant changes in abundance for five species and for all five species, the change in abundance revealed by the NGC was in the same direction, significantly so for grey squirrel. For this species, BBS and NGC results show marked but parallel variation in indices among years and are not significantly different from each other (Wald test of equal indices: $p=0.827$).

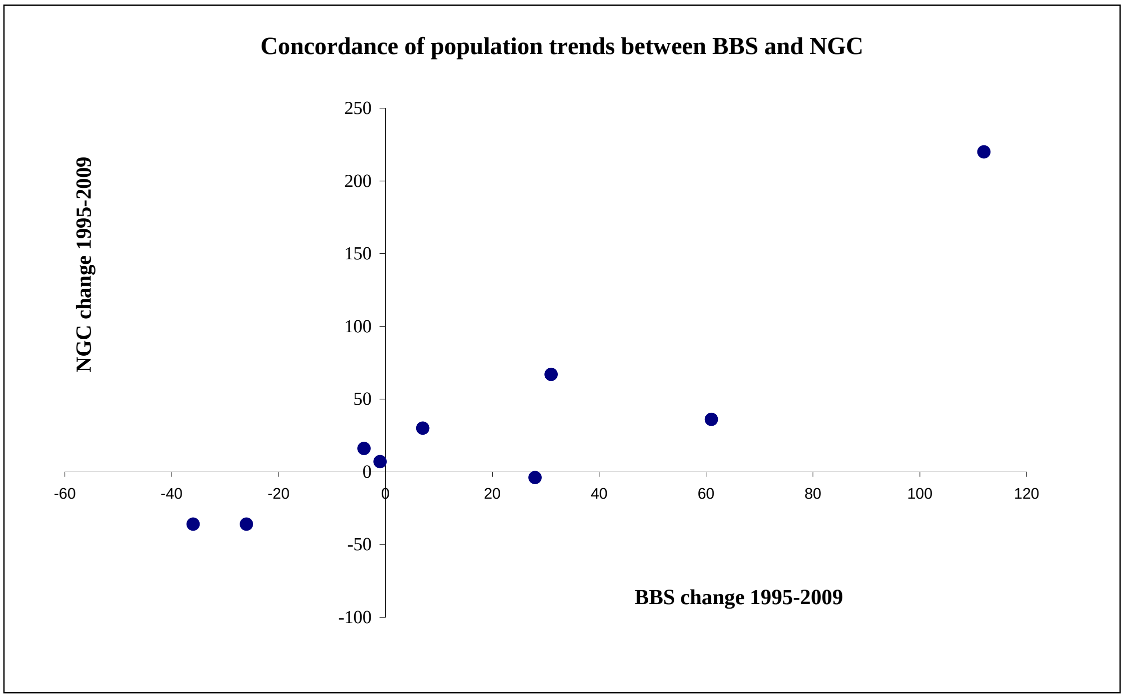


Figure 1. Scatterplot showing concordance in BBS and NGC population trends over the period 1995 to 2009, for nine mammal species.

Table 3. Comparison of population trends and measures of change for species monitored by the BBS and NGC and an assessment of whether they are significantly different from each other (Wald Test of equality of indices). A p value of >0.05 indicates no significant difference between the two indices.

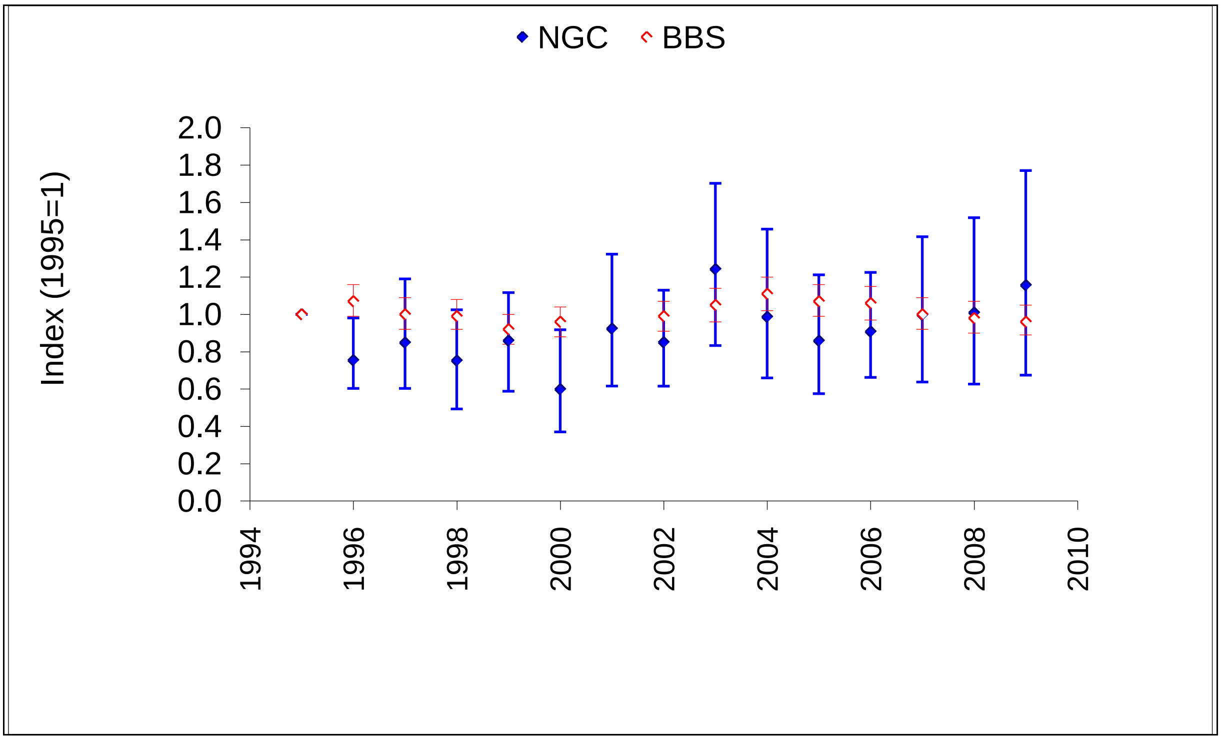
* Wald Test of equality of indices.

	BBS change 95-09		NGC change 95-09		χ^2	P*
Brown Hare	-4%	ns	16%	ns	19.27	0.115
Mountain Hare	-26%	ns	-36%	ns	19.04	0.122
Rabbit	-36%	sig decline	-36%	ns	9.76	0.713
Grey Squirrel	31%	sig increase	67%	sig increase	8.26	0.827
Fox	-1%	ns	7%	ns	11.5	0.569
Red Deer	28%	sig increase	-4%	ns	7.49	0.875
Fallow Deer	7%	ns	30%	ns	1.25	1.000
Roe Deer	61%	sig increase	36%	ns	8.73	0.793
Muntjac	112%	sig increase	220%	ns	1.62	1.000

Table 4. Measure of change in joint population trends derived from BBS and NGC.

	BBS-NGC joint change 95-09	
Brown Hare	-3%	ns
Mountain Hare	-28%	sig decline
Rabbit	-36%	sig decline
Grey Squirrel	34%	sig increase
Fox	0%	ns
Red Deer	24%	sig increase
Fallow Deer	7%	ns
Roe Deer	60%	sig increase
Muntjac	114%	sig increase

(a) Brown Hare



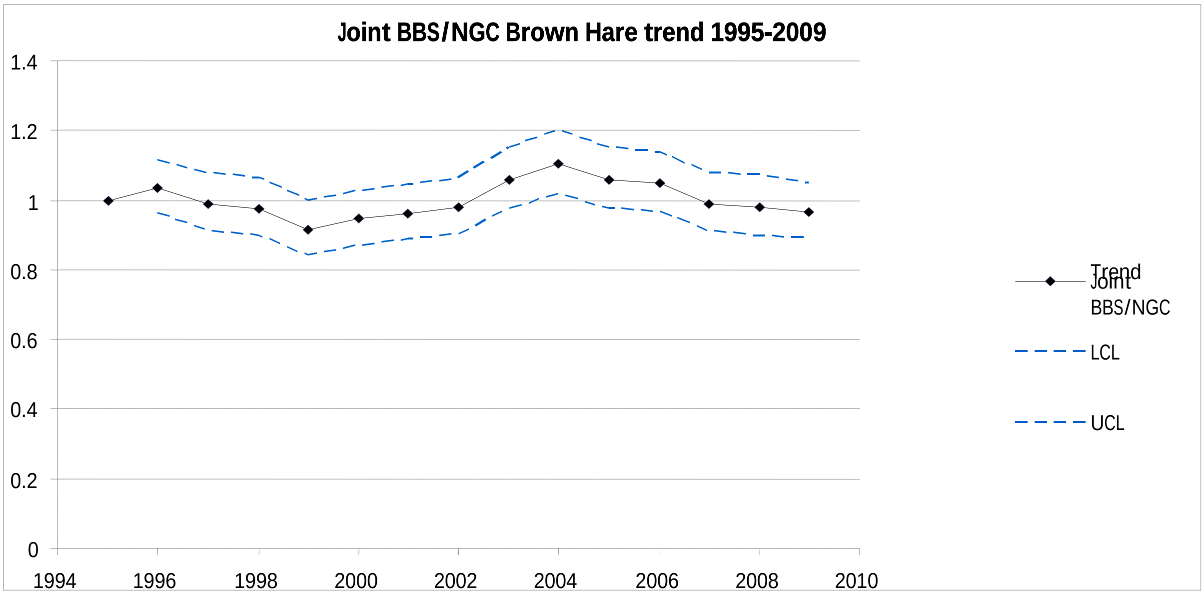
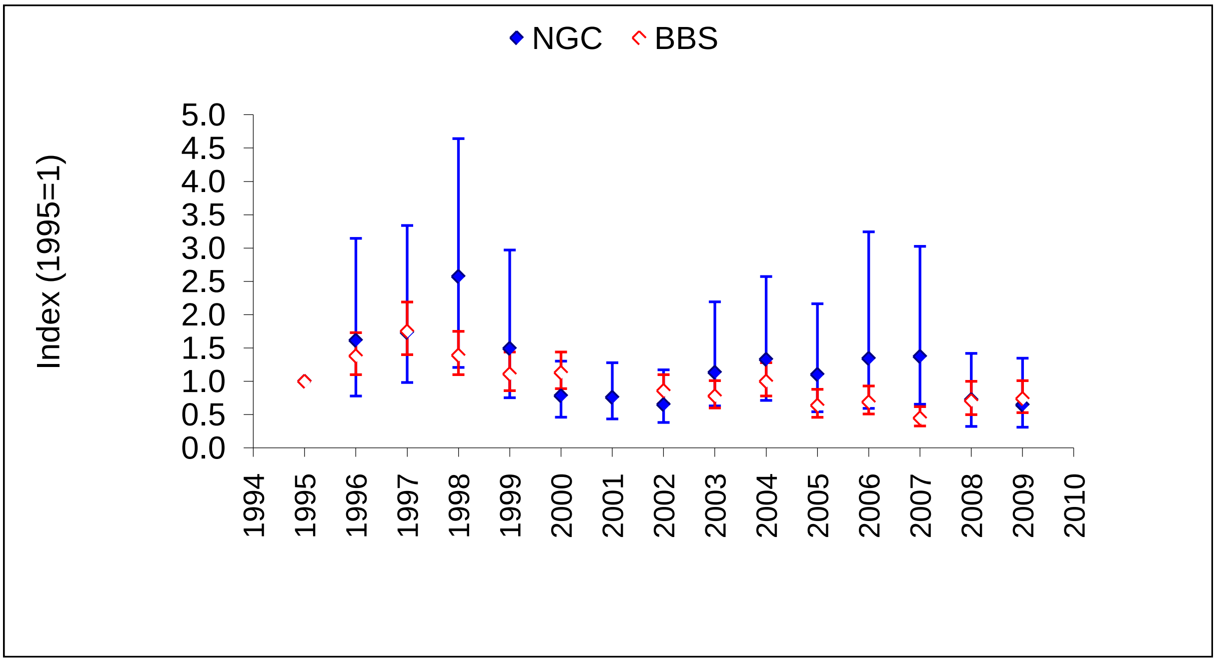


Figure 2 (a). Plots of the annual population indices, and 95% confidence intervals, for brown hare monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(b) Mountain Hare



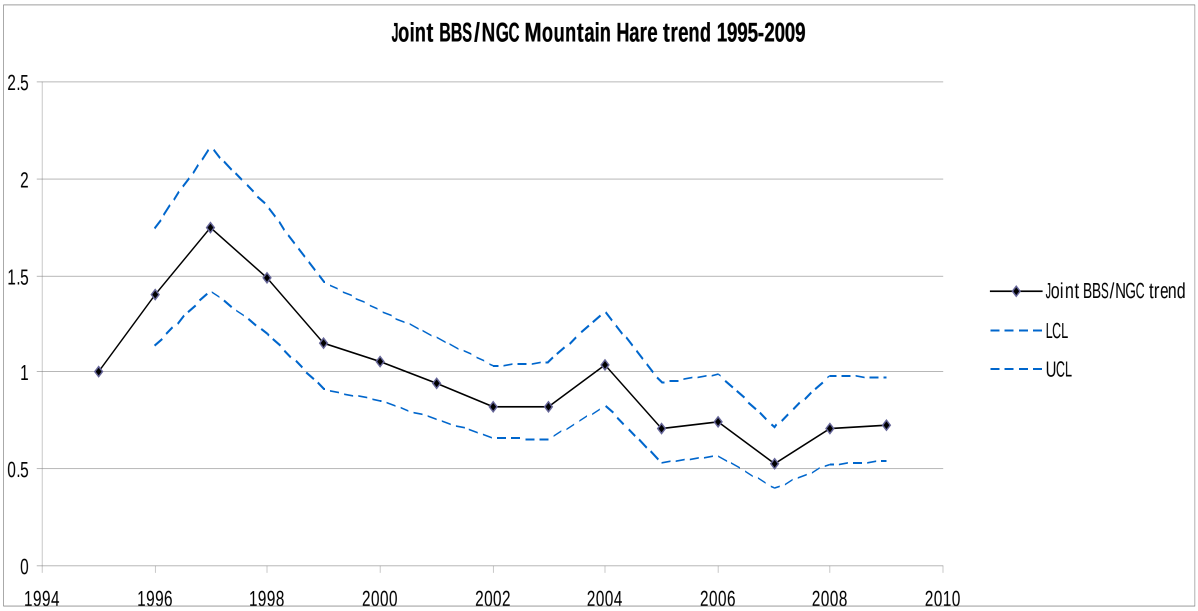
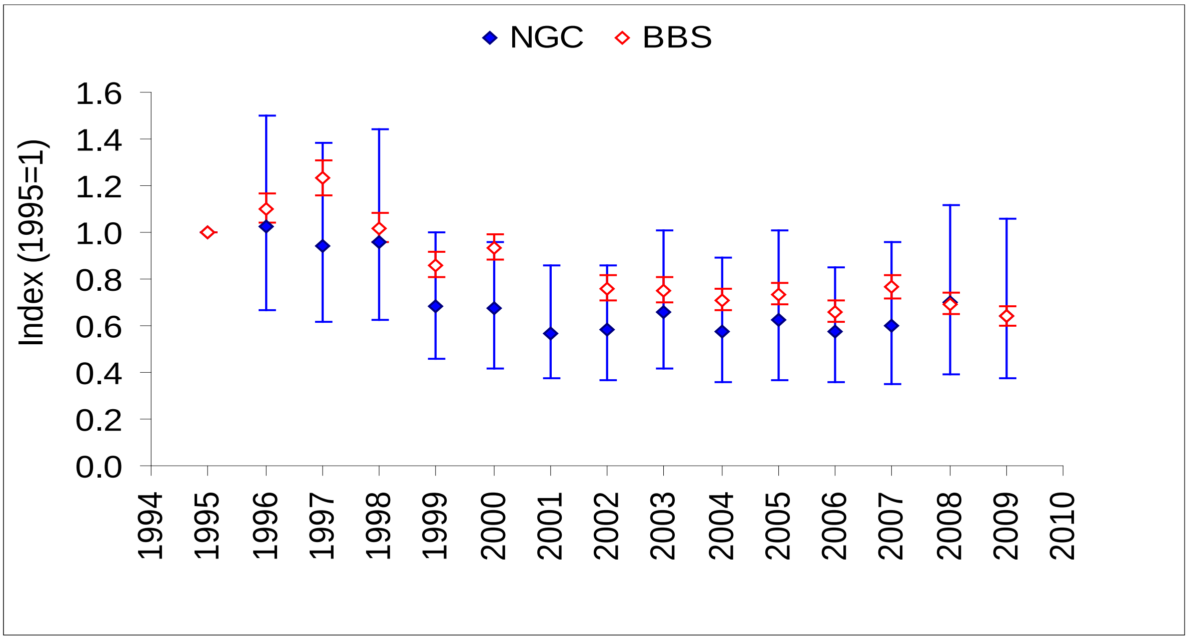


Figure 2 (b). Plots of the annual population indices, and 95% confidence intervals, for mountain hare monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(c) Rabbit



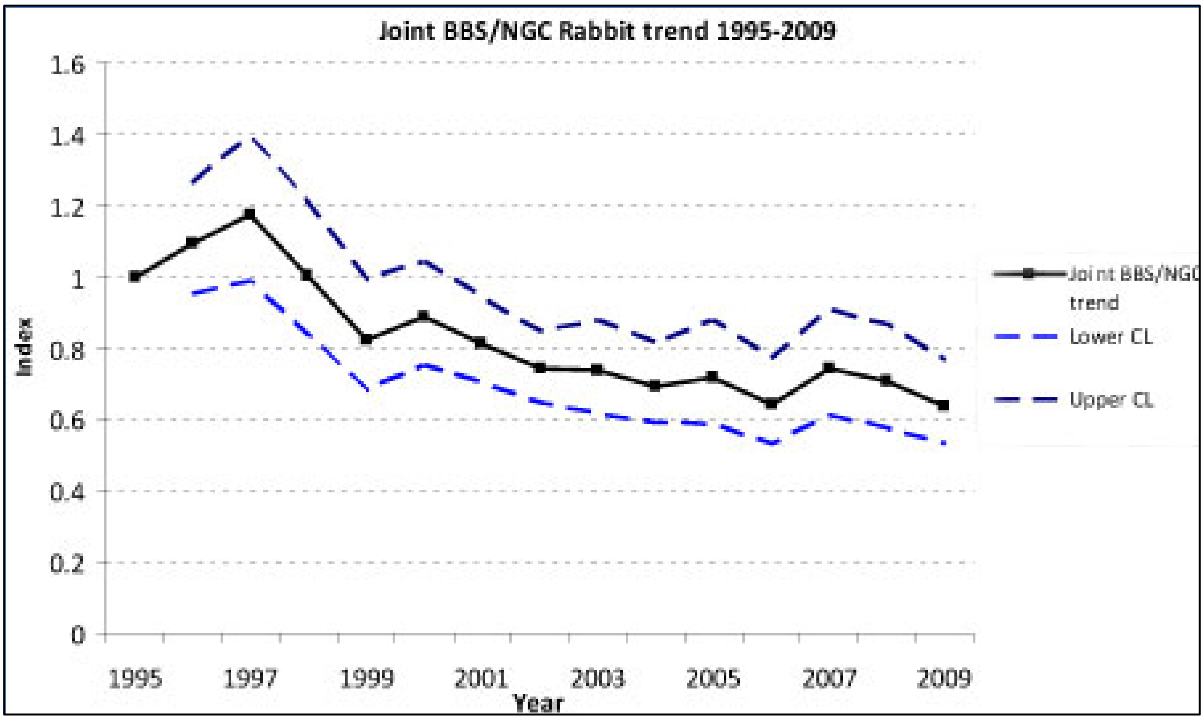
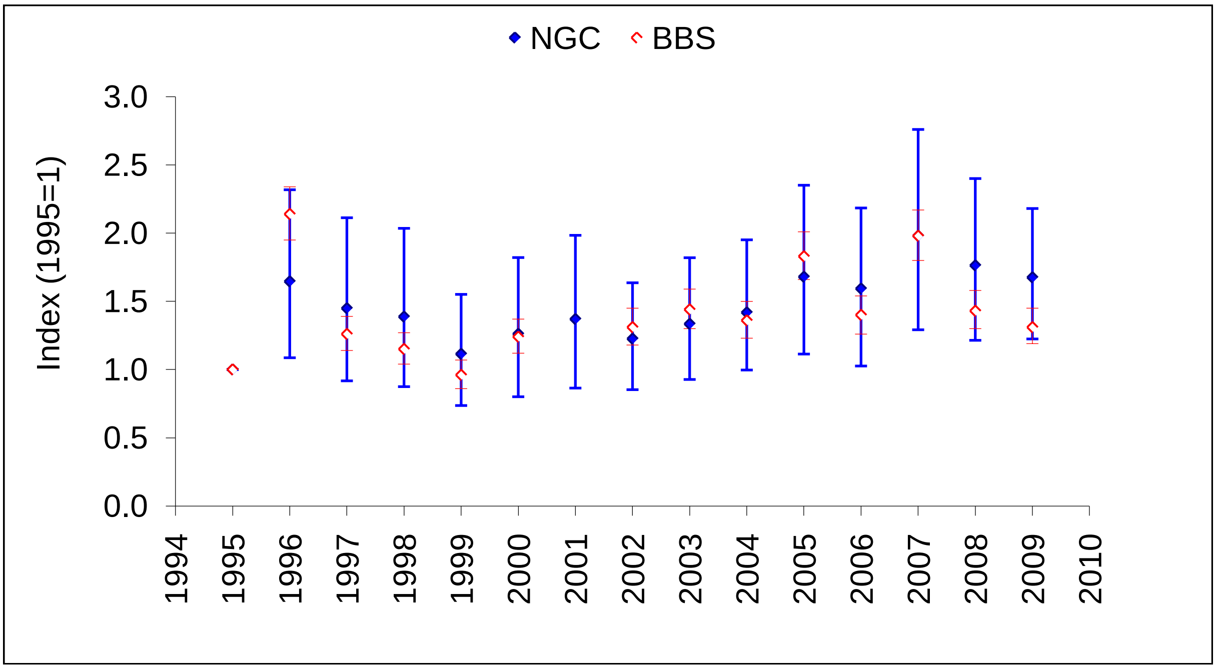


Figure 2 (c). Plots of the annual population indices, and 95% confidence intervals, for rabbit monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(d) Grey Squirrel



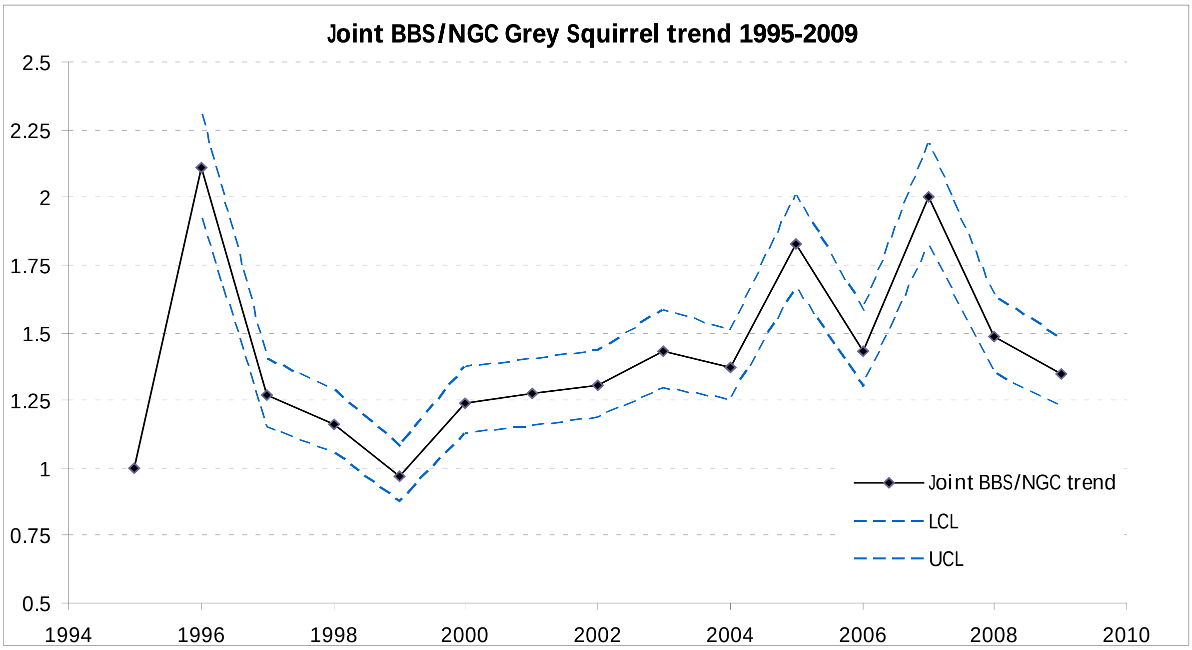
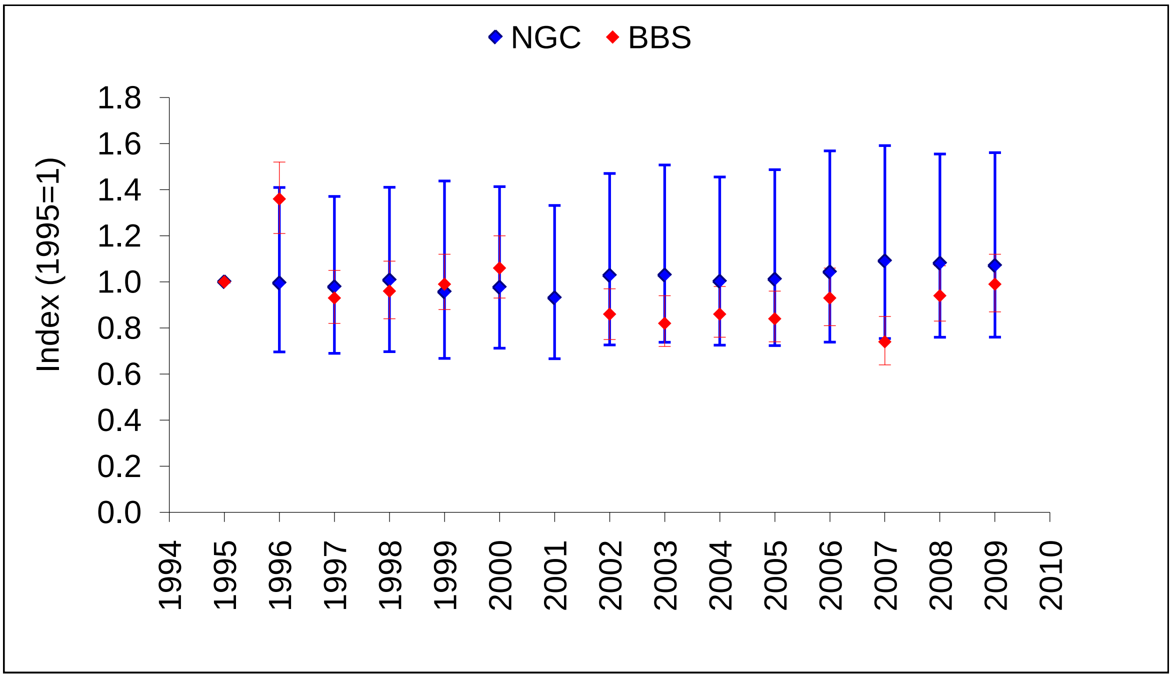


Figure 2 (d). Plots of the annual population indices, and 95% confidence intervals, for grey squirrel monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(e) Fox



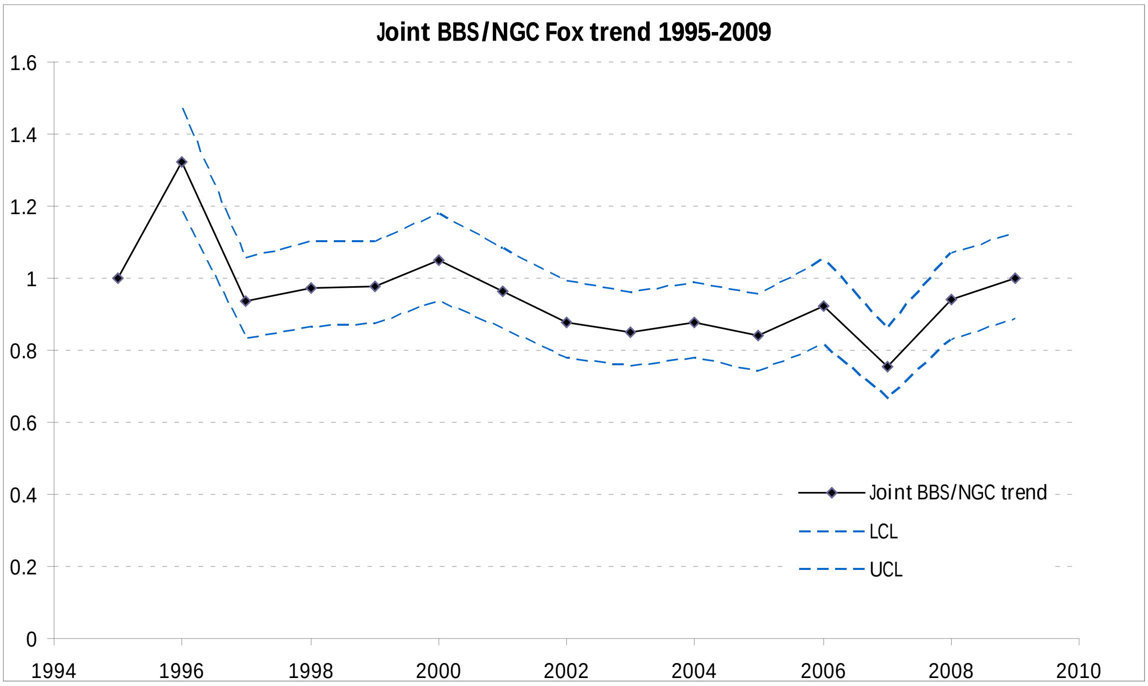
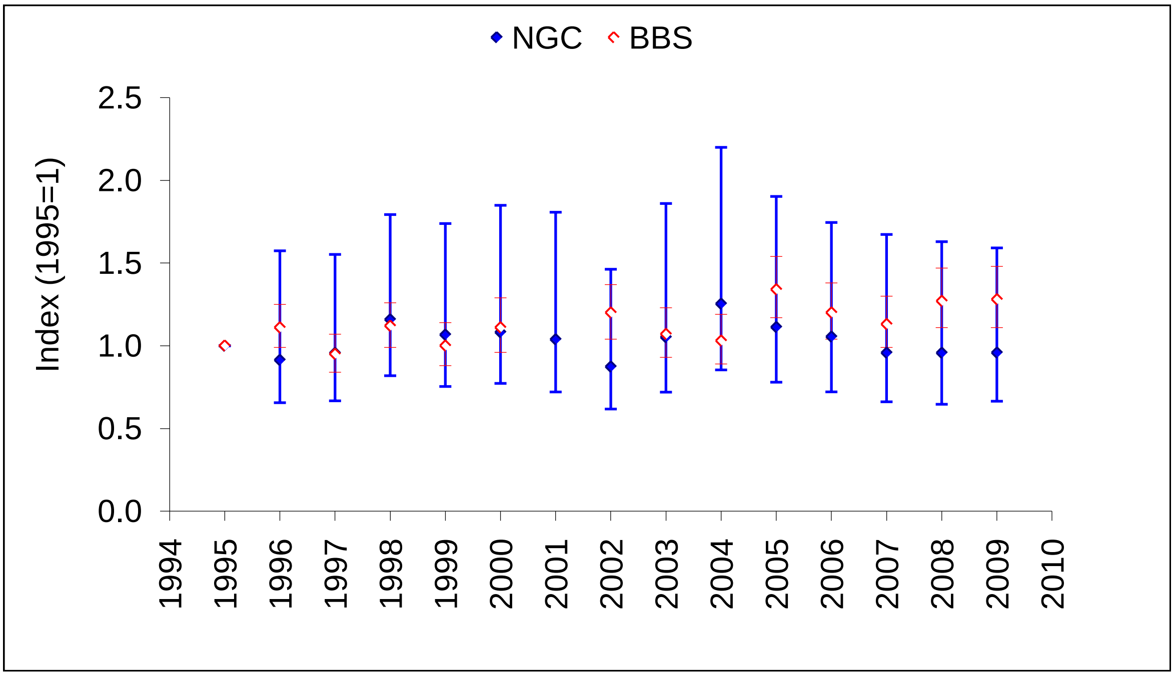


Figure 2 (e). Plots of the annual population indices, and 95% confidence intervals, for fox monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(f) Red Deer



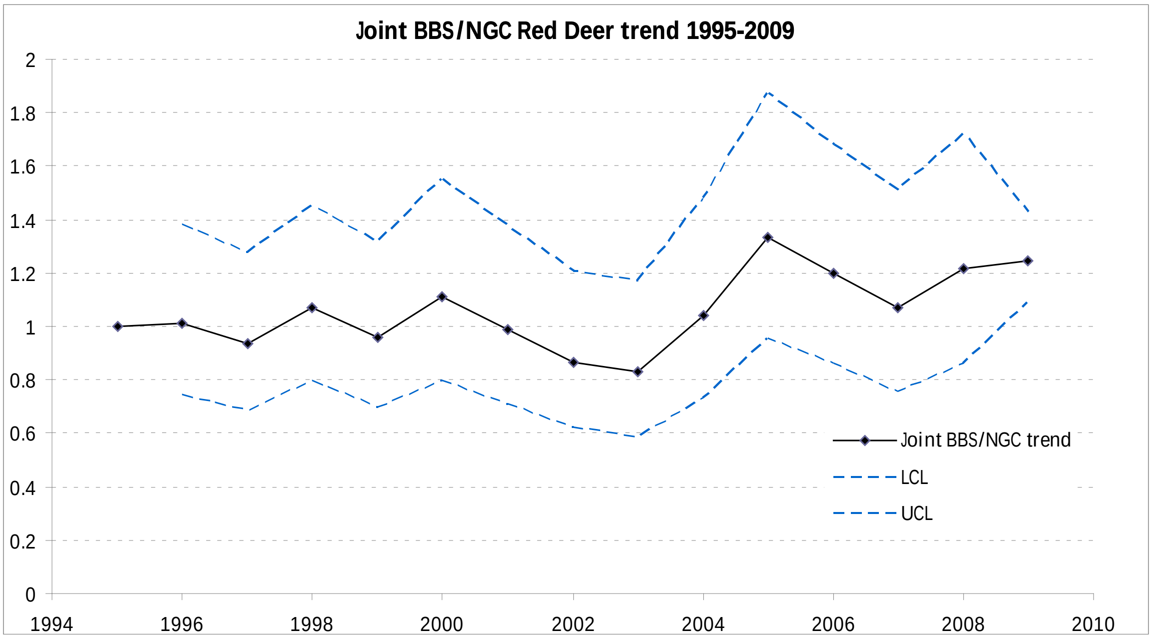
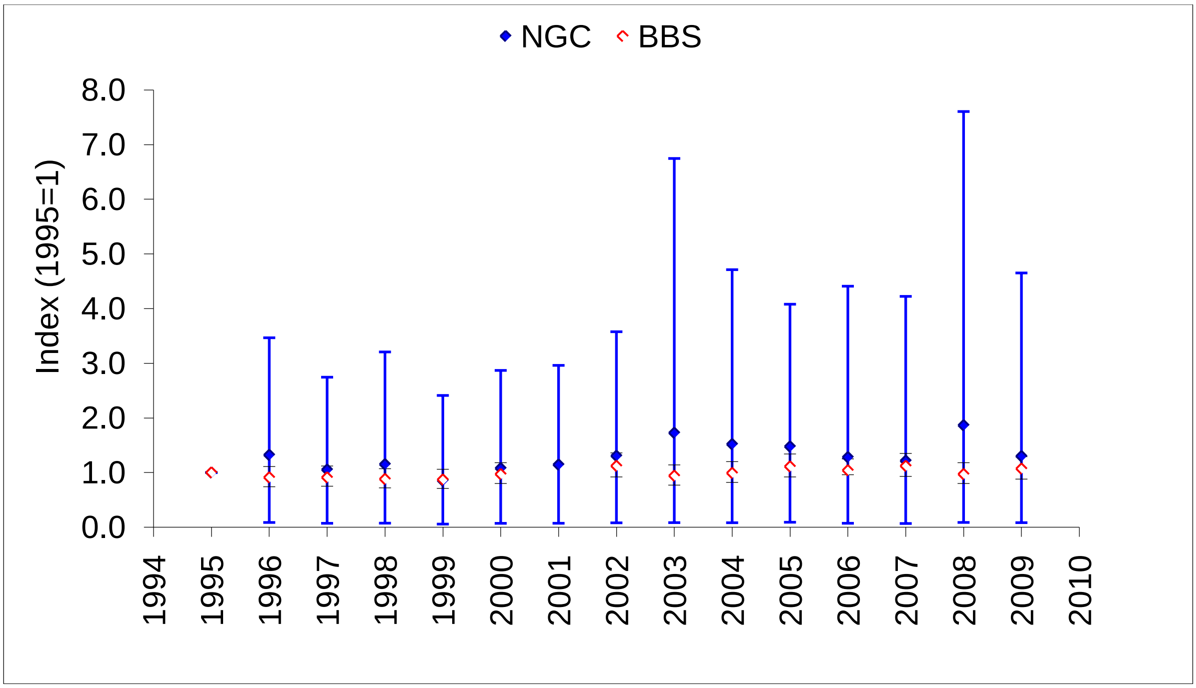


Figure 2 (f). Plots of the annual population indices, and 95% confidence intervals, for red deer monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(g) Fallow Deer



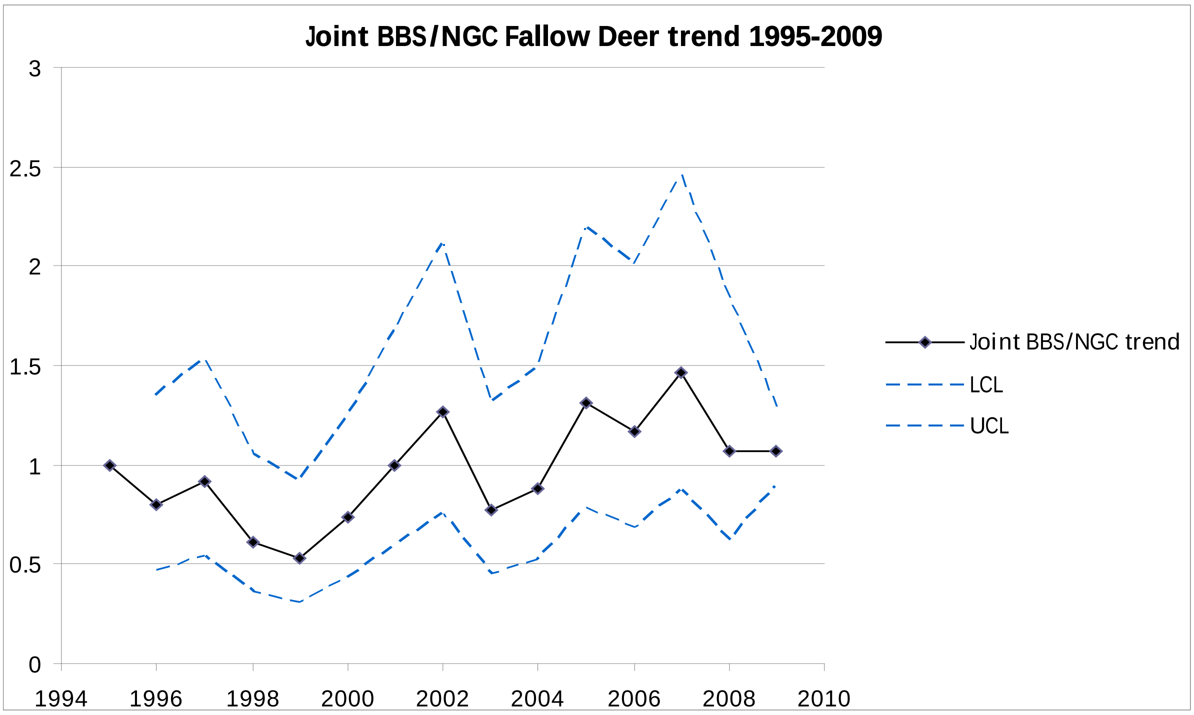
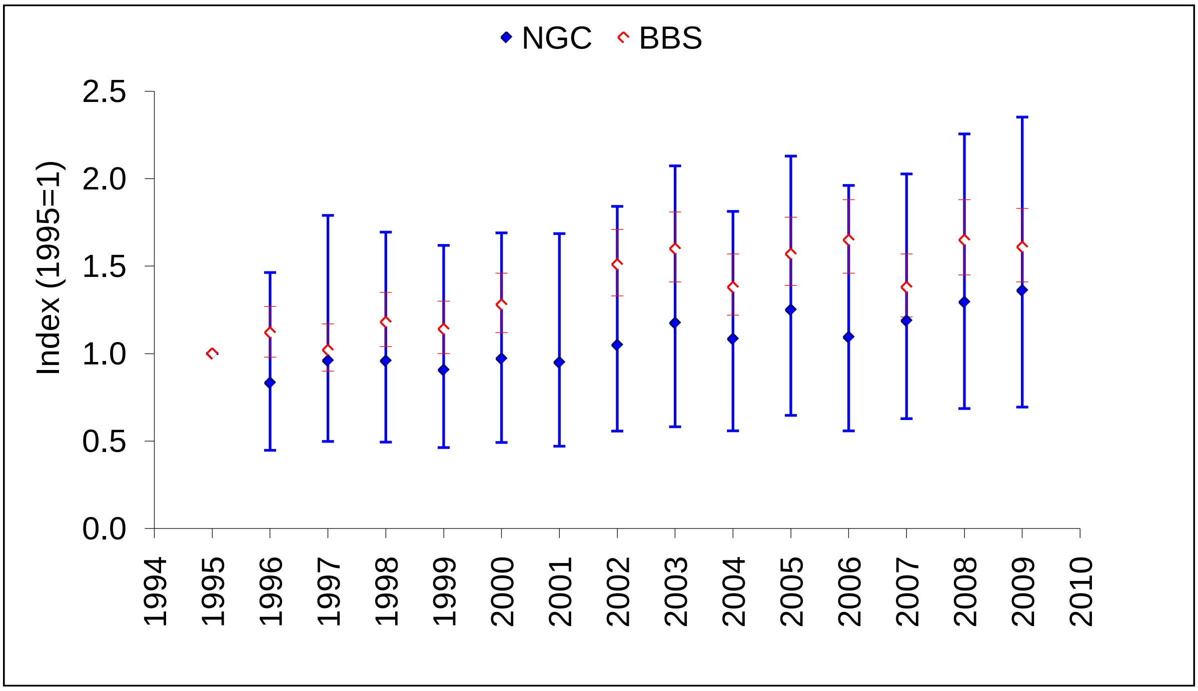


Figure 2 (g). Plots of the annual population indices, and 95% confidence intervals, for fallow deer monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(h) Roe Deer



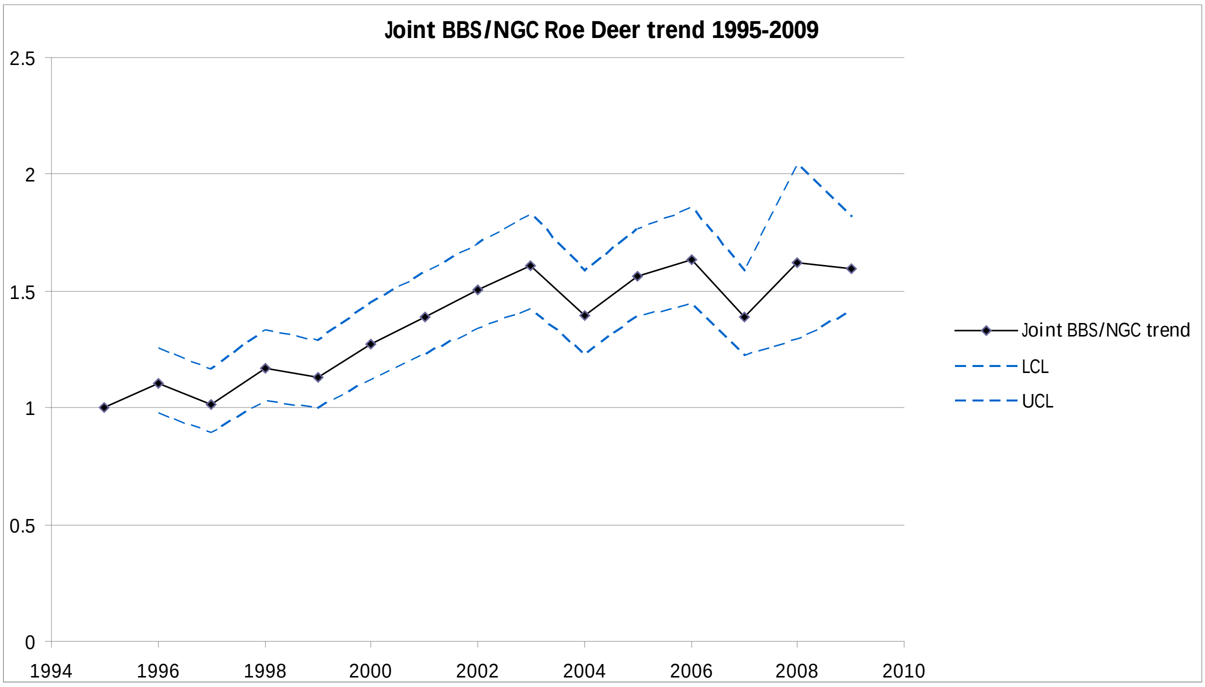
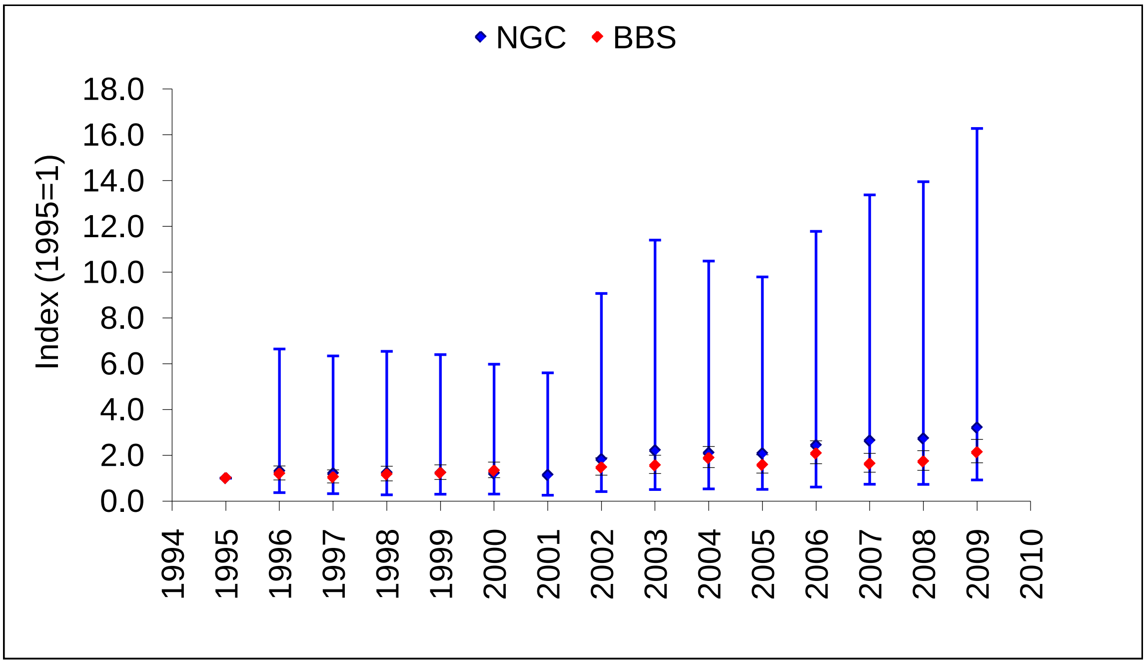


Figure 2 (h). Plots of the annual population indices, and 95% confidence intervals, for roe deer monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

(i) Muntjac



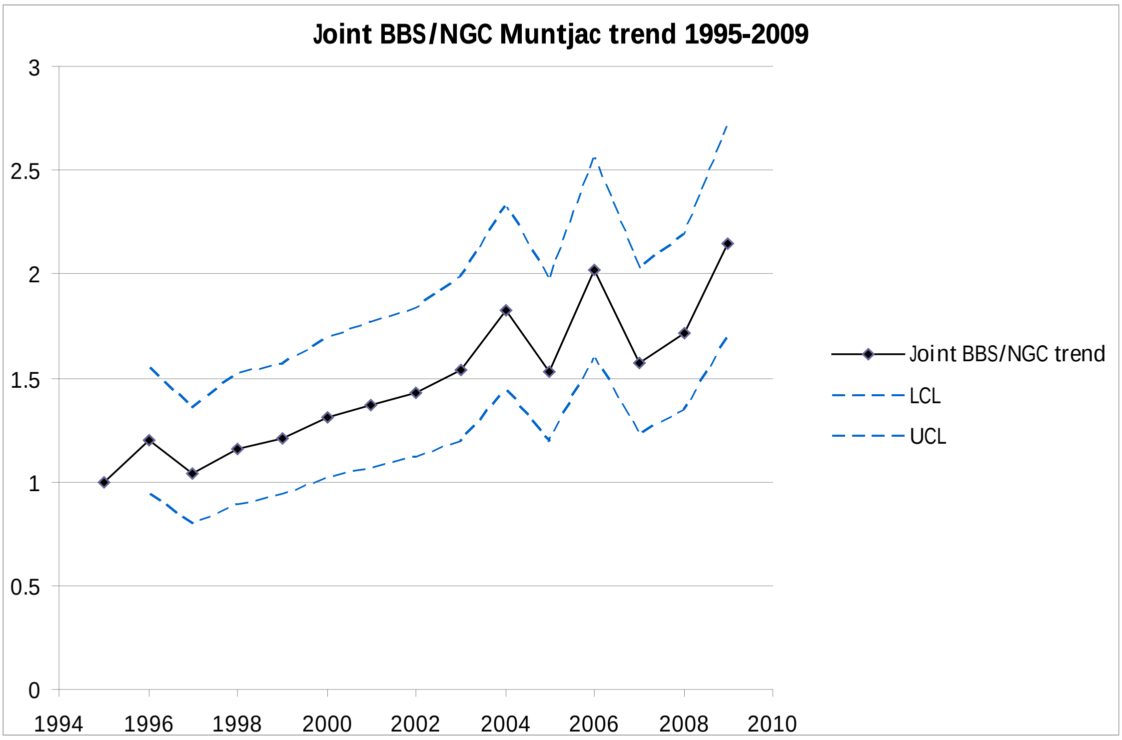


Figure 2 (i). Plots of the annual population indices, and 95% confidence intervals, for muntjac monitored by the BBS and the NGC. The second plot shows the joint population trend for each species, with calculated confidence intervals.

3.2 Spatial patterns in mammal abundance

Appendix 1 shows the mapped distributions of species recorded by BBS surveyors and species recorded from NGC participants. For each species and for each scheme, we present the earliest distribution (based on data from 1995 to 1999) and the current distribution (based on data from 2005 to 2009), as well as the map of change between the earliest and current time periods. The spatial patterns revealed by these maps are summarised as follows:

Rabbit: Both schemes highlight the higher relative abundance of rabbits in the east, with concentrations throughout the south-east, the east of England, East Yorkshire, and most of southern and eastern Scotland, as well as in the west Midlands and parts of north Wales. They differed in that the BBS showed concentrations in Cornwall; the NGC in south Wales. Between the early and current periods, the NGC maps suggest disappearances from parts of western England but especially Scotland. This was less apparent from BBS, where the change map was more pixelated, suggesting declines in rabbits in the middle longitudes from Scotland to the south-east.

Brown Hare: Both schemes highlight the concentrations of brown hares in eastern England and the Wiltshire downlands, with lower concentrations up through Scotland. The NGC shows large reductions in bag densities in the southern high-concentration areas between the earliest and current time periods, not apparent in the BBS map. Both schemes reveal increases in parts of the east Midlands.

Mountain Hare: The two schemes reveal similar patterns of relative abundance with highest concentrations in the central highlands of Scotland and slightly lower concentrations in southern Scotland. Both schemes reveal a population in the Yorkshire Dales. However, the NGC maps suggest more widespread occurrence than BBS. Between the two time periods, this hare declined most in the Central Scottish Highlands and increased in southern Scotland, especially according to the NGC map.

Grey Squirrel: Both schemes revealed highest concentrations of this species in south-east England, the west Midlands and along the Welsh borders, as well as scattered populations in other areas (e.g. the South West). Squirrels show increases almost everywhere in their UK range, and there is no clear concordance in the patterns.

Fox: The NGC maps reveal this species' ubiquitous distribution with highest concentrations in London and the south-east, the west Midlands and bordering areas of Wales, and also in the South West and a small area in south-western Scotland. The BBS maps reveal broadly similar distributions but also in south-west Wales and scattered concentrations in northern Scotland. The BBS change map suggests a checkerboard pattern of increases and decreases, whereas the NGC change map suggests strong increases in most of its areas of highest concentrations.

Red Deer: Both NGC and BBS maps showed highest concentrations of red deer in western and northern Scotland, with additional small populations scattered throughout England (Devon, East Anglia, south coast, in the uplands). There was little difference between the early and current maps for either NGC or BBS, and both showed similar patterns of change, at least at broader geographical scales.

Fallow Deer: Both NGC and BBS maps revealed the southerly distribution of this species, but the NGC map revealed the presence of this species in areas where the BBS often did not (e.g. in parts of Scotland, north Wales, north-west England). Both schemes' maps indicate strong increases in central/south/eastern England, the NGC also in central Scotland.

Roe Deer: Both schemes show the distinct separation of populations of this relatively widespread species, with concentrations in Scotland, the southern coast of England, and to a lesser extent in East Anglia and in north-east England. Roe deer are largely absent from Wales and much of the Midlands. Both schemes also showed similar patterns of change, with strong increases in all of its main concentrations.

Muntjac: This species was found by both schemes to be concentrated in central and eastern England, with scattered concentrations elsewhere, although not consistently between schemes or time periods. The NGC revealed strong increases in the core of its current range, whereas the BBS showed a more pixelated pattern of increases over broadly the same areas.

For four species (hedgehog, stoat, weasel, brown rat), the maps for BBS are based on presence-absence evidence rather than counts because these species are seldom seen during bird counting visits. This means that comparisons between the two schemes are confounded by further differences in the scheme methods. Another species (badger) could be mapped only using BBS data, and four other species (sika deer, feral cat, American mink and polecat) could be mapped only with NGC data. These maps are not discussed further in this report.

Hedgehog: The NGC map for this species in 1995-1999 showed concentrations in eastern England, central-southern England, north Wales and parts of north-west England and southern/central Scotland, and very few in the South West. By 2005-2009, the population in southern England and to a lesser extent throughout the UK, were much less evident. The BBS maps suggested a much more scattered distribution with patches of high concentration throughout, including Scottish islands, except in the highlands. The BBS change map shows overall declines with small pockets of increase in northern Scotland and Cornwall. The NGC change map reveals big declines in eastern England, northern Wales and elsewhere, and increases in the North-East.

Stoat: A widespread species, the NGC maps suggest highest concentrations in northern England, southern Scotland and in East Anglia. The BBS maps suggest more scattered areas of concentration throughout northern England and all of Scotland. The NGC change map suggests strong increases in the east, particularly Yorkshire and the east Midlands, and declines in southern Scotland and south-east England, whereas the BBS change map shows scattered areas of increase and little evidence of declines.

Weasel: Also widespread, the NGC maps indicate concentrations in northern England, East Anglia, the east Midlands and southern Scotland, whereas the BBS maps show very little variation in relative presence. The NGC change map shows strongest increases in northern England as well as in parts of Scotland, whereas the BBS change map suggests a more even distribution of increases and decreases.

Brown Rat: The NGC maps show brown rats to be ubiquitous, with highest concentrations in southern England (especially the South-East, East Anglia, the east Midlands and Devon). The BBS maps suggested a smaller range, with scattered concentrations throughout, but generally closer to coasts. The NGC change map suggested strong increases in the cores of its NGC range (except the southeast where it has declined) whereas the BBS change map suggested increases mainly in the Midlands, as well as in East Anglia and parts of Scotland.

4 Conclusions and discussion

4.1 Reporting temporal changes

None of the nine species for which population trends could be estimated by both BBS and NGC exhibited significant inter-scheme differences at the 5% level of confidence, or even at the 10% level of confidence. The probability of detecting significant differences is clearly influenced by the power of the test, in this case ultimately measured by the standard error. This in turn is dependent on the sample size of sites contributing to the trends, the degree of between-site variation within each scheme, and the analytical approach. For example the standard errors derived from the bootstrapping approach, as used for the NGC population trends, tend to be larger than those derived from the maximum-likelihood approach used for the BBS population trends. The other important variable is sample size, and for some species (e.g. rabbit, brown hare and grey squirrel) these were much larger for the BBS than for the NGC. This was not always the case, with the NGC comprising a larger number of sites where species such as red and fallow deer bags were recorded. The relative size of the standard errors for each scheme also influenced the pattern in the joint trends such that where the standard error for the BBS was small (e.g. rabbit), the joint trend was very similar to that of the BBS.

In order to investigate the influence of different methods of calculating confidence limits, we undertook a second set of BBS analyses with two of the mammal species (rabbit and mountain hare), both of which exhibited moderate (>25%) declines over the period 1995 to 2009. The aim was to determine whether using a bootstrapping method to generate the 95% confidence intervals in the BBS trends would result in any significant change in the results of the comparisons or in the significance of changes in the joint BBS-NGC trend. The two species, although both declining, differ considerably in abundance with the rabbit trends based on a very large sample (>1000 sites) and mountain hare based on a very small sample (<50 sites). The results of these analyses are provided in Table 5 below.

The new mountain hare joint BBS-NGC trend obtained using the bootstrapped estimates for BBS exhibited a slightly steeper decline (-32% rather than -28%) and, importantly, because of the wider confidence limits of the joint trend, this change was not significant.

The new rabbit joint BBS-NGC trend obtained using the bootstrapped estimates for BBS exhibited almost exactly the same level of decline (-36%) and remained significant. However, the confidence limits on the change between 1995 and 2009 were considerably wider than previously (Table 5. -23 to -47% compared to -32 to -40%).

Table 5. Comparison of trends using the bootstrapping and maximum likelihood approaches for two mammal species.

* indicates statistical significance at the P<0.05 level.

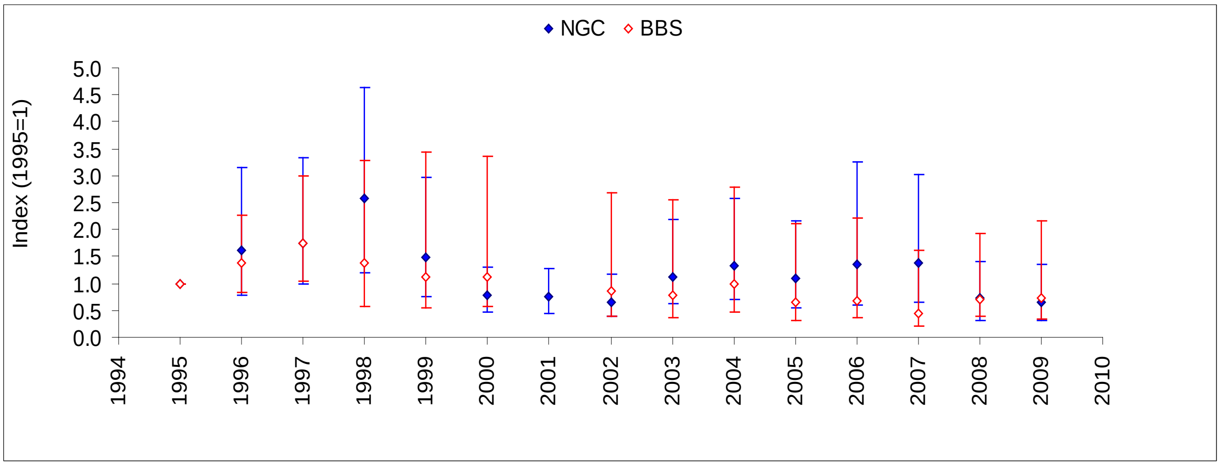
Rabbit

	Trend calculated using maximum-likelihood approach (BBS only)	Trend calculated using bootstrapping approach
BBS 1995-2009 change (+/- 95% confidence intervals)	-36 % * (-40% to -32%)	-36.1% * (-47.5% to -22.8%)
NGC 1995-2009 change (+/- 95% confidence intervals)	Not tested	-36% NS (-62% to +6%)
Wald Test BBS vs NGC	X^2 =1.84, NS, p=0.999	X^2 =1.63, NS, p=0.999
Joint BBS -NGC 1995-2009 change (+/- 95% confidence intervals)	-36% * (-39.9% to -31.9%)	-36.1 % * (-46.6% to -23.4%)

(b) Mountain Hare

	Trend calculated using maximum-likelihood approach (BBS only)	Trend calculated using bootstrapping approach
BBS 1995-2009 change (+/- 95% confidence intervals)	-26% NS (-47% to +1%)	-25.5% NS (-66.5% to +116%)
NGC 1995-2009 change (+/- 95% confidence intervals)	Not tested	-36% NS (-69% to +35%)
Wald Test (BBS vs NGC)	X^2 =19.04, NS, p=0.122	X^2 =7.95, NS, p=0.847
Joint BBS-NGC 1995-2009 change (+/- 95% confidence intervals)	-27.7% * (-46.1% to -2.8%)	-31.9% NS (-61.7% to +21.1%)

(a) Revised annual indices, and 95% confidence intervals, for mountain hare generated from the BBS and NGC datasets



(b) Revised annual joint indices, and 95% confidence intervals, for mountain hare generated from the BBS and NGC datasets

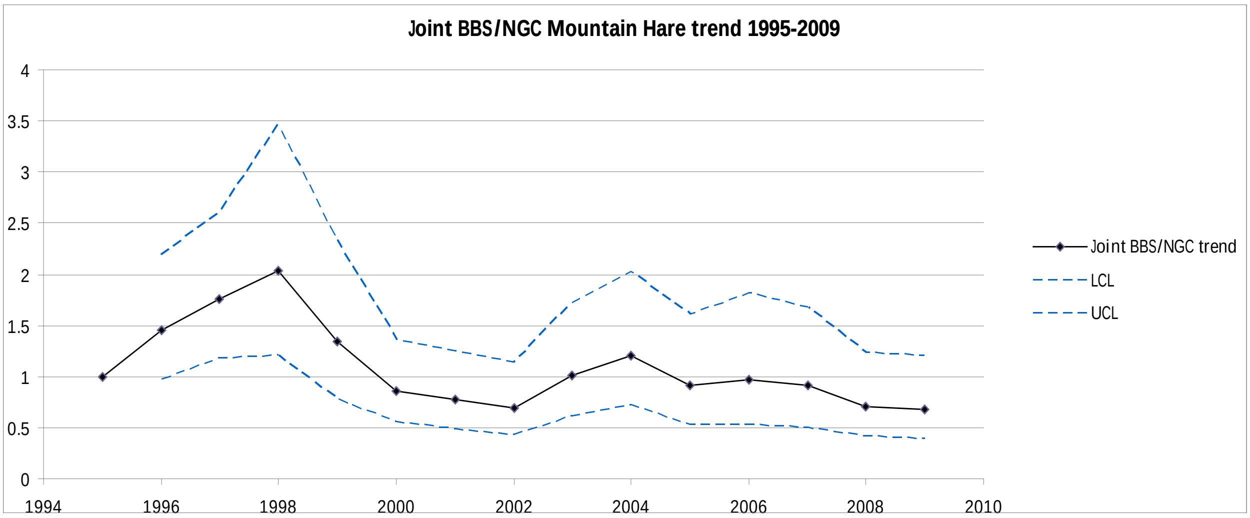
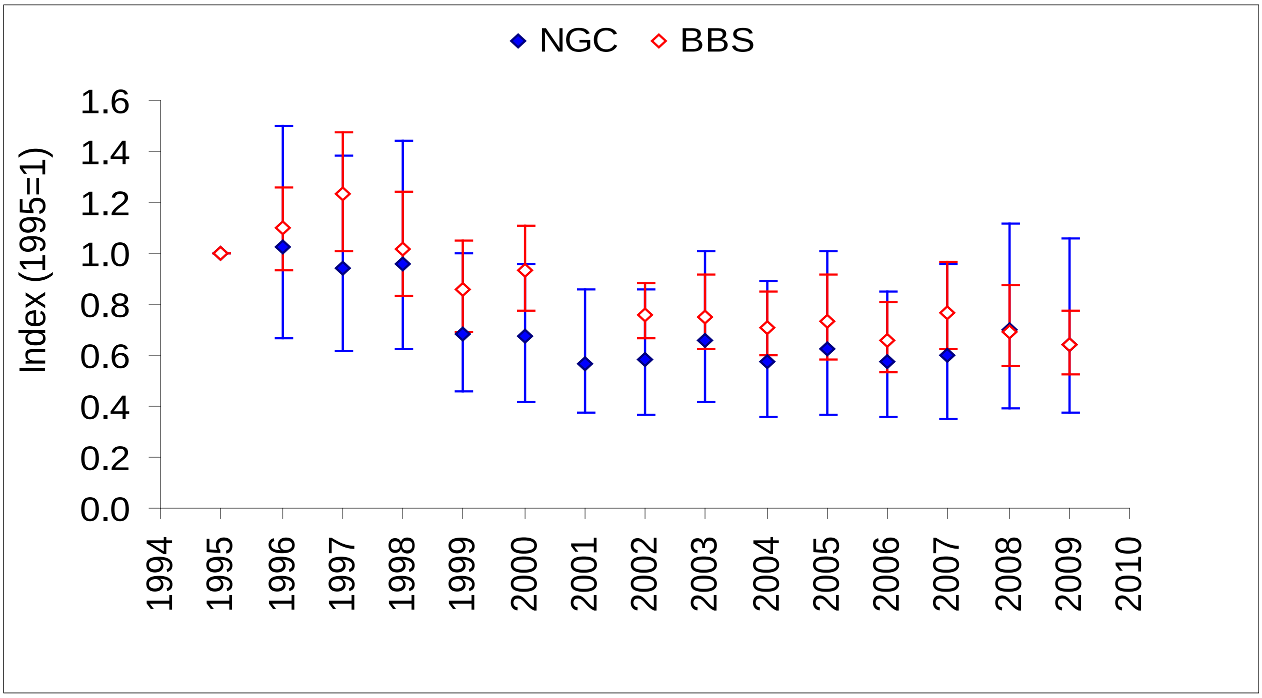


Figure 3. Results of analyses to compare and combine BBS and NGC mountain hare data using a bootstrapping approach for estimating error in the BBS indices.

(a) Revised annual indices, and 95% confidence intervals, for rabbit generated from the BBS and NGC datasets



(b) Revised annual joint indices, and 95% confidence intervals, for rabbit generated from the BBS and NGC datasets

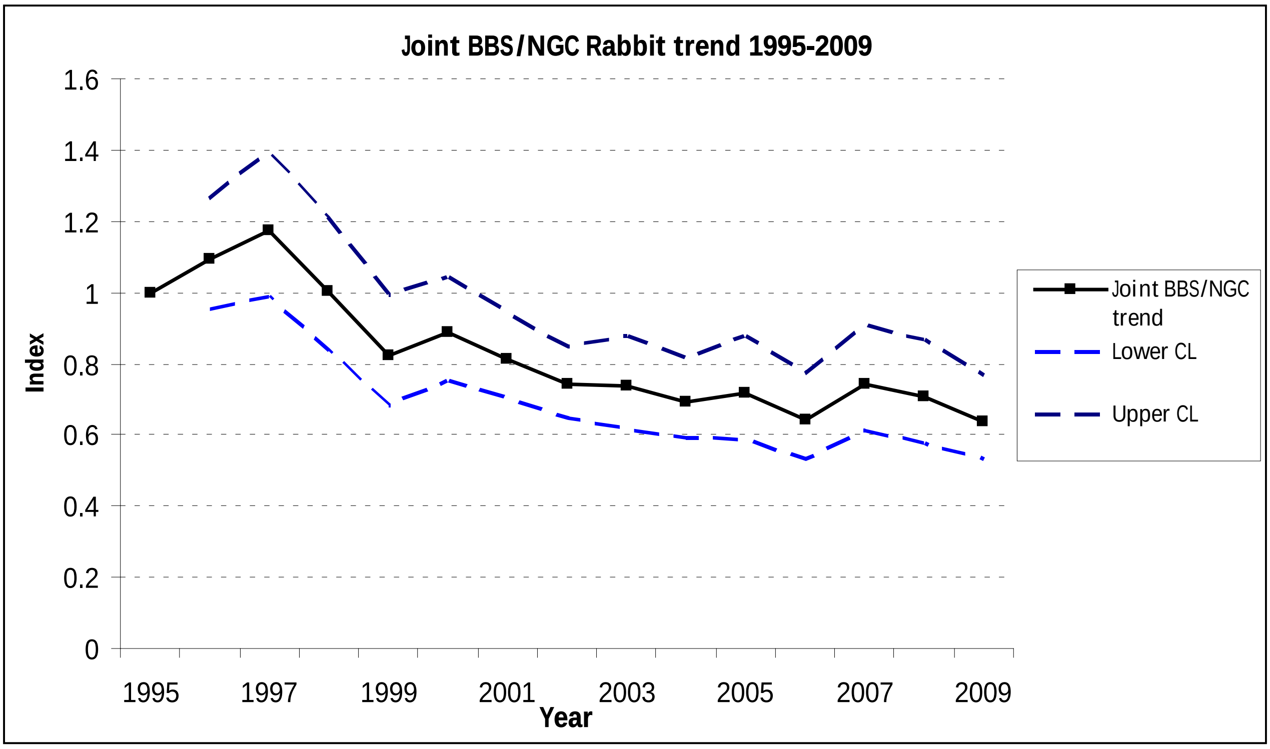


Figure 4. Results of analyses to compare and combine BBS and NGC rabbit data using a bootstrapping approach for estimating error in the BBS indices.

One of the aims of this work was to investigate the feasibility of combining results from two independent mammal monitoring schemes and agree on a single measure of change for species in common. Two important conclusions can be made from these analyses. Firstly, justified by the lack of statistical differences in trends, we were able to calculate joint trends for all nine species (see Table 4. and Figure 1.) using a simple approach using summarised scheme data (annual indices and associated error). Joint trends most closely resemble those of the BBS, owing to the smaller estimated standard error and its generally larger sample sizes.

However, despite the lack of any statistical significance between schemes for any of the species tested, there may nevertheless be real differences in the trends due to differences in the samples (geographical, random sites versus hunting estates) and in the measures (counts versus bags) and subsequently methods used to estimate trends. It would therefore be preferable to report results from the two schemes separately including different caveats in their interpretation. Moreover, participants and funders of each scheme will continue to be interested in the separate results. We recommend using the joint trends for assessing population change for statutory purposes, where a single figure is needed to assess whether changes in populations have reached a critical threshold, e.g. as is used in red-listing. This would avoid the problem of different assessments depending on which scheme results are used.

A second important finding is that by combining datasets, we were able to increase the precision of estimated trends when using the maximum likelihood estimate of estimating error for BBS, and hence more species show significant changes in numbers than as measured by the individual schemes. This is exemplified by the significant decline of 28% for mountain hare using the joint trend compared to similar but non-significant declines in each of the two schemes. However, when using the bootstrapping approach for BBS, the joint trend was no longer significant even though the estimated decline was slightly steeper. For rabbit, a species with a particularly large BBS sample size, bootstrapping increased the width of the confidence intervals but both methods of estimating error revealed a significant decline for BBS trends and in the joint trends, the latter strongly influenced by the BBS data. Producing joint trends did not result in any change in conservation status for brown hare, fox or fallow deer, all of which showed no statistically significant change between 1995 and 2009. Grey squirrels increased significantly in both schemes and when combined in a joint trend. For the three other deer species, NGC trends were positive but not significant, whereas BBS and joint trends were positive and significant. Using the bootstrapping approach to estimate confidence in these species, may make those increases non-significant, especially given the relatively small samples of red deer and muntjac.

All of the above raises the question of which method of estimating error is most suitable, especially given its influence on the joint trend and particularly on the error in the joint trend and hence the significance of the observed change. Bootstrapping is a more conservative approach but might lead to failure to detect important changes in abundance of these species. The GWCT uses a site-based bootstrapping approach to estimate confidence intervals for trends in the National Gamebag Census because of the potential problem of serial correlation (non-independence) of bags in consecutive years. This problem may be more critical to the NGC where keeper behaviour could be as important a factor as numbers of animals present. The BBS is a sampling survey with only a small proportion of the individual mammals detected, and hence possibly less likely to show serial correlation. Nevertheless, a bootstrapping approach makes fewer assumptions about the distribution of the underlying data. Given the variation in mammal numbers and sampling errors inherent in both BBS and NGC methodologies, we suggest that adopting a bootstrapping approach to error estimation in generation of joint trends would be suitable for determining whether species are in significant decline or not. Clearly, also, there is a need to find out more about the degree of serial correlation inherent in the two monitoring schemes. Given the differences in methodologies and also in patterns of geographical coverage, it will remain important to explore any differences in species trends between the two schemes and what that might reveal about the underlying mechanisms.

Based on these considerations and taking the longest period feasible for joint trends (1995 to 2009), none of the nine mammal species have undergone severe decline of greater than 50%. In the initial calculations, mountain hare was shown to have undergone a significant decline greater than 25%. However, when the bootstrapped BBS estimates of error were used, the estimated decline was slightly steeper but not significant (see Table 5). We would, moreover, urge caution because of the cyclical nature of the fluctuations in mountain hare numbers (Reynolds *et al* 2006). Kinrade *et al* (2010) found no change in distribution over a similar timescale. It is possible that the mountain hare population is currently at the bottom of its cycle, and it is advisable to continue monitoring the abundance of this species for several more years before concluding that the decline is genuine.

4.2 Potential further work

The joint work has thrown up some major differences in the size of the confidence intervals obtained for the BBS and the NGC series, which are related not just to sample size but also to approach (maximum likelihood versus bootstrapping). Further investigation of these approaches and of the degree of serial correlation present in the data from the two schemes is warranted in order to pin down which is the most appropriate for each of the surveys. It would also be useful to investigate in more detail the statistical robustness of the method used to compare BBS and NGC series and then derive a joint trend. For instance, our approach ignored the covariances between annual indices – did it matter, or did it cause bias in the joint trend?

The comparisons in these analyses were undertaken using annual indices from the respective schemes, i.e. where trends were not smoothed but were allowed to exhibit the annual fluctuations inherent in the real populations as well as due to the sampling error in the schemes according to their respective methodologies. It was appropriate to use annual indices to compare scheme results because smoothing induces autocorrelation among the smoothed indices, in violation of the usual assumptions underpinning the statistical tests used for comparison. However, in assessing population change over specified periods (e.g. 10 or 25 years) for conservation purposes, it would be useful to explore the possibility of producing smoothed trends. This would require further resources to explore different approaches, including the combining of smoothed trends with associated errors from the separate schemes, post-hoc smoothing of the joint trend generated through the analyses in this report, or by more complicated modelling using the site-specific data for each scheme.

In addition to the nine species for which temporal trends were compared in this report, the NGC collects bag statistics for 10 other mammal species, namely sika deer, Chinese water deer, wild boar, hedgehog, feral cat, weasel, stoat, polecat, mink, and brown rat. All of these apart from Chinese water deer and wild boar are recorded sufficiently to produce a trend in the National Gamebag Census. However, although occasionally seen and recorded by BBS surveyors, none of these species are counted in sufficient numbers to generate a comparable BBS trend.

Further work would be required to assess the change in occupancy of sites through presence-absence data from the BBS. Provisional BBS presence-absence trends have been generated for hedgehog, stoat, weasel and brown rat (as well as for badger and mole, species not covered by the NGC) but changes in recording methodologies over the early parts of the BBS period make them more difficult to interpret. It could be informative to look at the four species where BBS has presence/absence and NGC has bag data, and to compare both temporal trends and distribution obtained from BBS data to those obtained from NGC data after reducing the latter to presence/absence. Inclusion of the comparison in trends and maps between NGC bags and NGC bags reduced to presence/absence might shed some interesting light on what the BBS presence/absence data mean in terms of abundance. In addition to BTO data, there is also presence/absence data for all six deer species from the British Deer Society. The BDS is interested in moving from reporting presence/absence to abundance on their maps and it would help to calibrate abundance against presence/absence, or at least to determine a threshold of abundance that leads to presence being recorded.

4.3 Reporting spatial patterns of change

The spatial maps produced by these analyses provide a useful visualisation of spatial patterns in abundance and geographical patterns of change. Although utilising the same methods and buffer zone size, for all species compared, the BBS maps were more pixelated than those of the NGC. This may reflect the larger number of sites surveyed annually (ca3,500 annually by BBS and ca900 annually by NGC). It may also reflect the spatial and seasonal differences between the two surveys. Spatially, the BTO sites are limited to 1km^2 whereas this is the minimum size of the NGC sites, some of which exceed 100km^2. Seasonally, the BTO surveys represent two visits in April-July, whereas the NGC data represent multiple visits (shoot days) across the open season (game species) or the whole year ("pest" species). Hence inter-site variation is likely to be higher in the BTO survey than in the NGC one. This, combined with the fact that detection rates for many of the mammal species during BBS surveys were lower than for NGC, resulted in more distinctly evident geographical differentiation on the NGC maps. Without independent data, it is not, however, possible to ascertain which of the two representations better reflects the real situation.

Given the big differences in the methodologies between the two schemes, and the high likelihood that at many sites (particularly BBS) where particular mammal species are not detected, they are actually present, we do not think it advisable to combine data from the two schemes for mapping. This differs from the production and reporting of joint trends because temporal change is essentially assessed by differences between years at the same site (whether BBS or NGC). In contrast, spatial patterns from combining data would be confounded with differences in the measures used (seasonal totals of killed animals versus counts during brief summer visits). Within schemes, BBS surveys are undertaken using a standardised methodology and NGC bag counts are standardised by accounting for estate size, but spatial measures from the two schemes would be difficult to compare, and the relationships are likely to change over time and among species. Further consideration might be given to the approach of using a non-parametric scale and using rankings as a common measure across the schemes. However, transforming these datasets into ordinals is likely to introduce a greater set of problems owing to the distortions that it would introduce.

The most valuable information revealed by the maps is probably the degree of concordance between schemes in geographical patterns, and in broad rather than fine-scale patterns. There are many small-scale differences in both patterns of relative abundance and in change, which are most likely to reflect scheme differences in sampling design, rather than different processes (for example a mismatch in the direction of change in numbers seen by BBS surveyors with numbers of animals in local hunting bags). The methodologies used to generate the maps were informed by the availability, geographical spread and site-specific variation in the separate datasets, and the ideal methodology is likely to vary across species. Nevertheless, the maps, in combination with the population trends, present a remarkable degree of consistency in the picture of changes in the population status of the mammal species that are common to both BBS and NGC.

4.4 Summary of recommendations for future reporting

(i) Investigate the statistical issues that this work has raised in order to identify the best approaches for index error estimation, trend comparison between BBS and NGC, trend smoothing, calibration of presence/absence and the production of joint BBS/NGC maps.

(ii) Continue to use the data collected from the BBS and NGC schemes, respectively, to annually generate national population trends for each of the species covered sufficiently by the schemes.

(iii) Periodically undertake analyses using the approach described in this report, to generate joint trends with confidence intervals for the nine species investigated in this report, and incorporate a smoothing process. Use changes in these trends over specified time periods to assess whether each species has experienced significant changes in abundance. Changes over particular periods (e.g. 10 years or three generation times) could be one of the criteria for red-listing but changes over other periods could also be used to assess the impact of other drivers or policies. This would require a very small amount of resources and it is probably sufficient to undertake these analyses every three years.

(iv) Periodically undertake the spatial mapping analyses to investigate geographical patterns of changes in abundance. These can be used to inform results from the trends analysis and could be focused on species of conservation concern. Given the approach in this report of combining data over five year periods, we would recommend updating these analyses every five years.

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6 Appendices

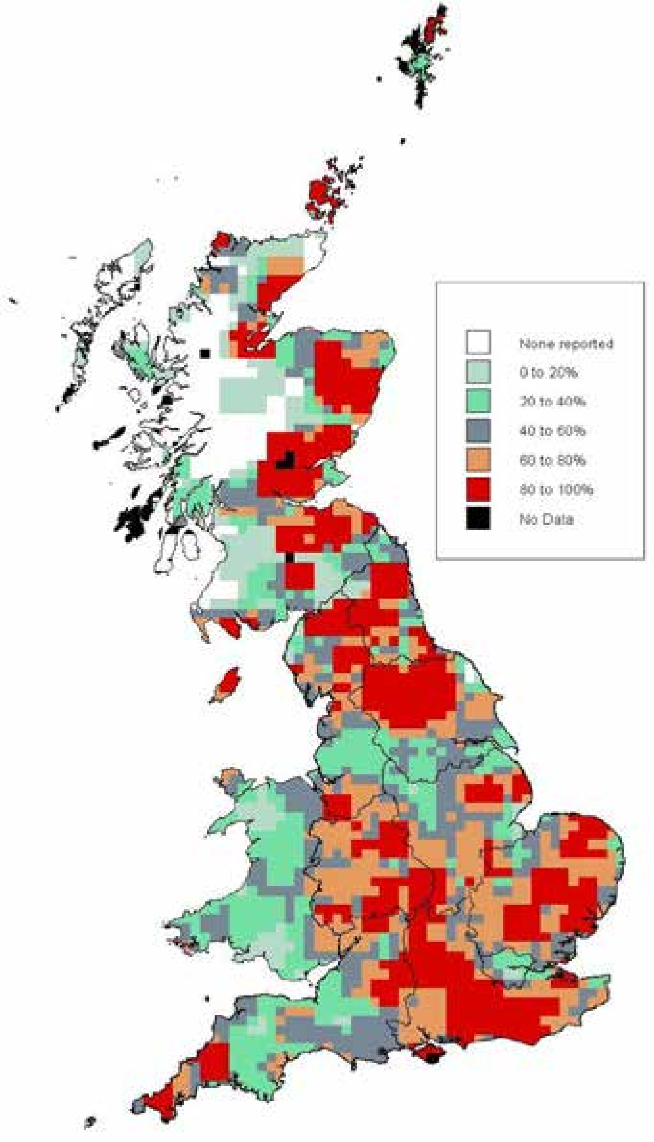
Appendix 1(a) Spatial maps of relative abundance based on BBS and on NGC data for 13 species (rabbit, brown hare, mountain hare, grey squirrel, fox, red deer, fallow deer, roe deer, muntjac, hedgehog, stoat, weasel & brown rat) in each of two periods (1995-99 & 2005-09) and map showing change in relative abundance between these two periods. See methods for a description of methods.

Appendix 1(b) Spatial maps of relative abundance based on BBS data (only) for one species badger in each of two periods (1995-99 & 2005-09) and map showing change in relative abundance between these two periods.

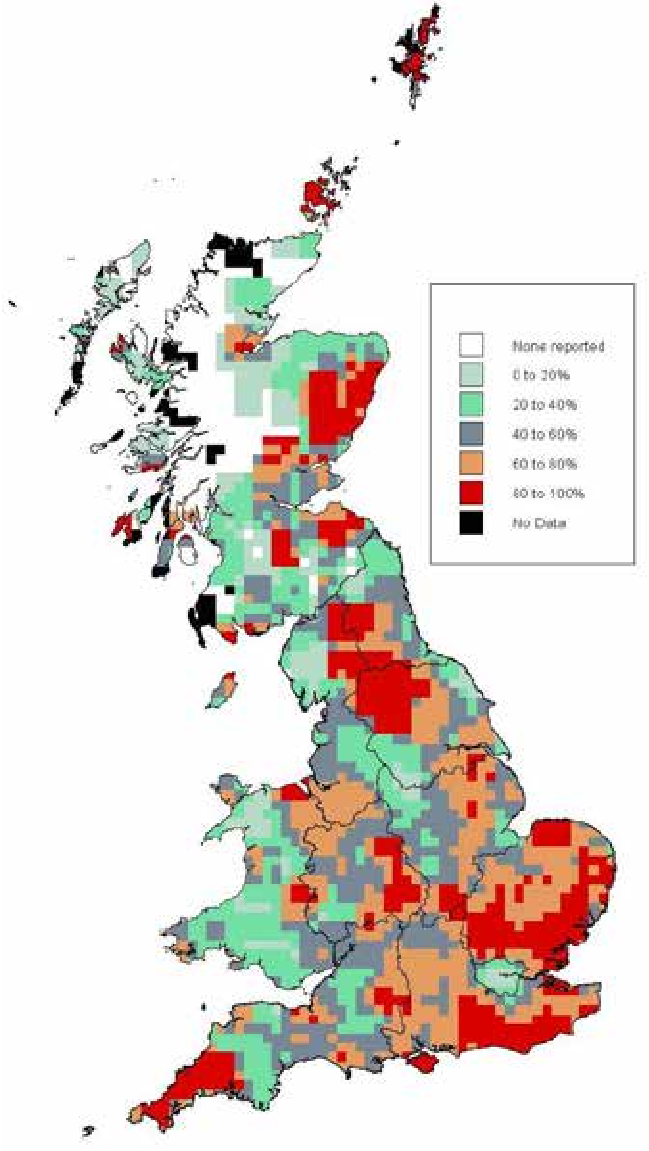
Appendix 1(c) Spatial maps of relative abundance based on NGC data (only) for four species (polecat, feral cat, sika deer & American mink) in each of two periods (1995-99 & 2005-09) and map showing change in abundance between these two periods.

Appendix 1 (a) Spatial maps of relative abundance based on BBS and on NGC data for 13 species (Rabbit, Brown Hare, Mountain Hare, Grey Squirrel, Fox, Red Deer, Fallow Deer, Roe Deer, Muntjac, Hedgehog, Stoat, Weasel & Brown Rat) in each of two periods (1995-99 & 2005-09) and map showing change in relative abundance between these two periods. See methods for a description of methods.

Rabbit BBS 1995-1999



Rabbit BBS 2005-2009



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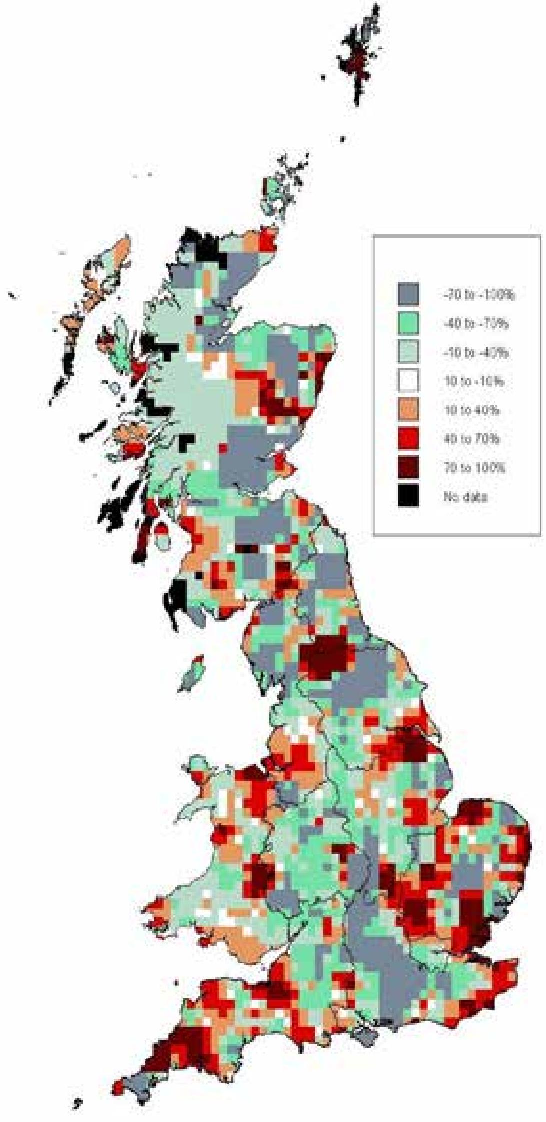

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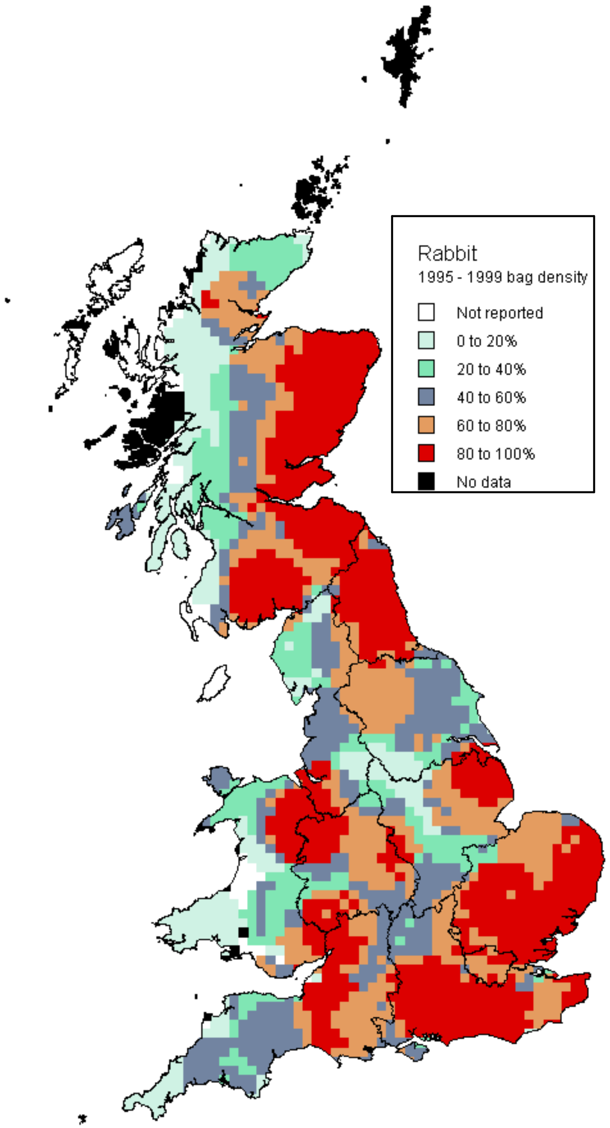
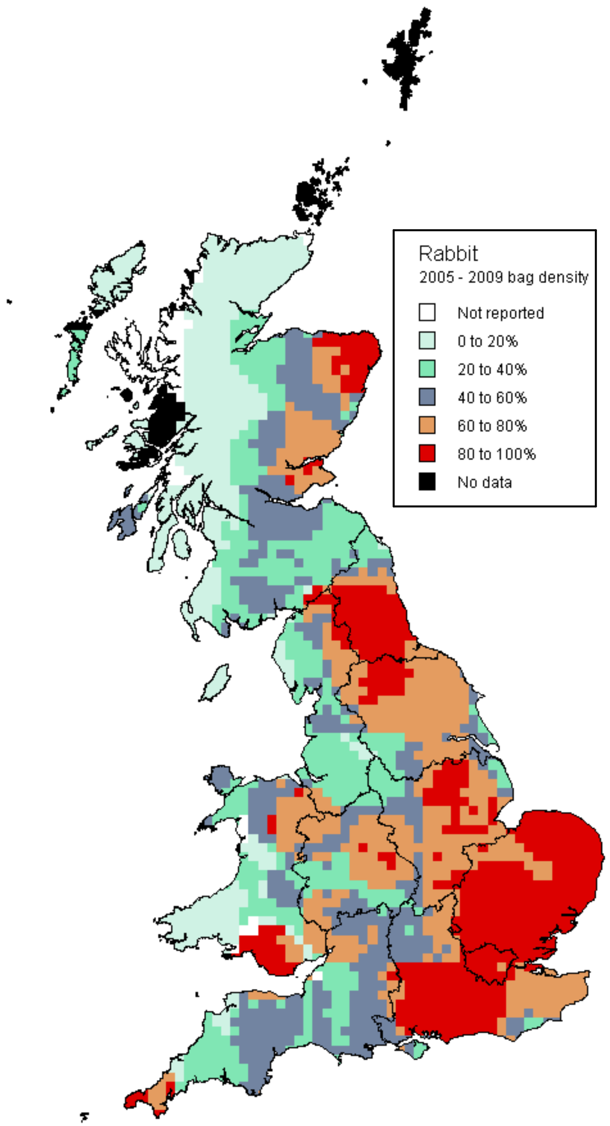


Rabbit NGC 2005-2009



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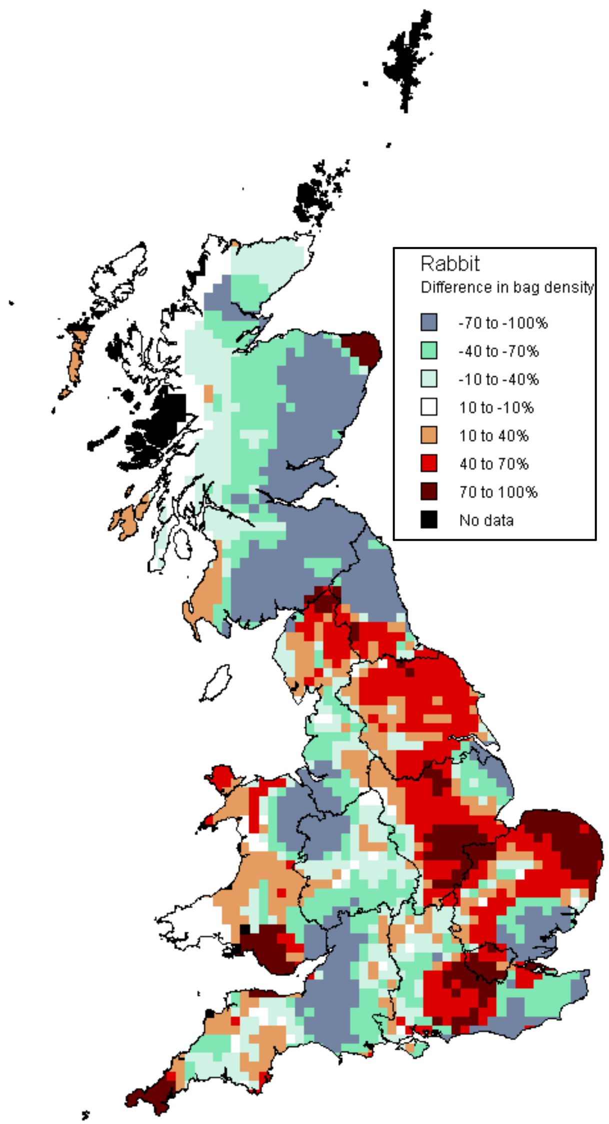
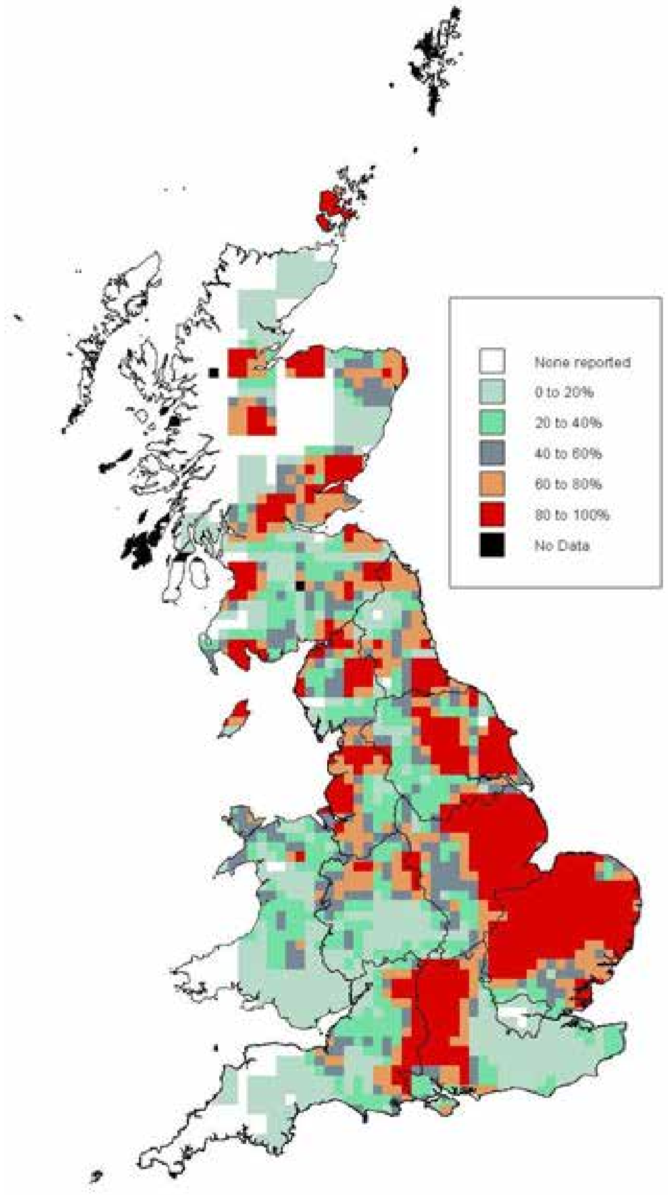
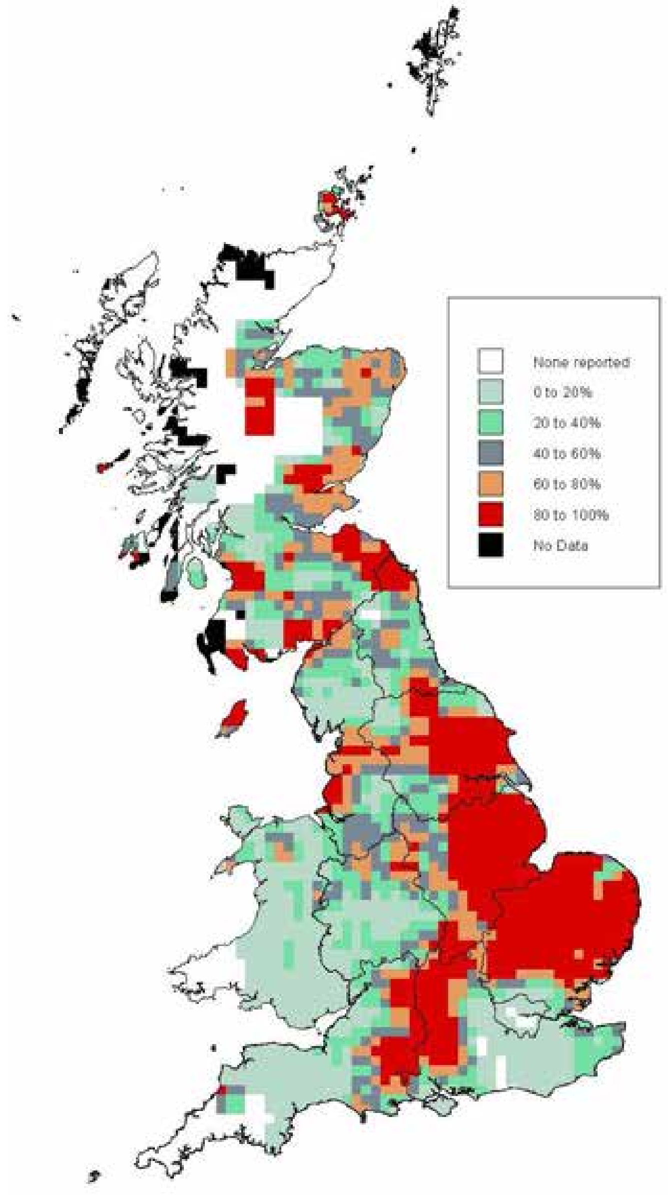


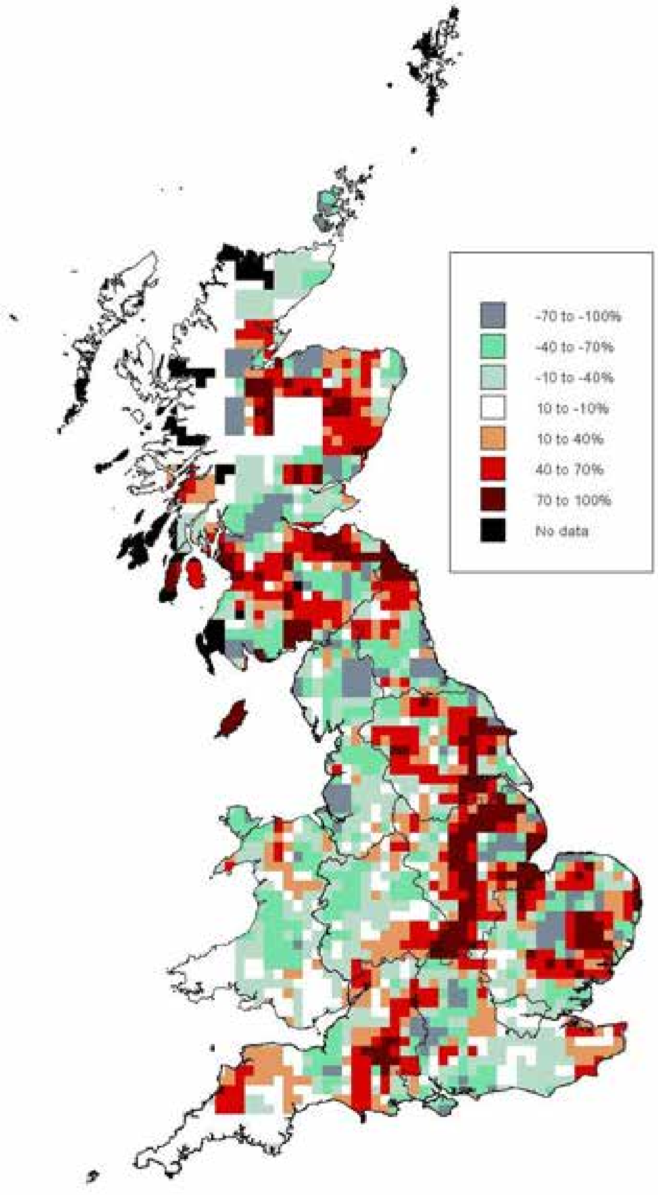
Brown Hare BBS 1995-1999



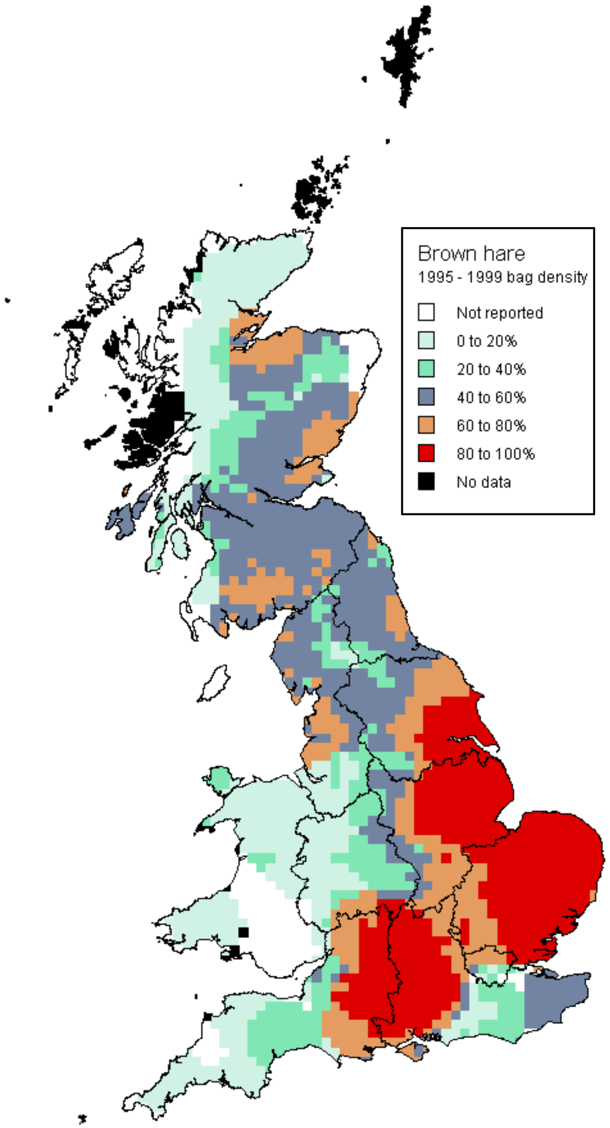
Brown Hare BBS 2005-2009



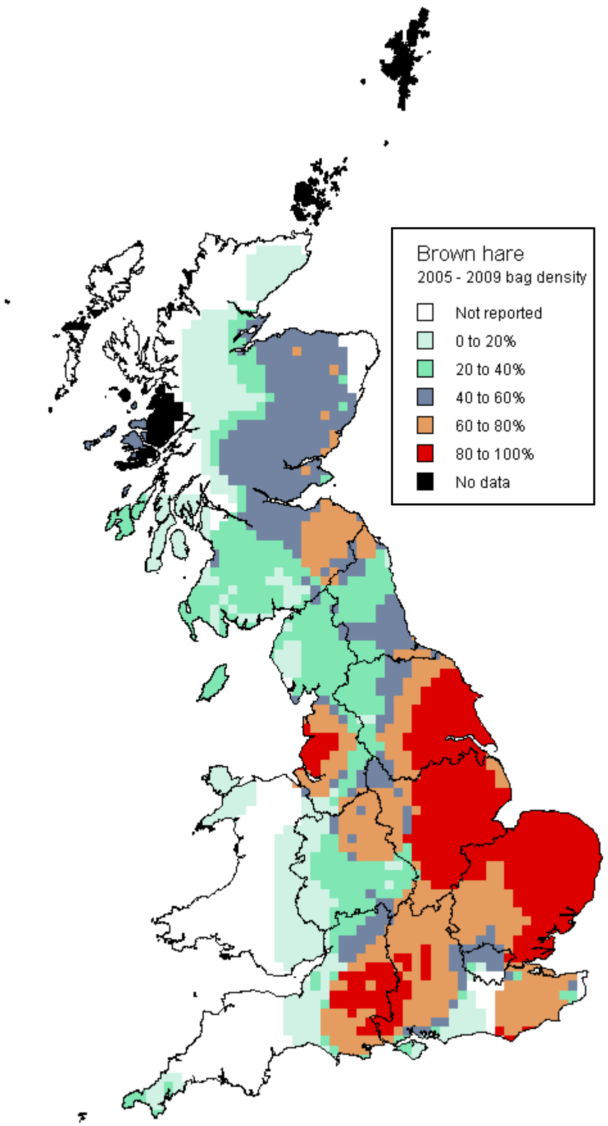
Brown Hare BBS Change



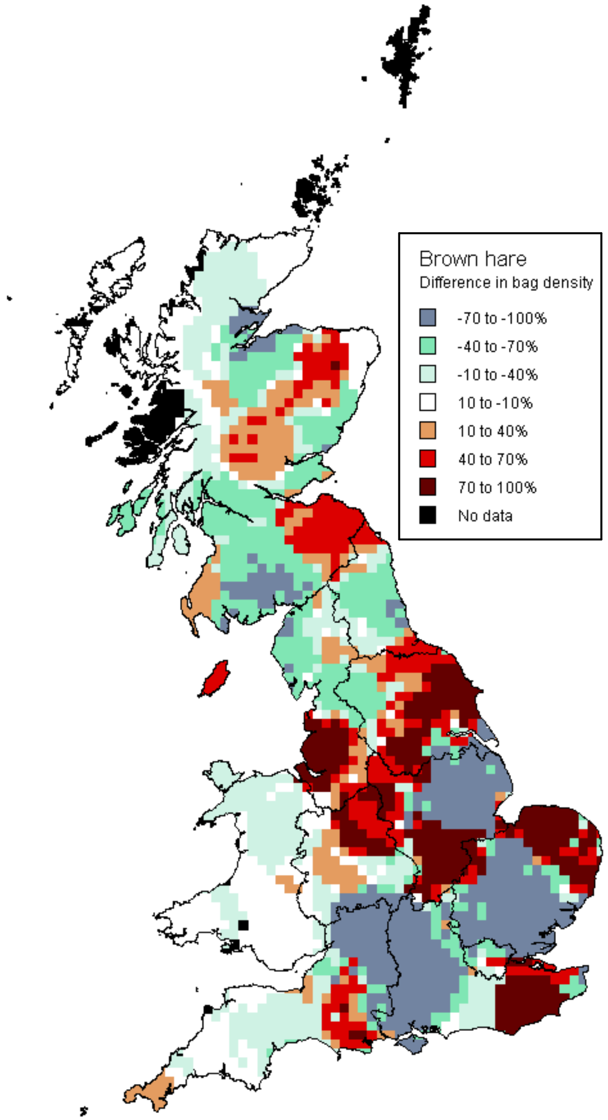
Brown Hare NGC 1995-1999



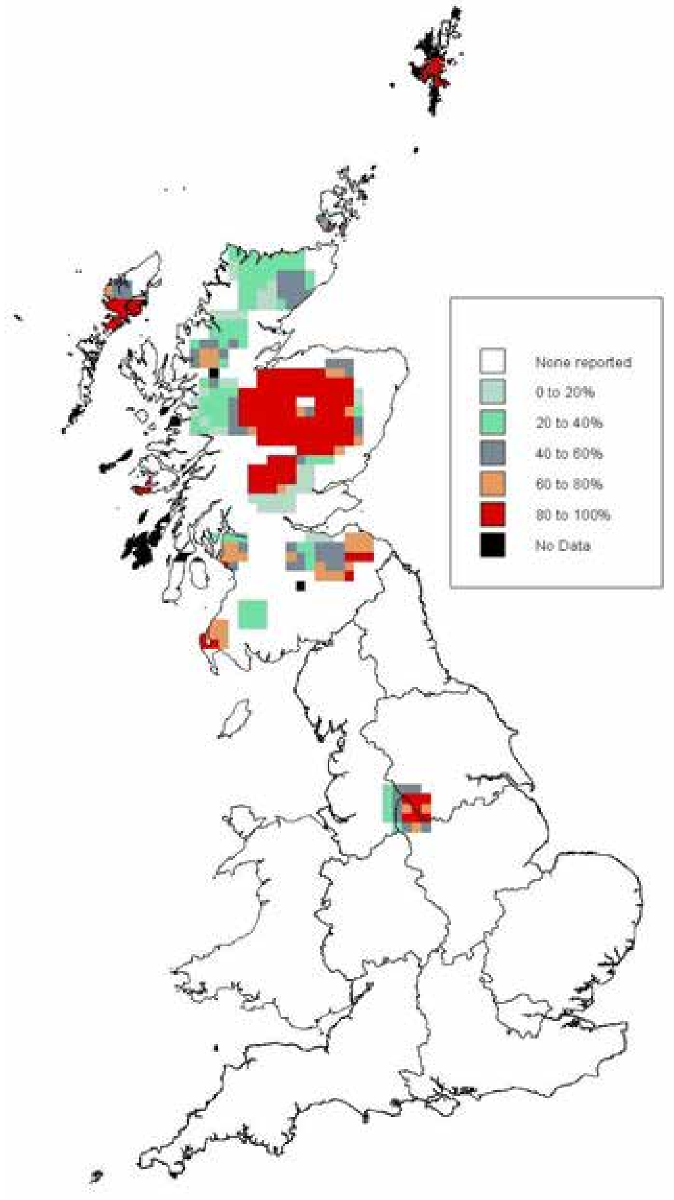
Brown Hare NGC 2005-2009



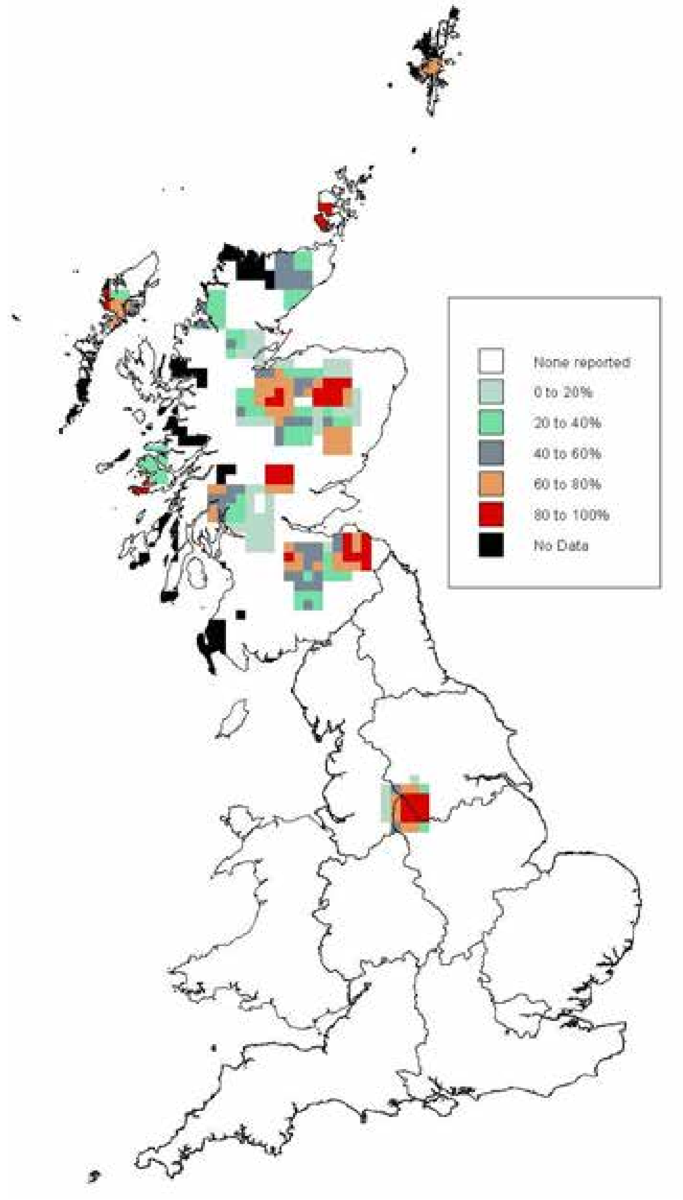
Brown Hare NGC Change



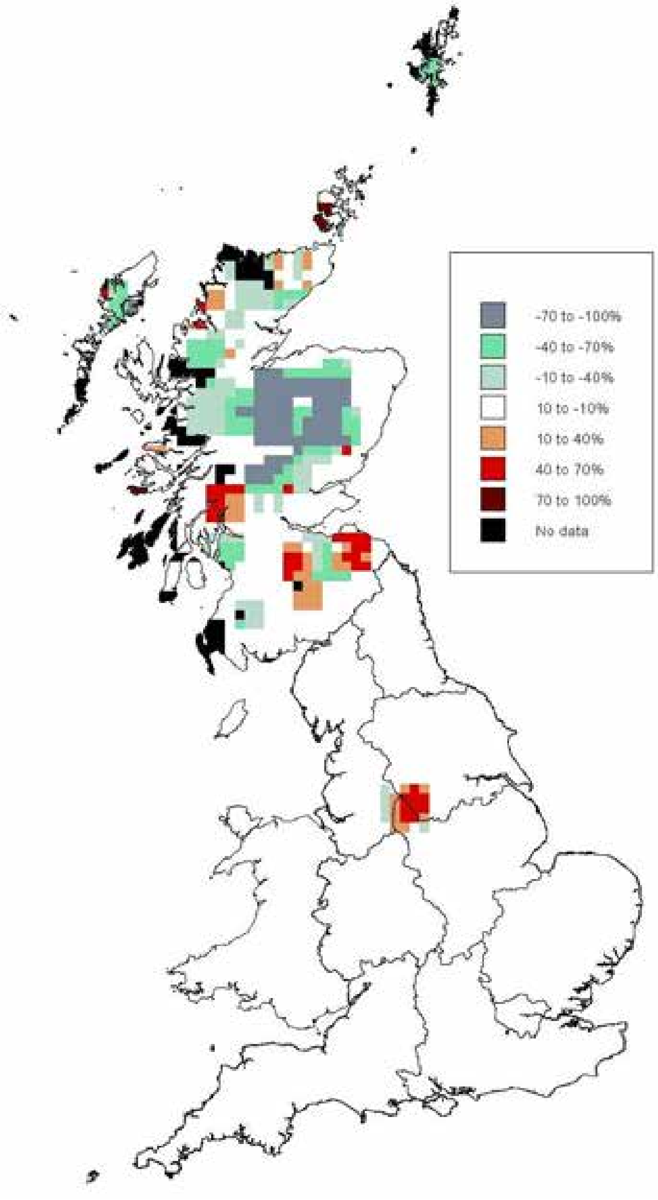
Mountain Hare BBS 1995-1999



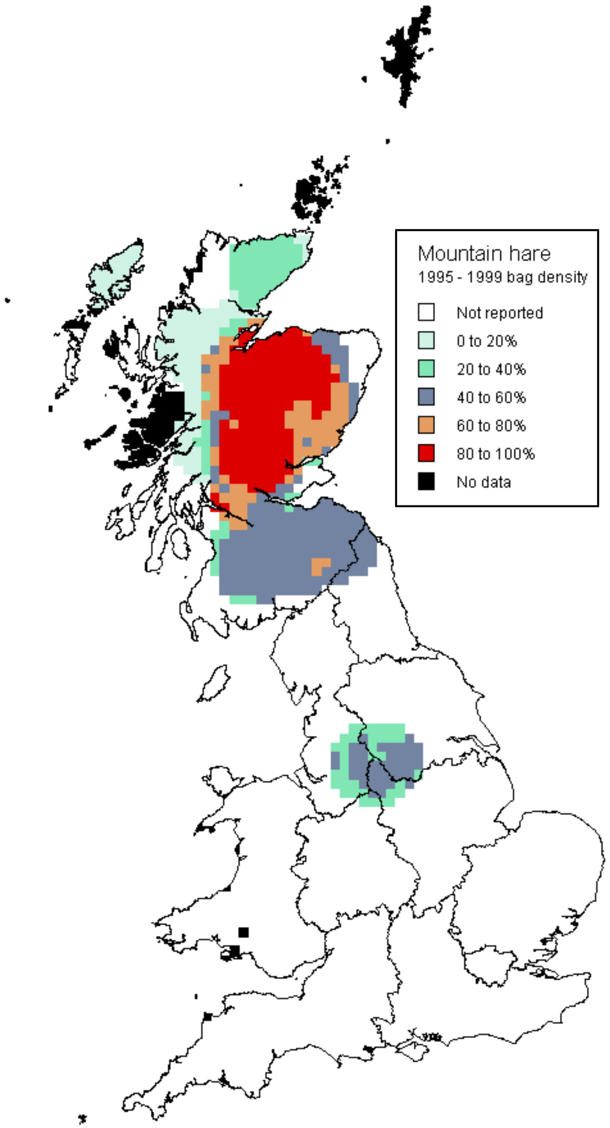
Mountain Hare BBS 2005-2009



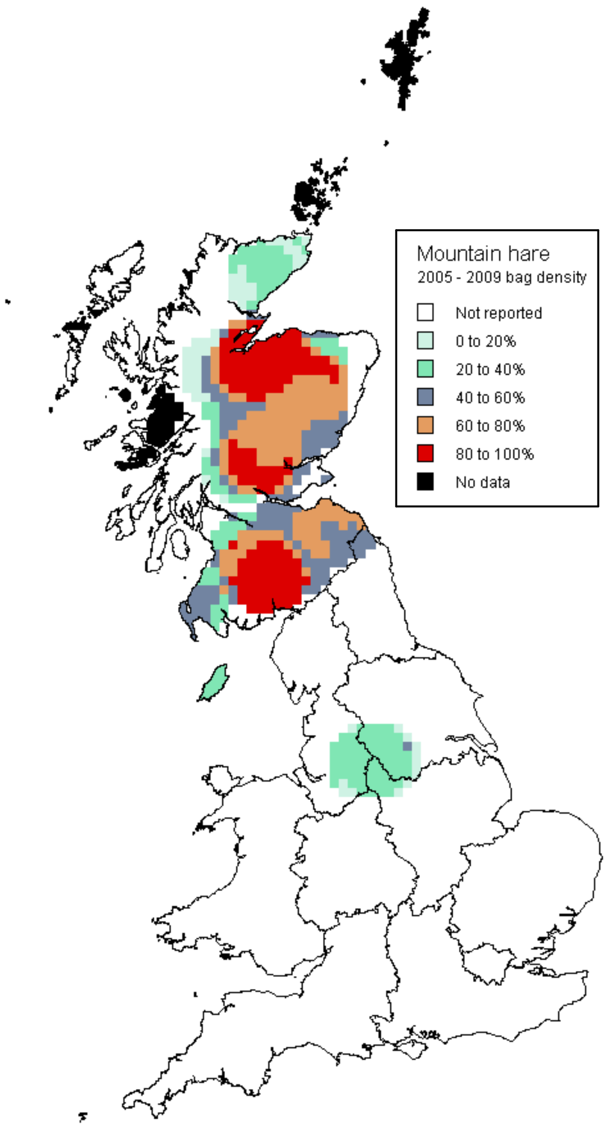
Mountain Hare BBS Change



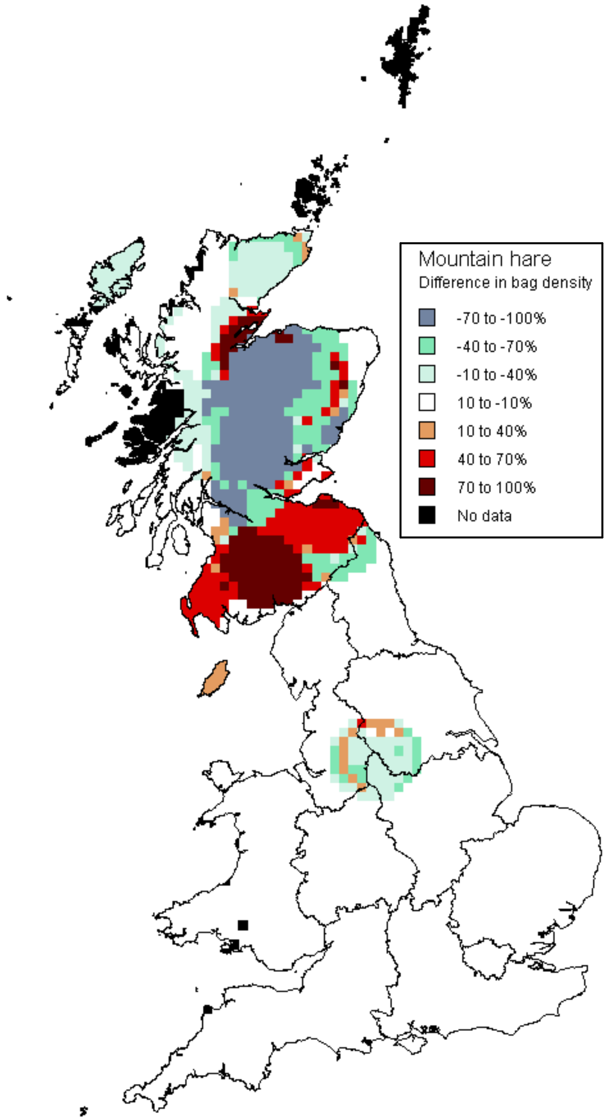
Mountain Hare NGC 1995-1999



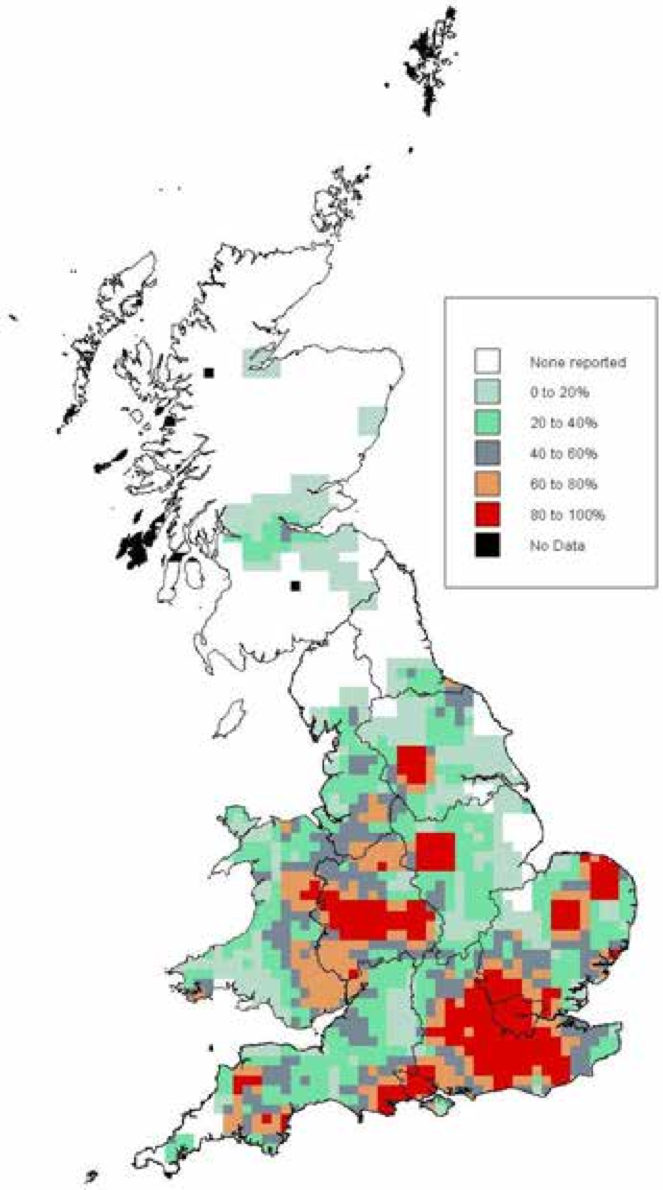
Mountain Hare NGC 2005-2009



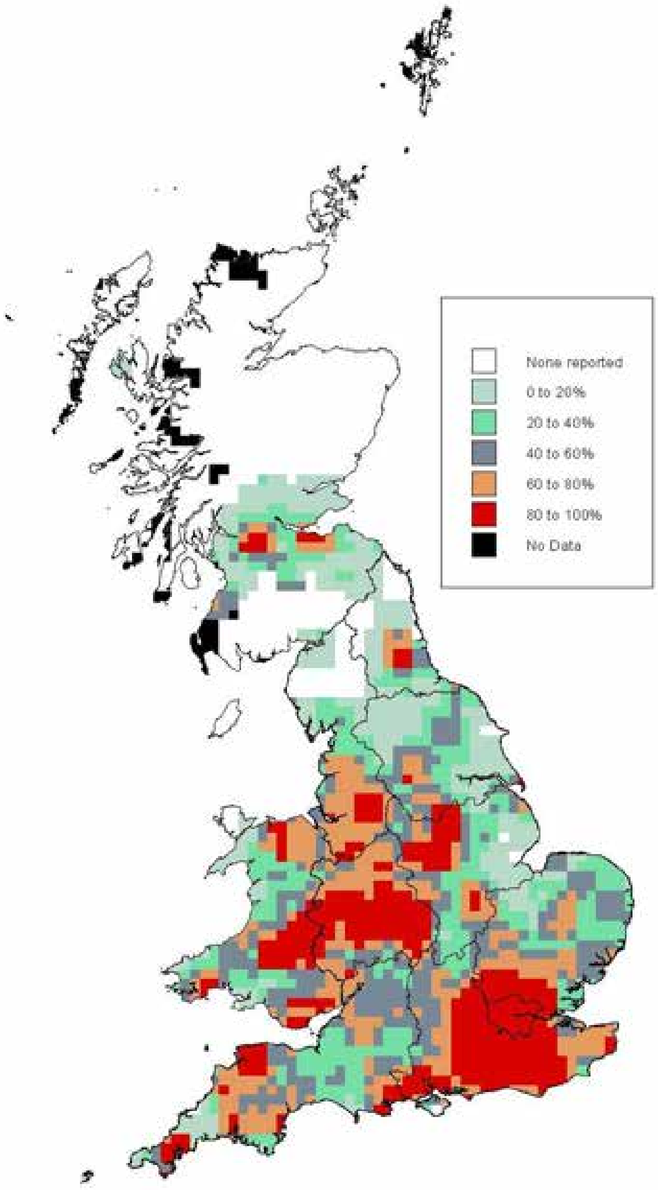
Mountain Hare NGC Change



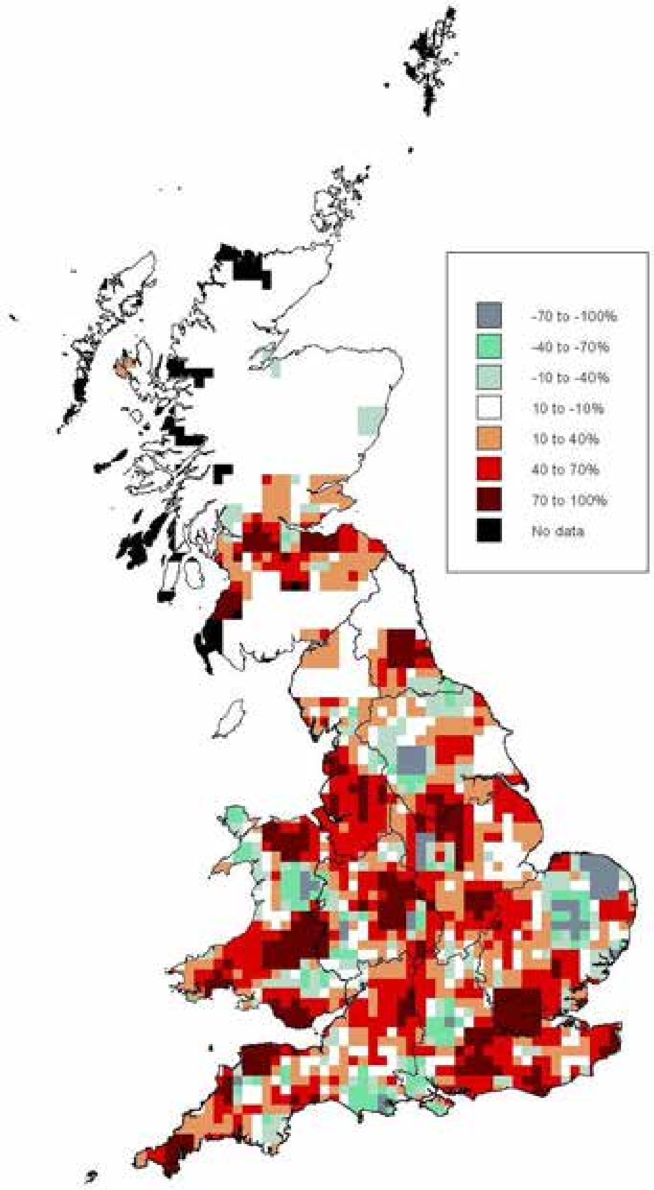
Grey Squirrel BBS 1995-1999



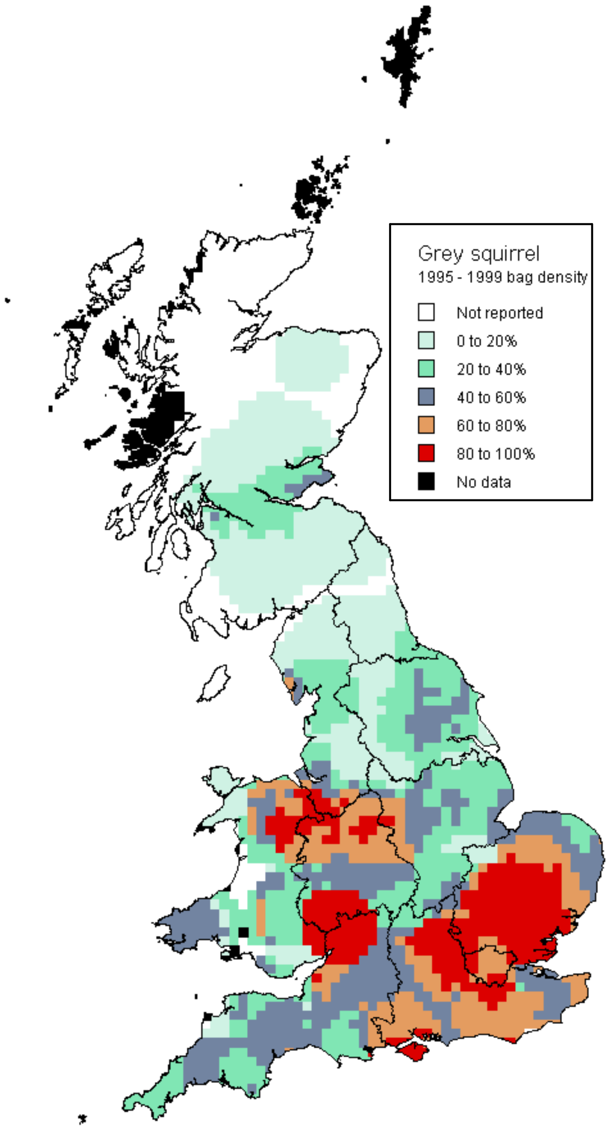
Grey Squirrel BBS 2005-2009



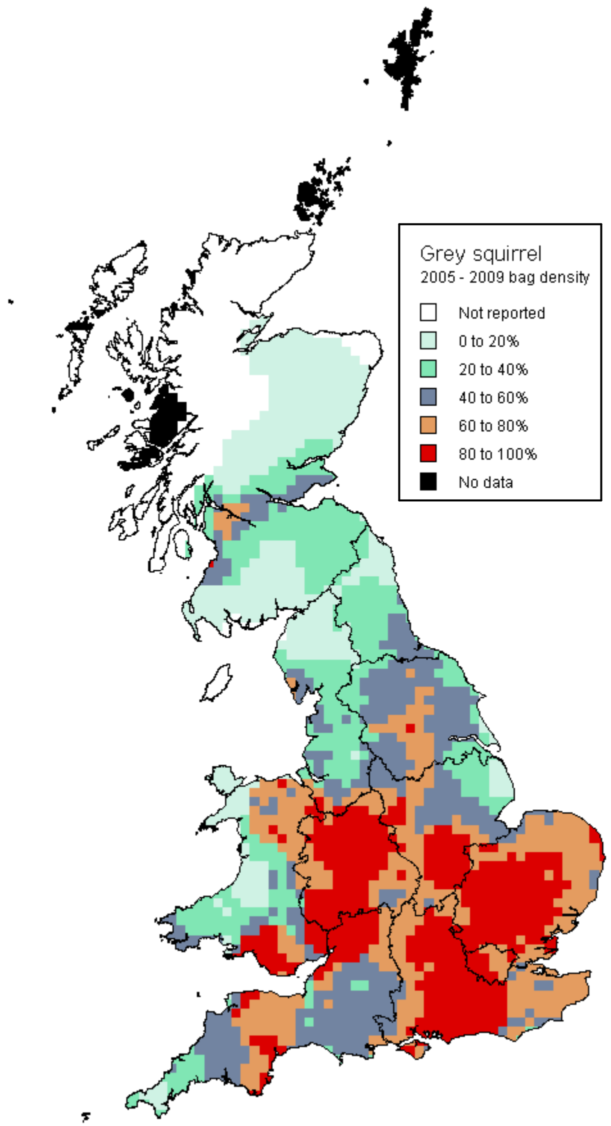
Grey Squirrel BBS Change



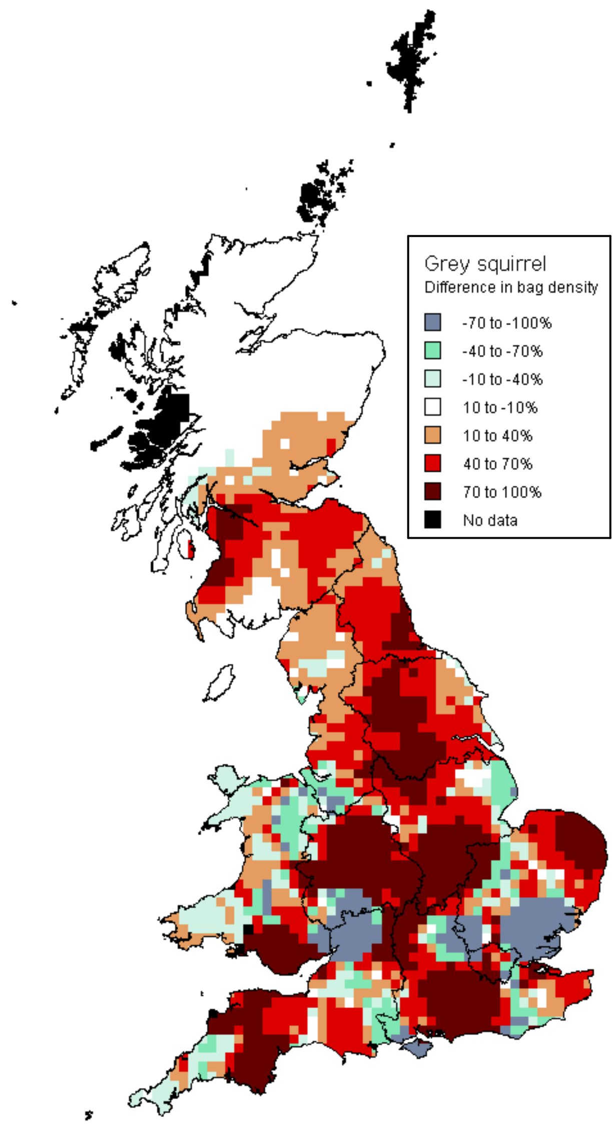
Grey Squirrel NGC 1995-1999



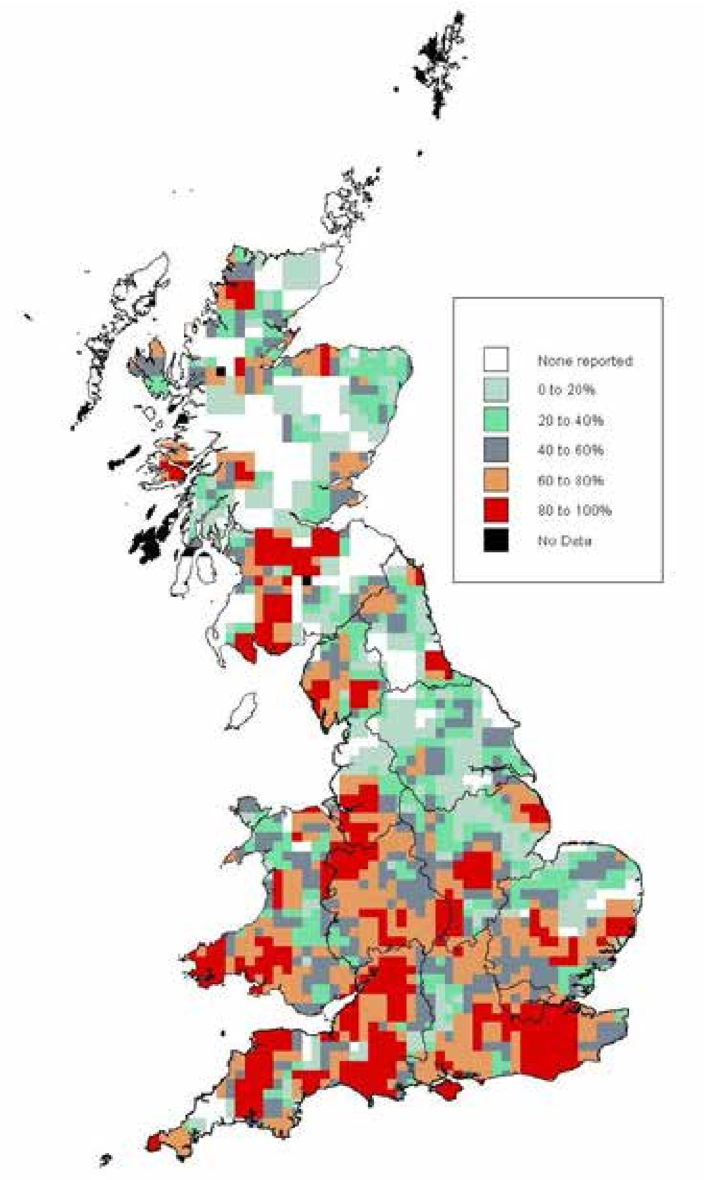
Grey Squirrel NGC 2005-2009



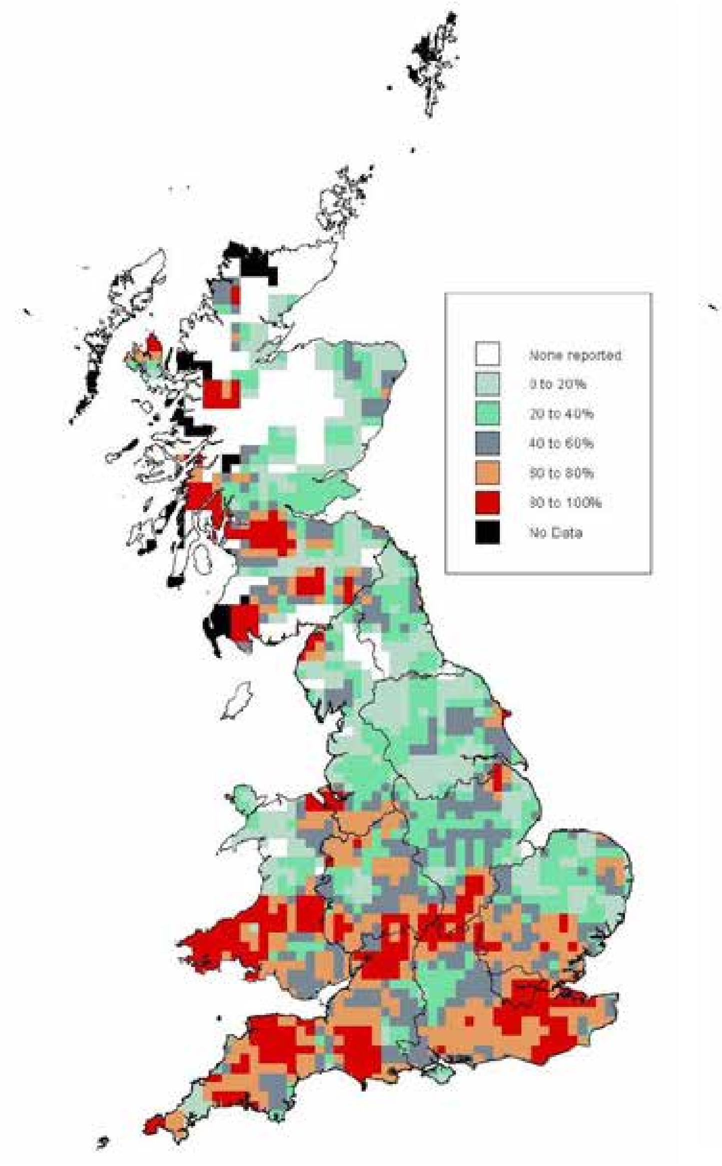
Grey Squirrel NGC Change



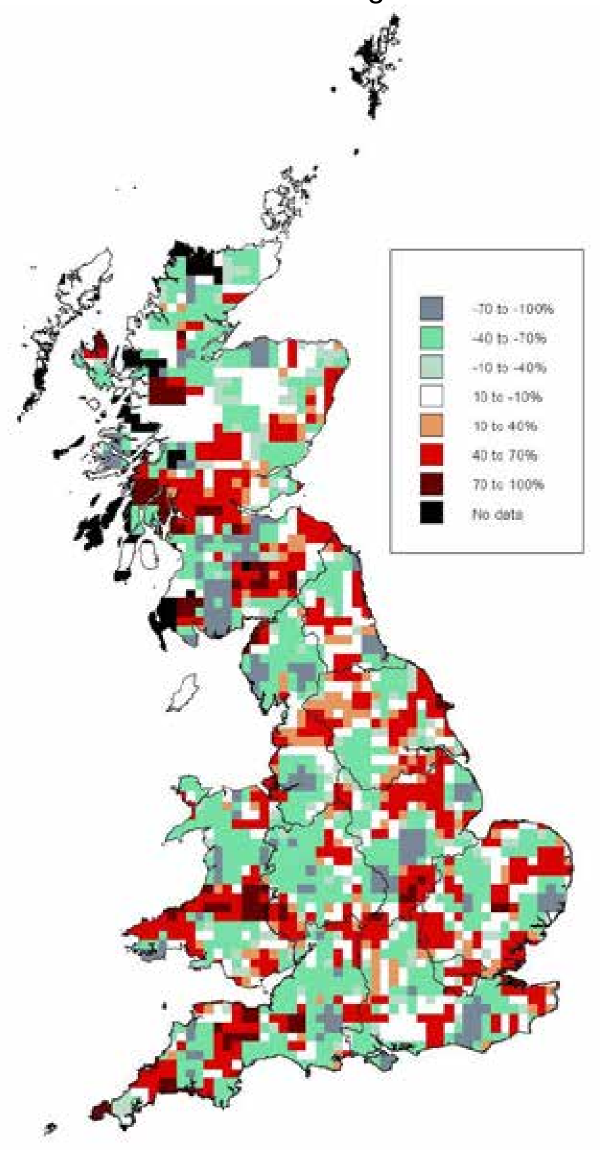
Fox BBS 1995-1999



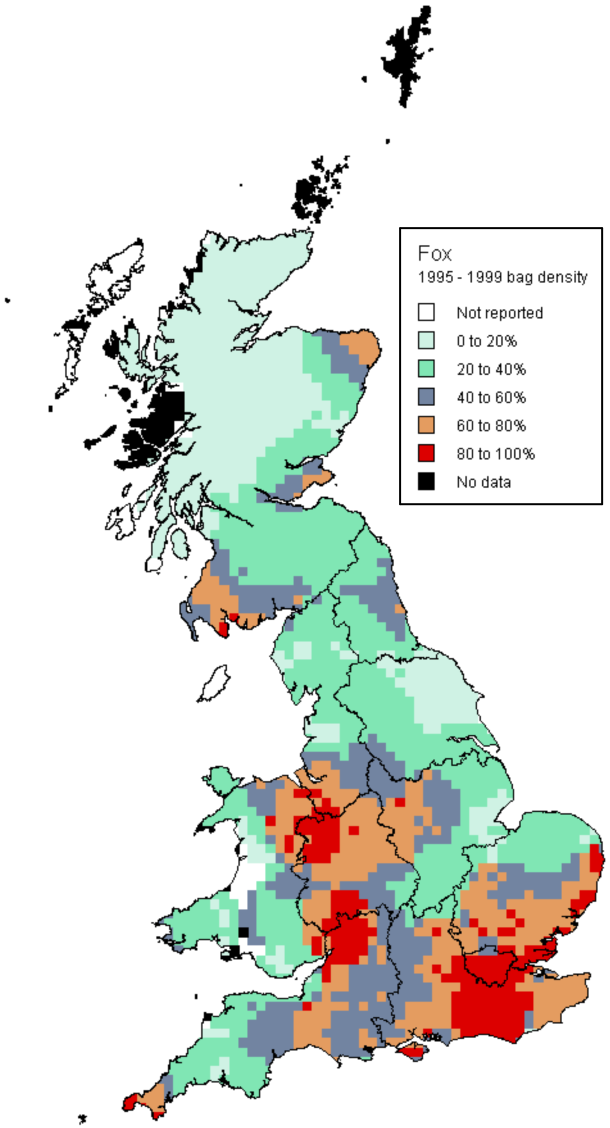
Fox BBS 2005-2009



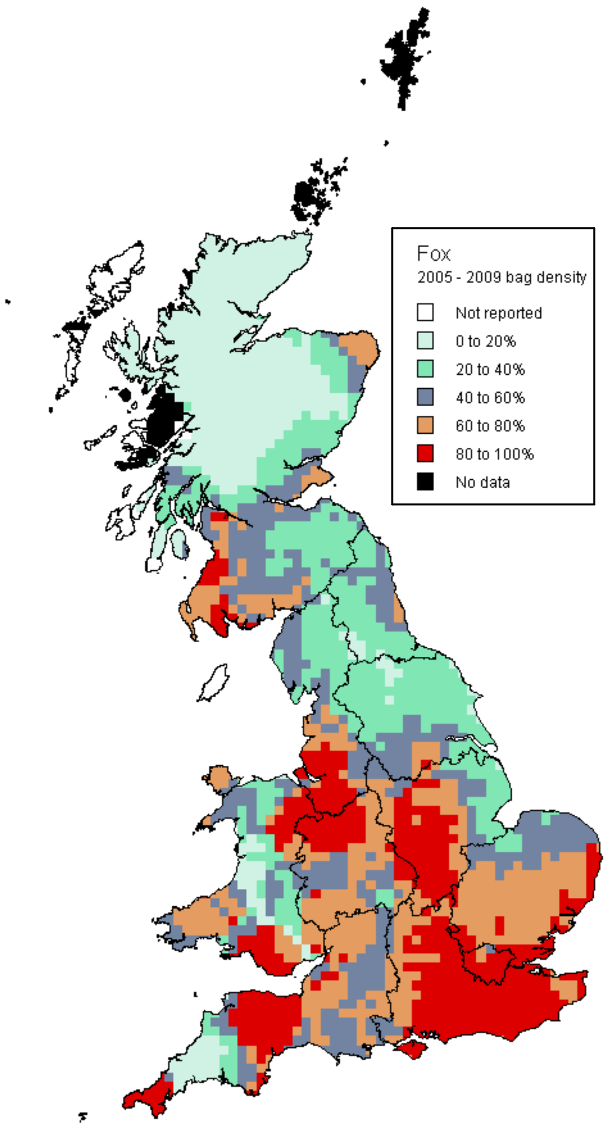
Fox BBS Change



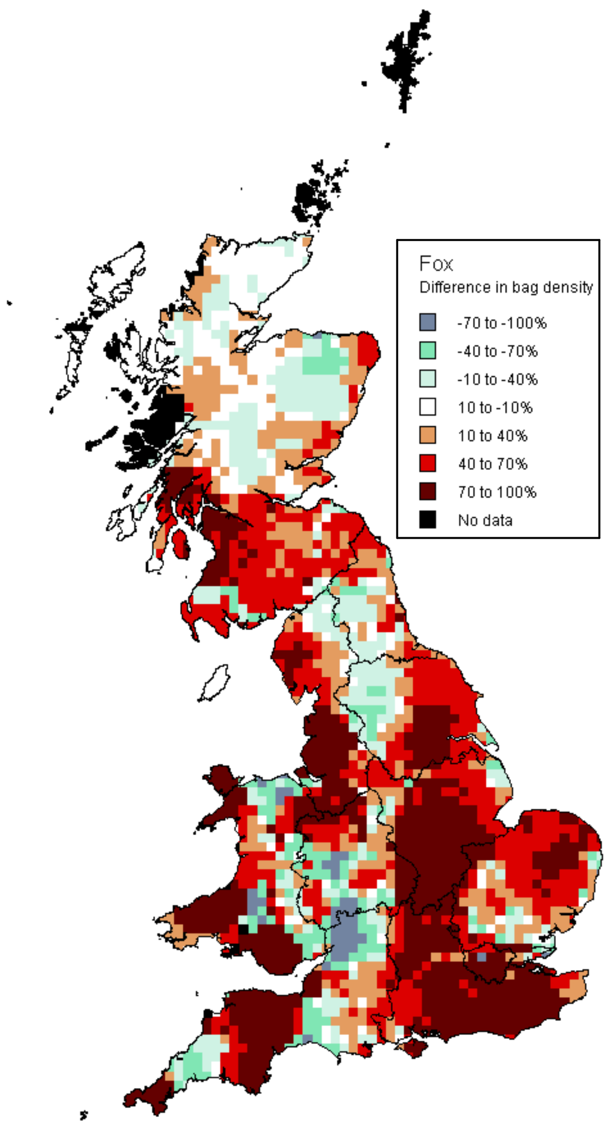
Fox NGC 1995-1999



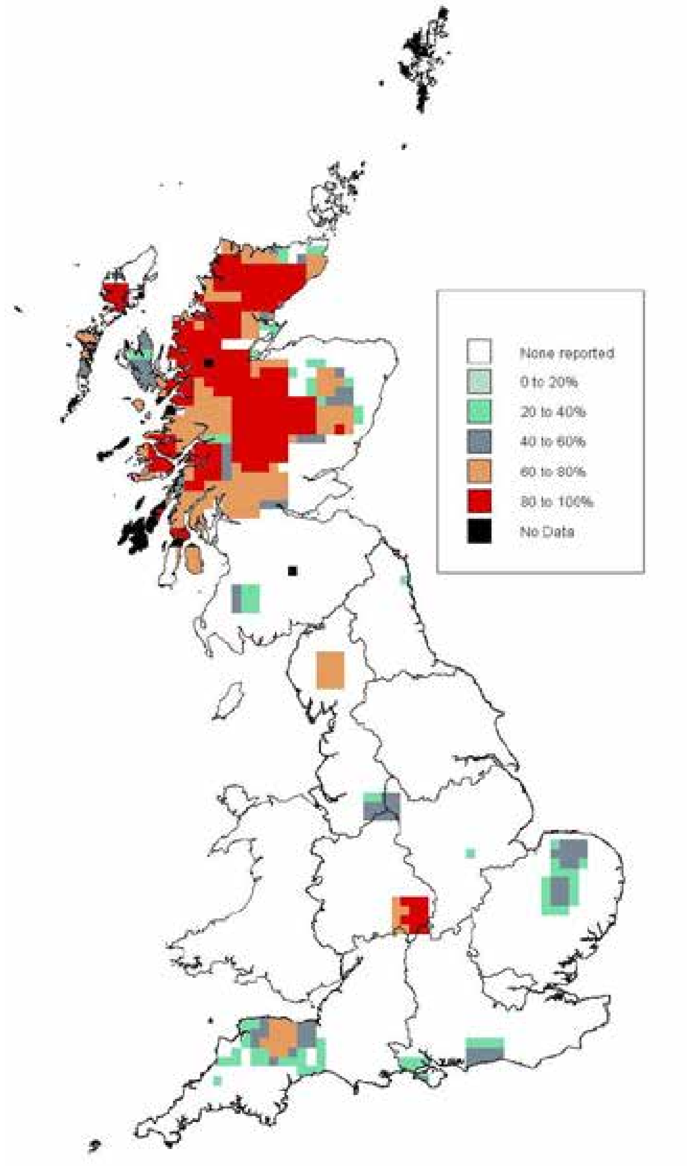
Fox NGC 2005-2009



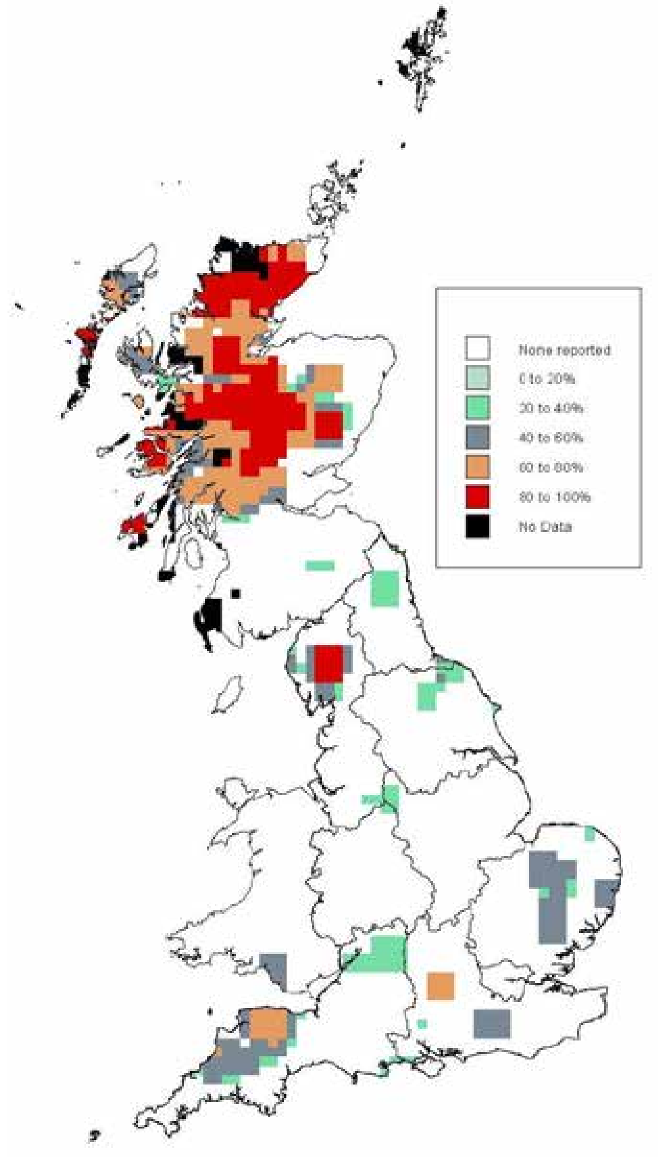
Fox NGC Change



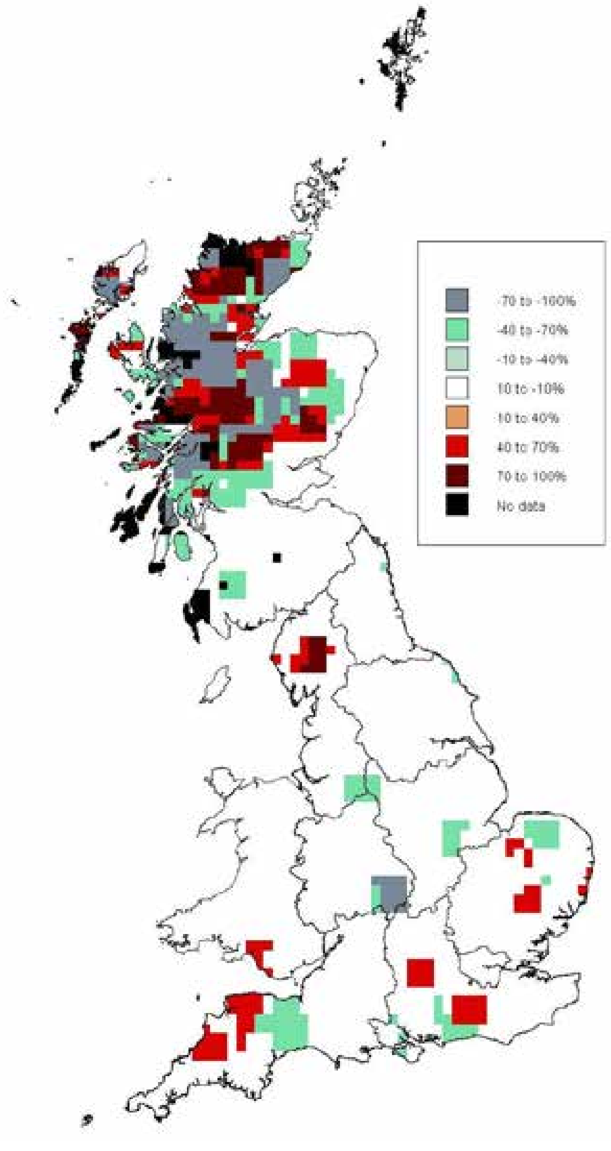
Red Deer BBS 1995-1999



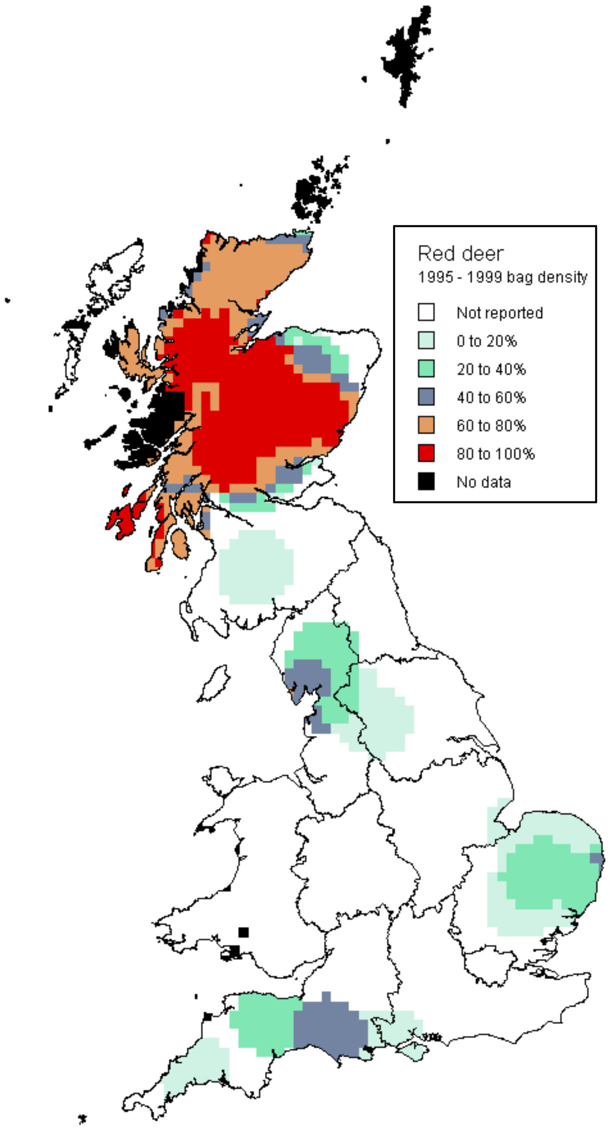
Red Deer BBS 2005-2009



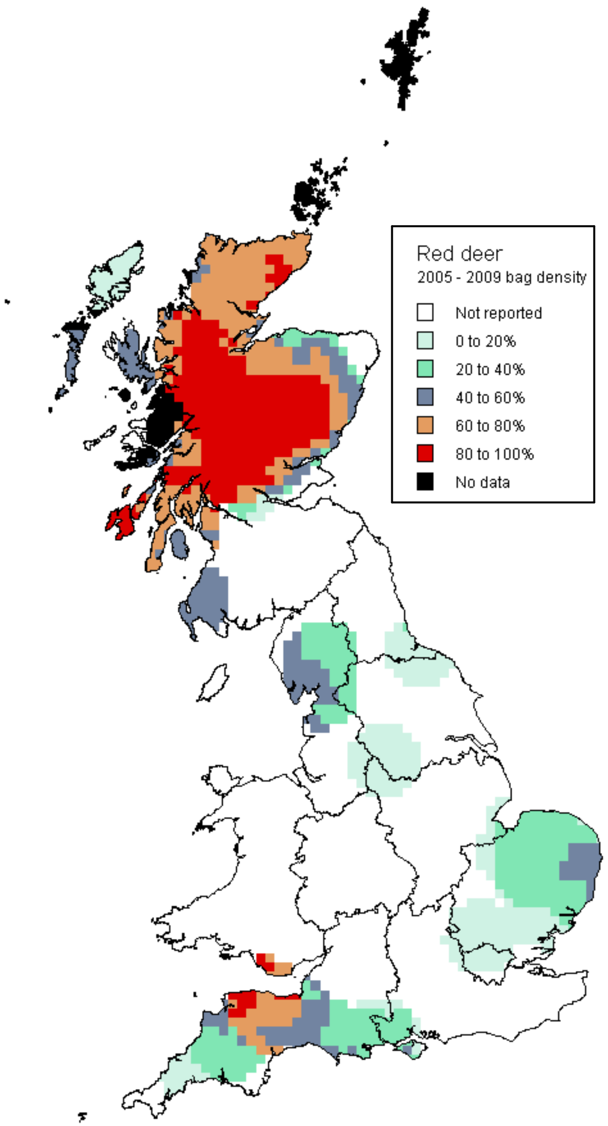
Red Deer BBS Change



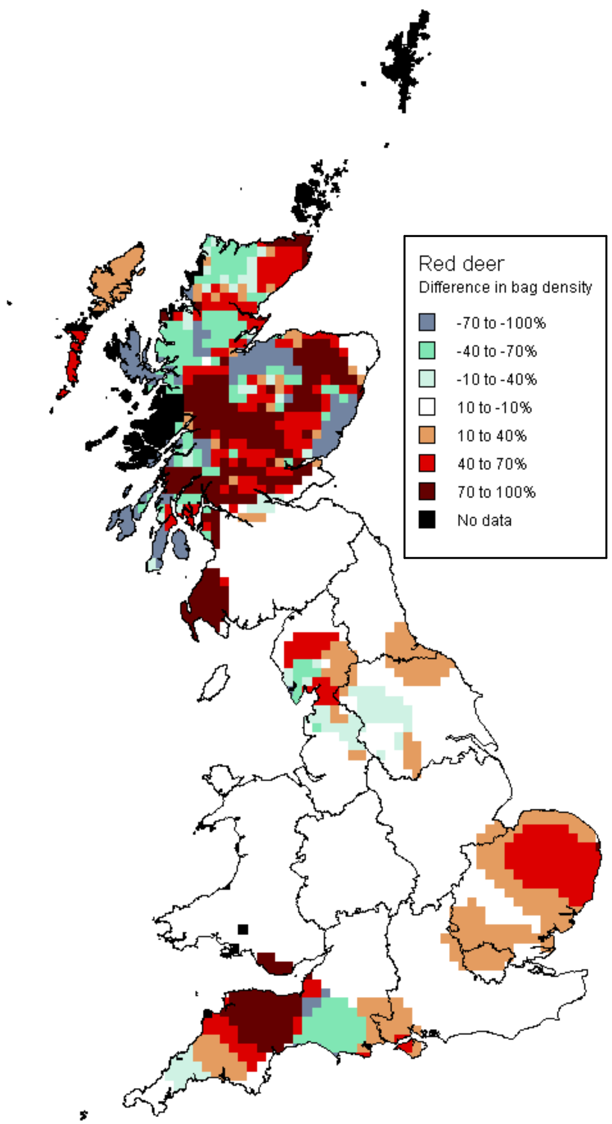
Red Deer NGC 1995-1999



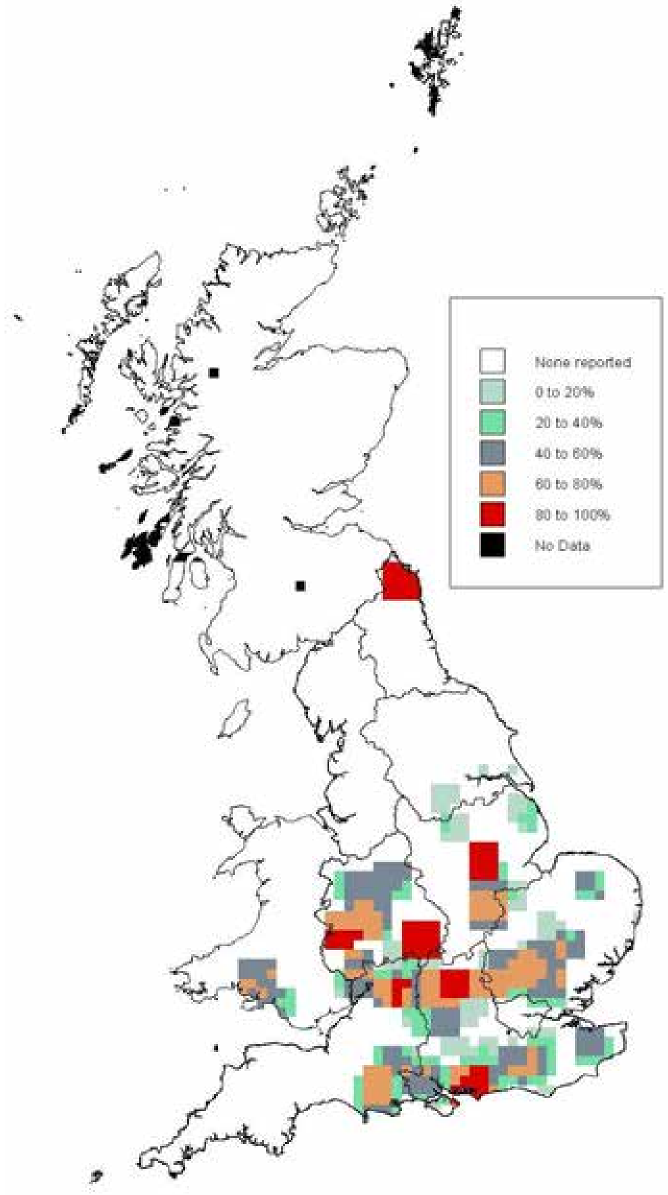
Red Deer NGC 2005-2009



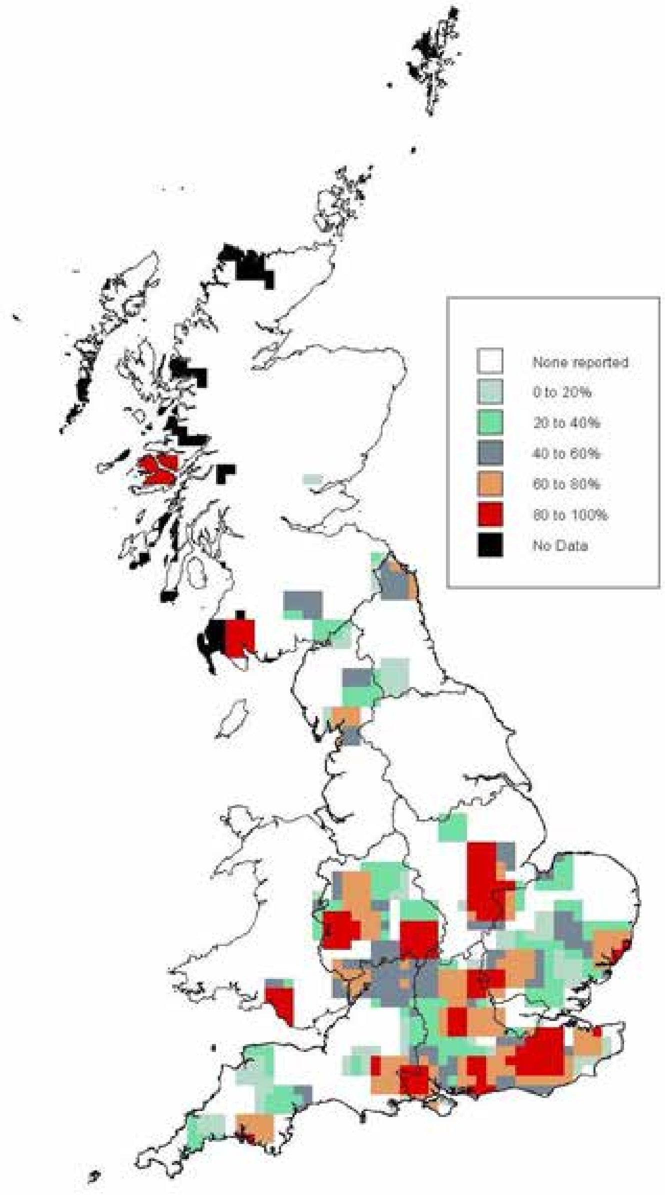
Red Deer NGC Change



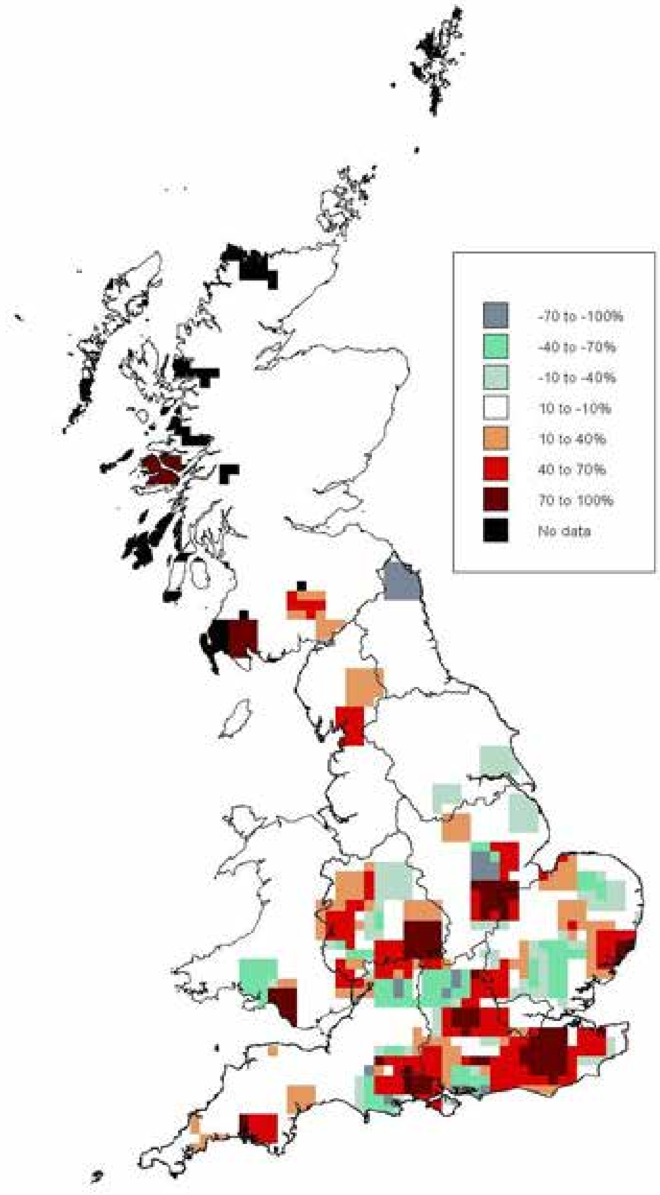
Fallow Deer BBS 1995-1999



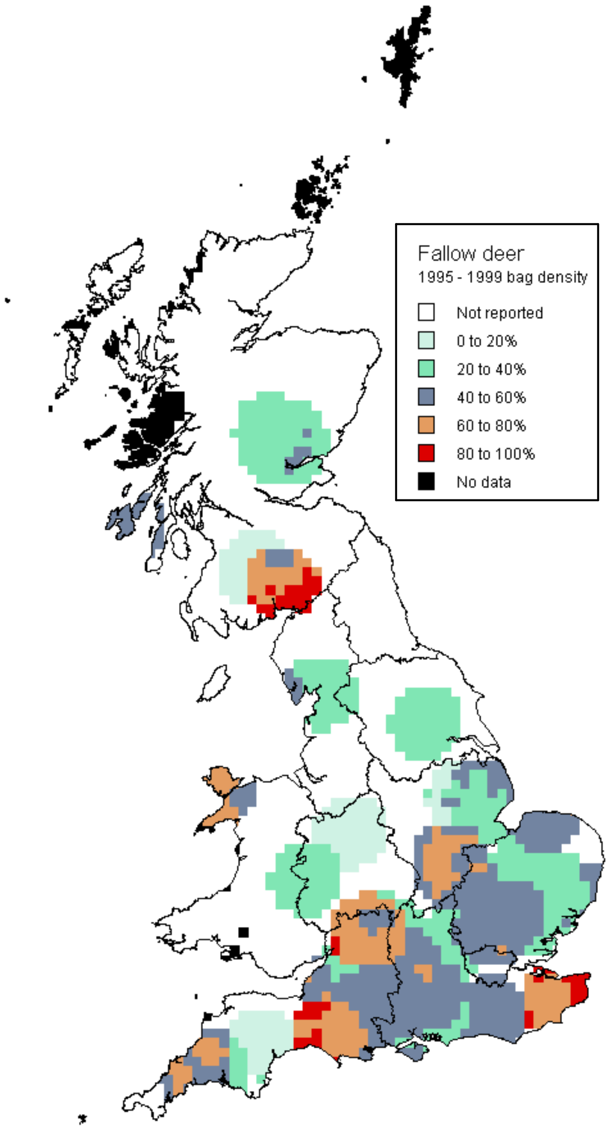
Fallow Deer BBS 2005-2009



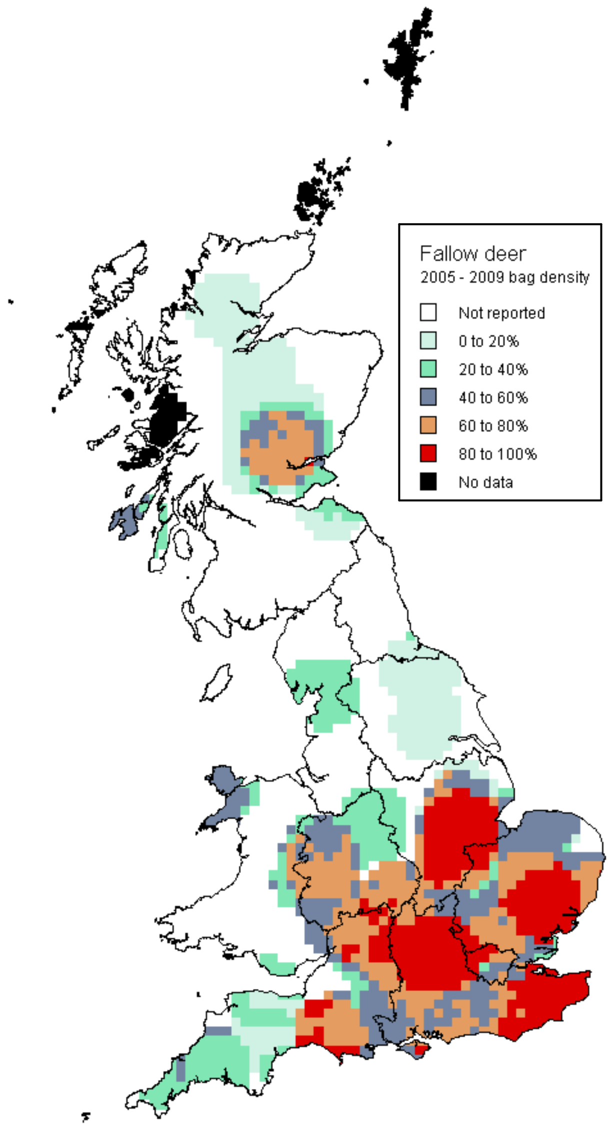
Fallow Deer BBS Change



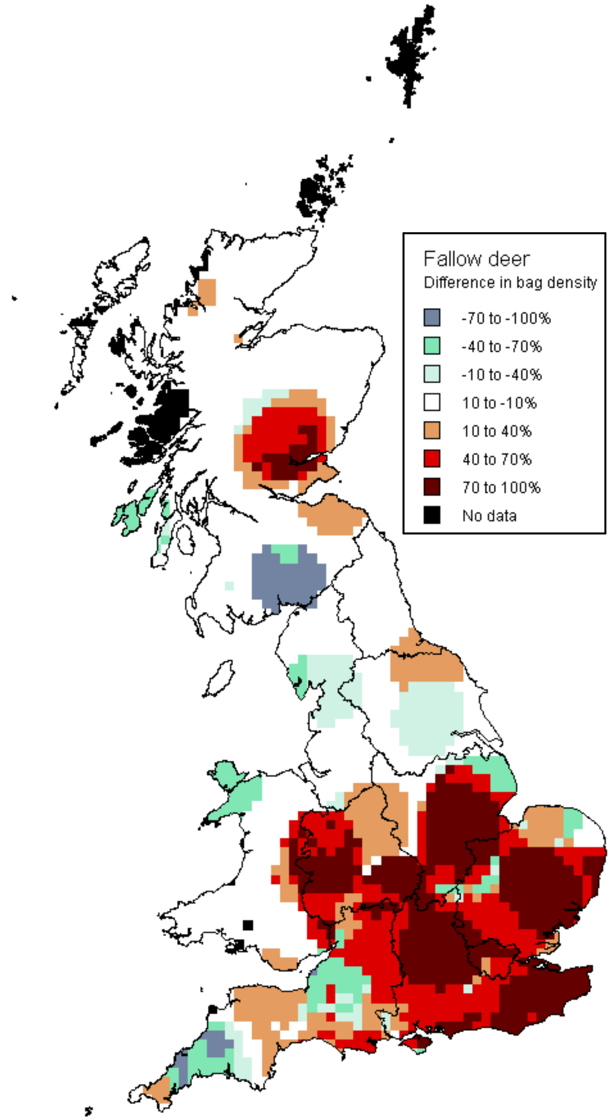
Fallow Deer NGC 1995-1999



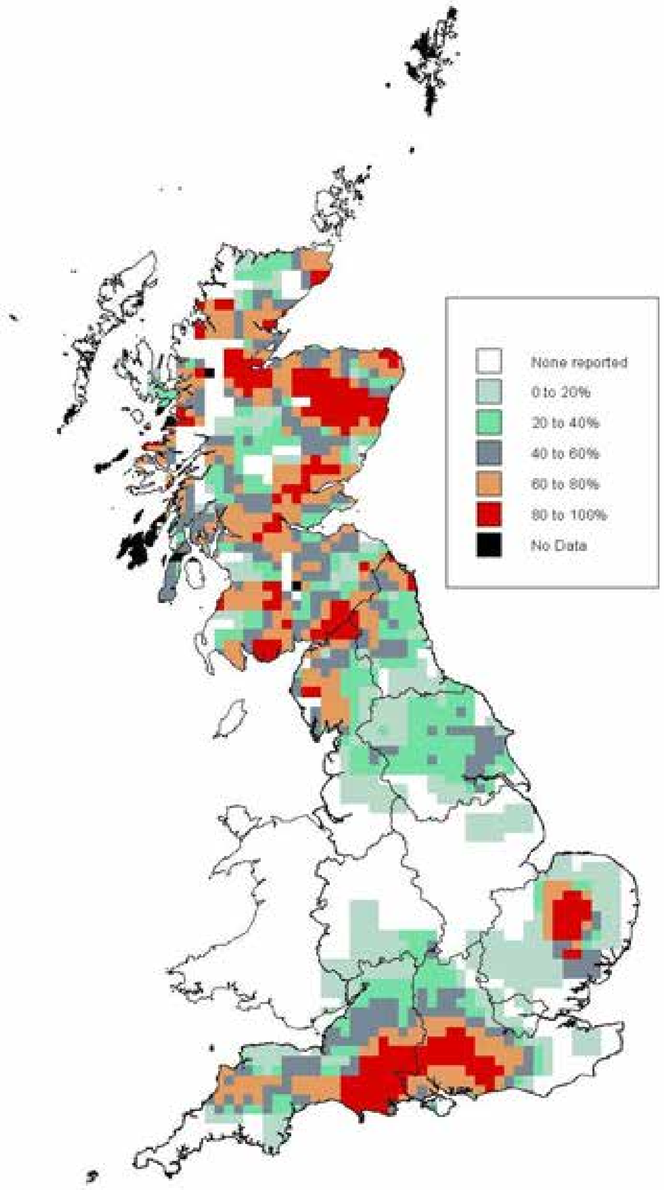
Fallow Deer NGC 2005-2009



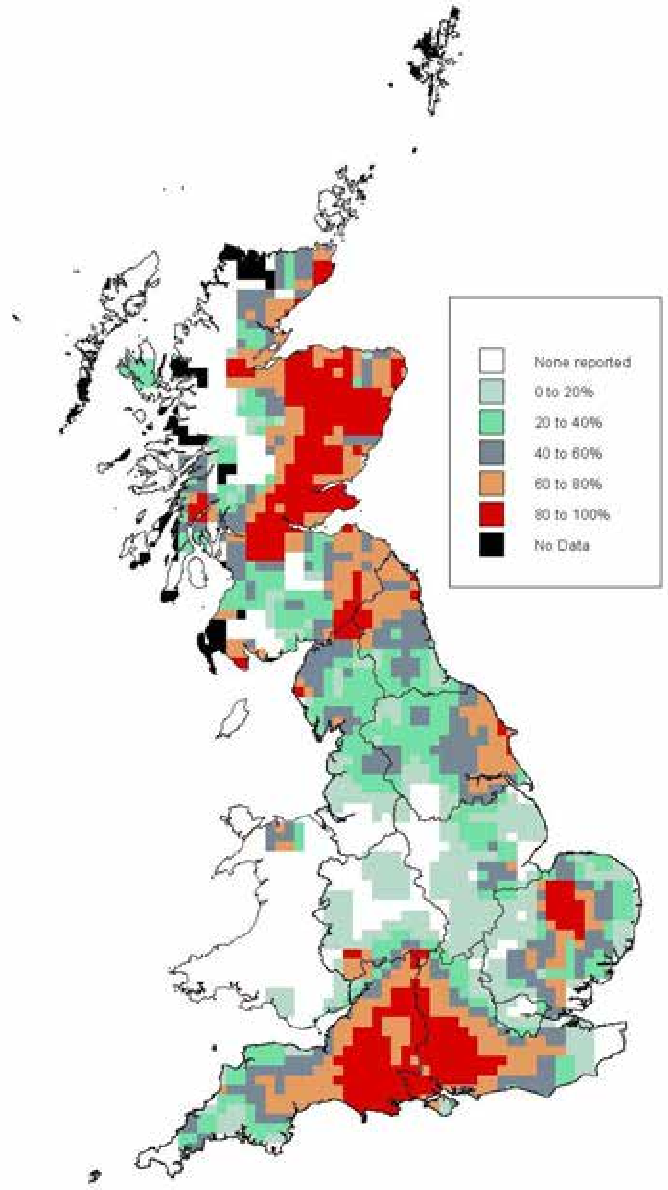
Fallow Deer NGC Change



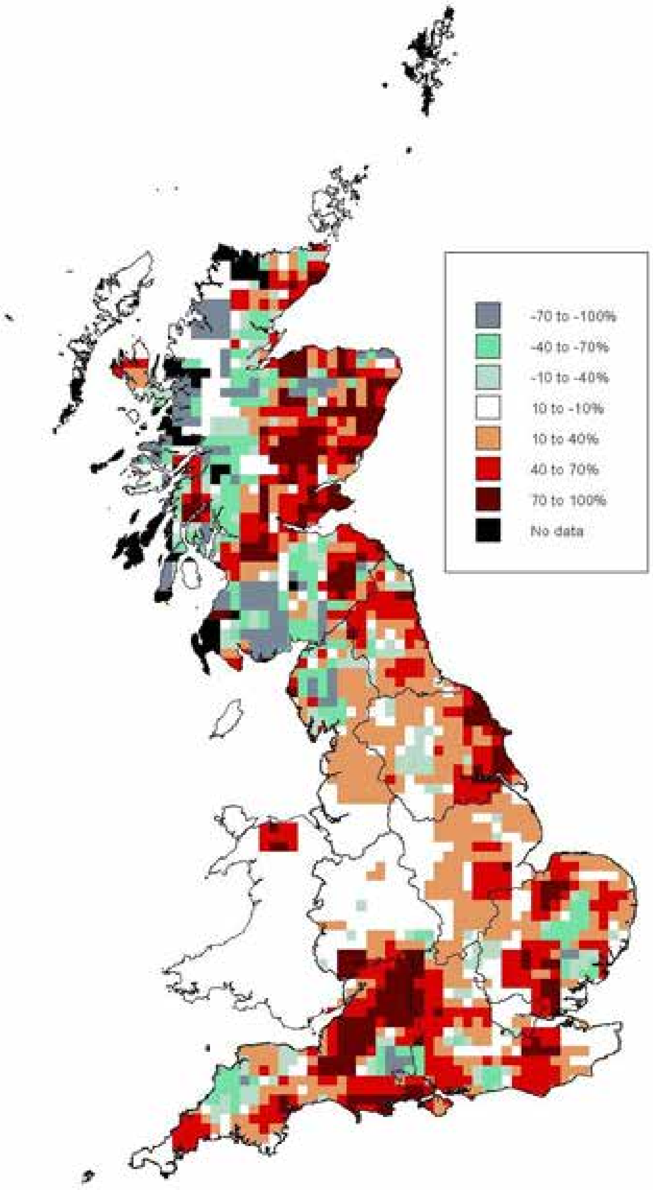
Roe Deer BBS 1995-1999



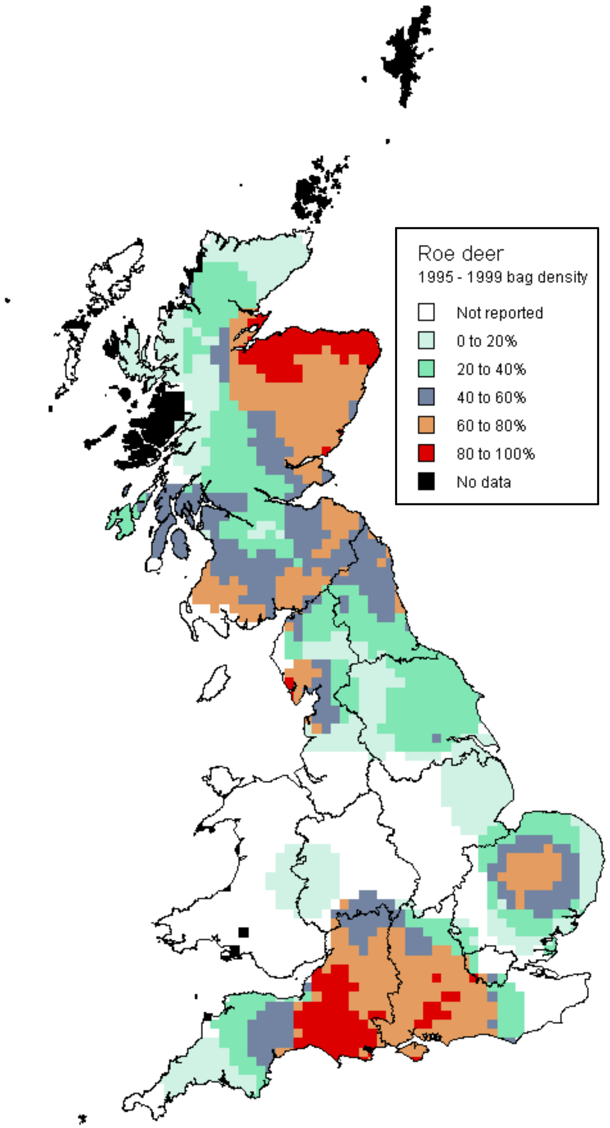
Roe Deer BBS 2005-2009



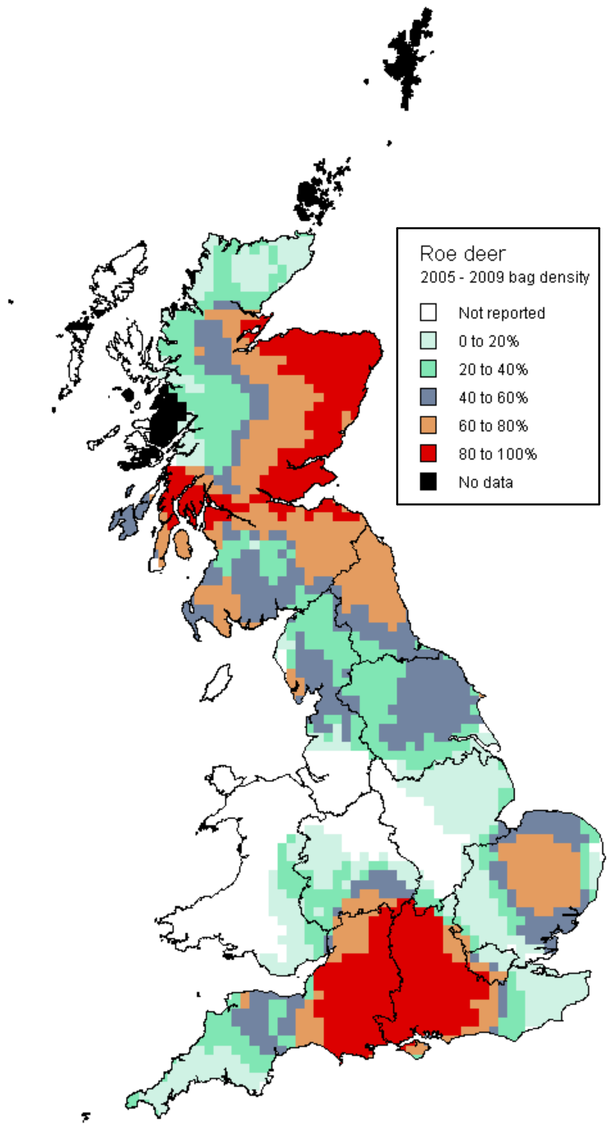
Roe Deer BBS Change



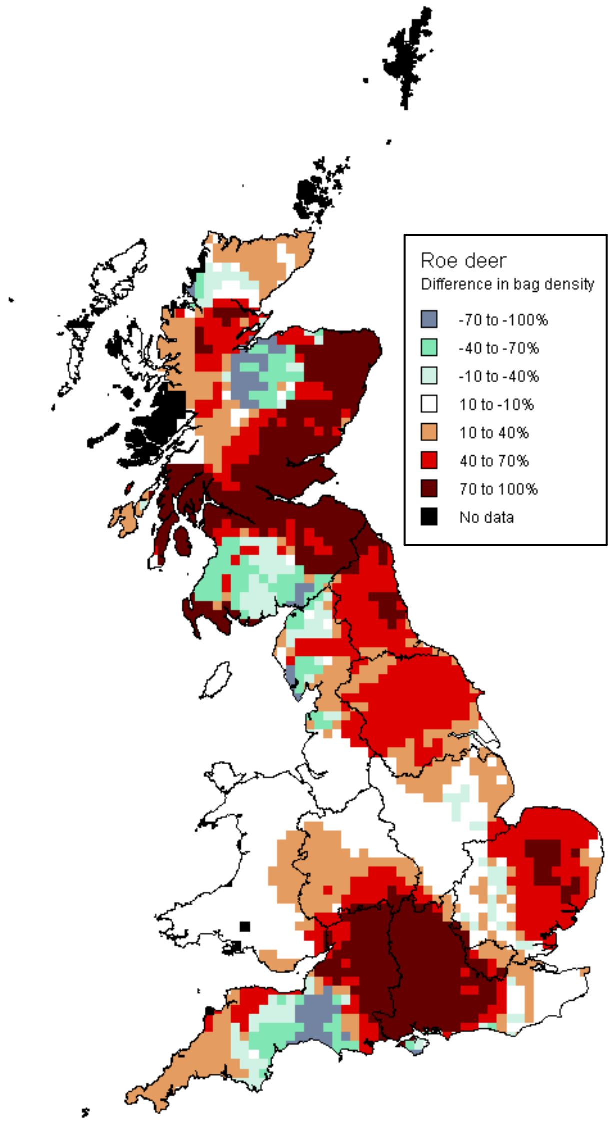
Roe Deer NGC 1995-1999



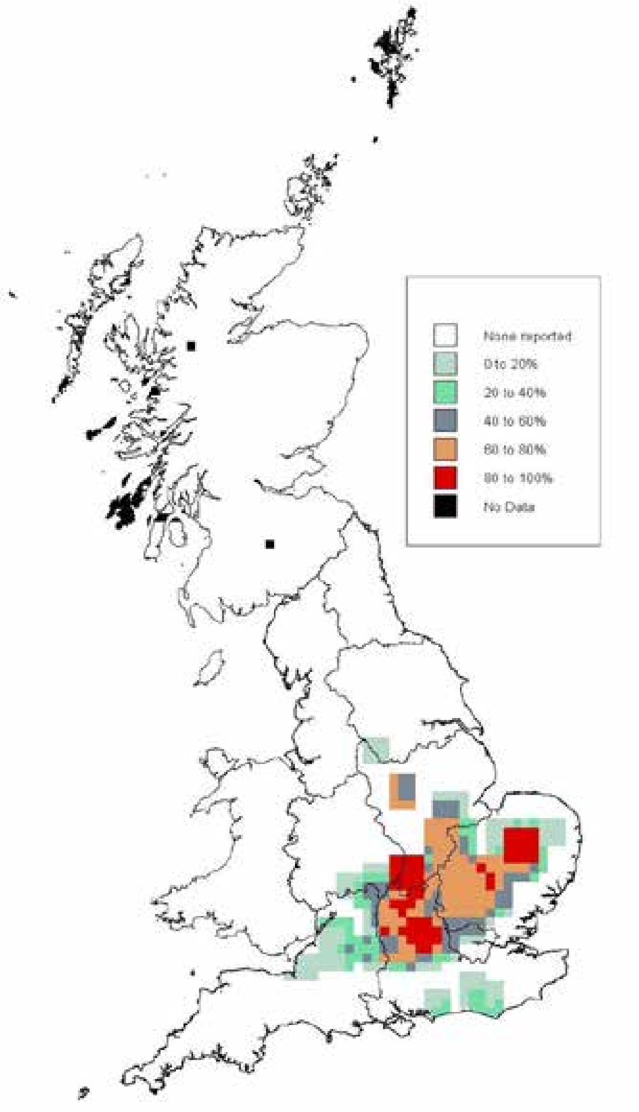
Roe Deer NGC 2005-2009



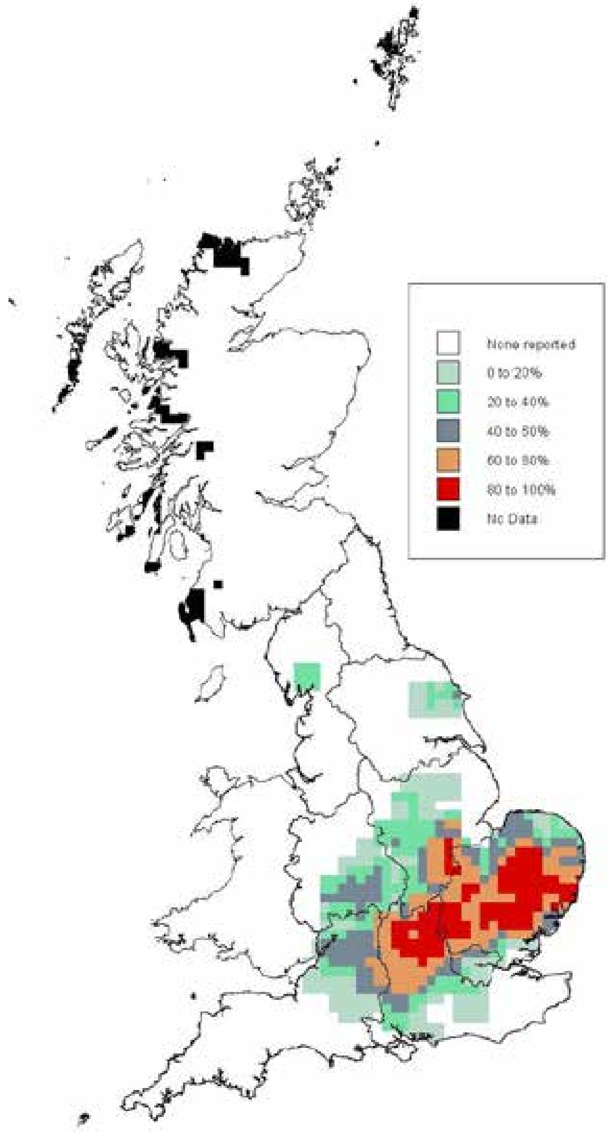
Roe Deer NGC Change



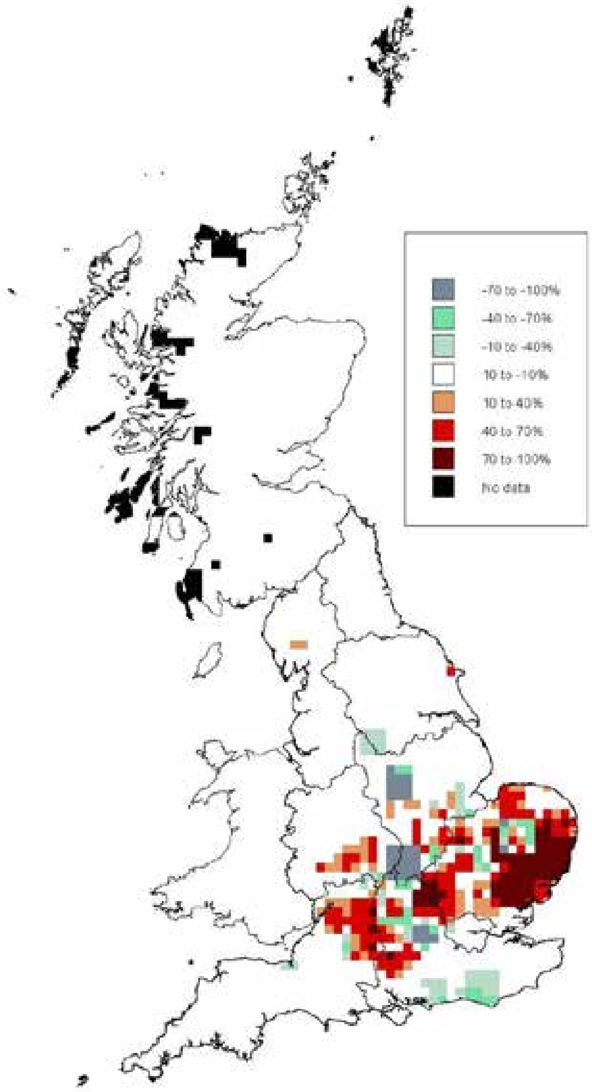
Muntjac BBS 1995-1999



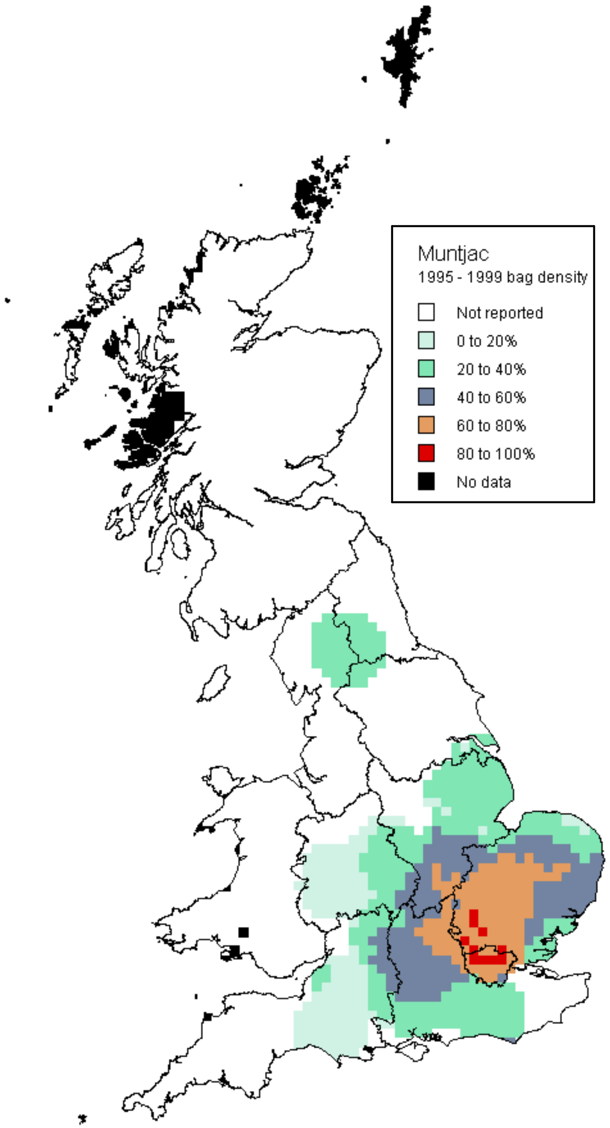
Muntjac BBS 2005-2009



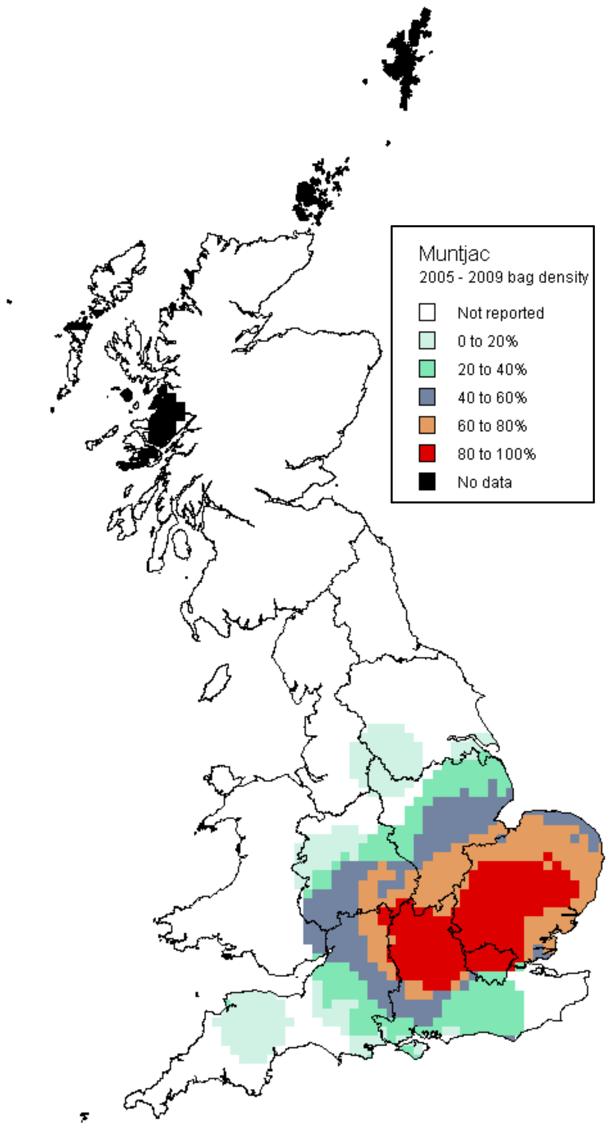
Muntjac BBS Change



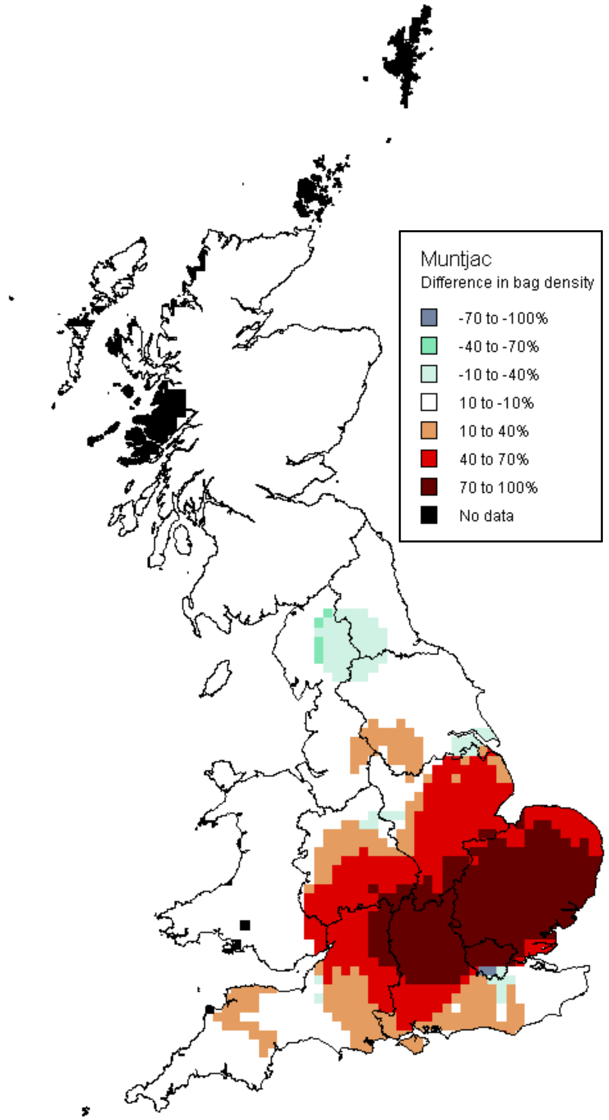
Muntjac NGC 1995-1999



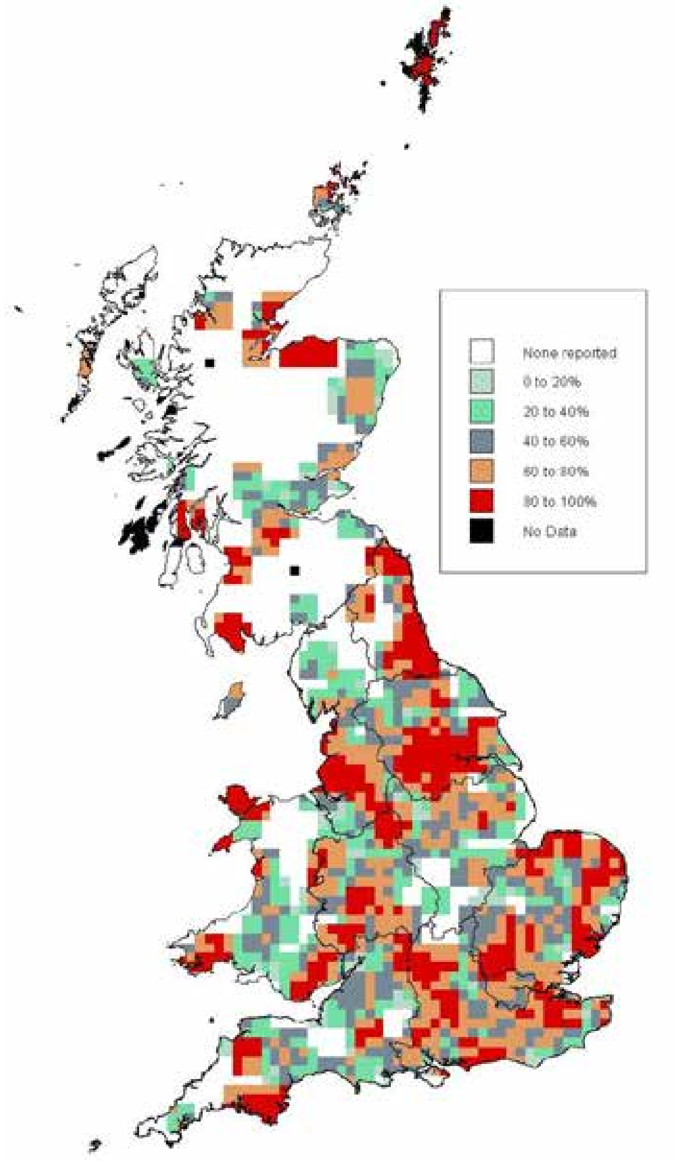
Muntjac NGC 2005-2009



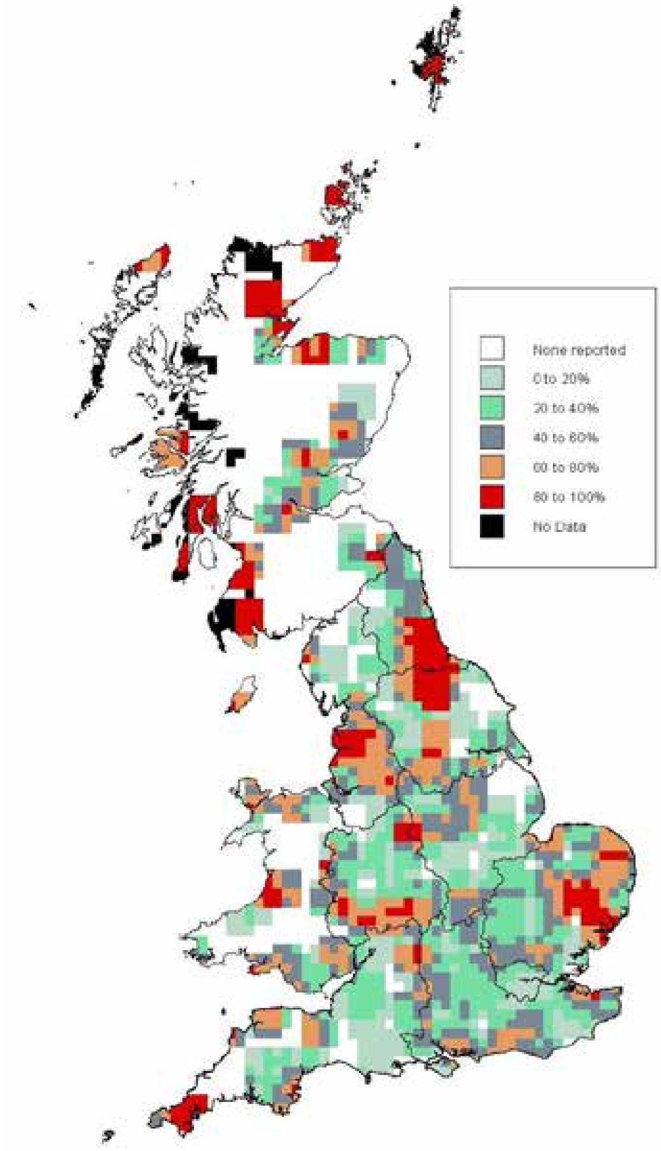
Muntjac NGC Change



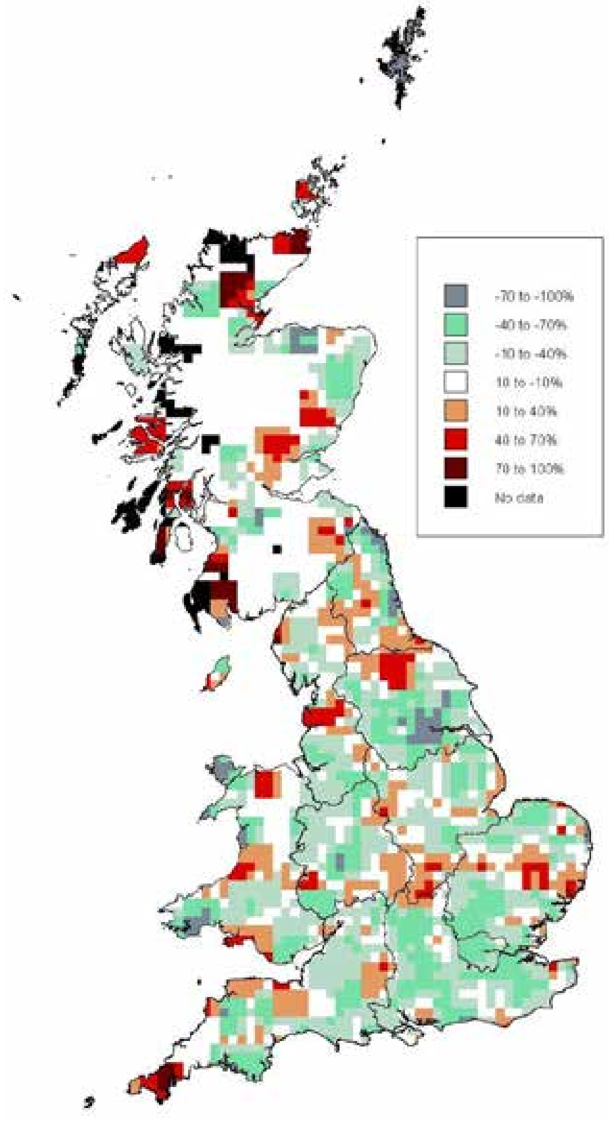
Hedgehog BBS 1995-1999



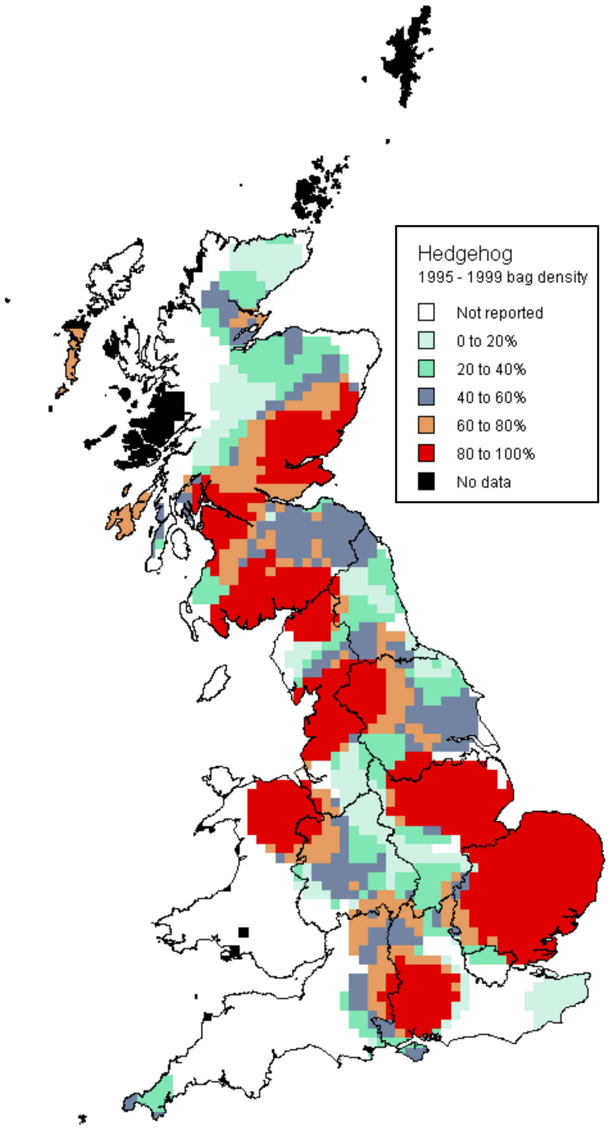
Hedgehog BBS 2005-2009



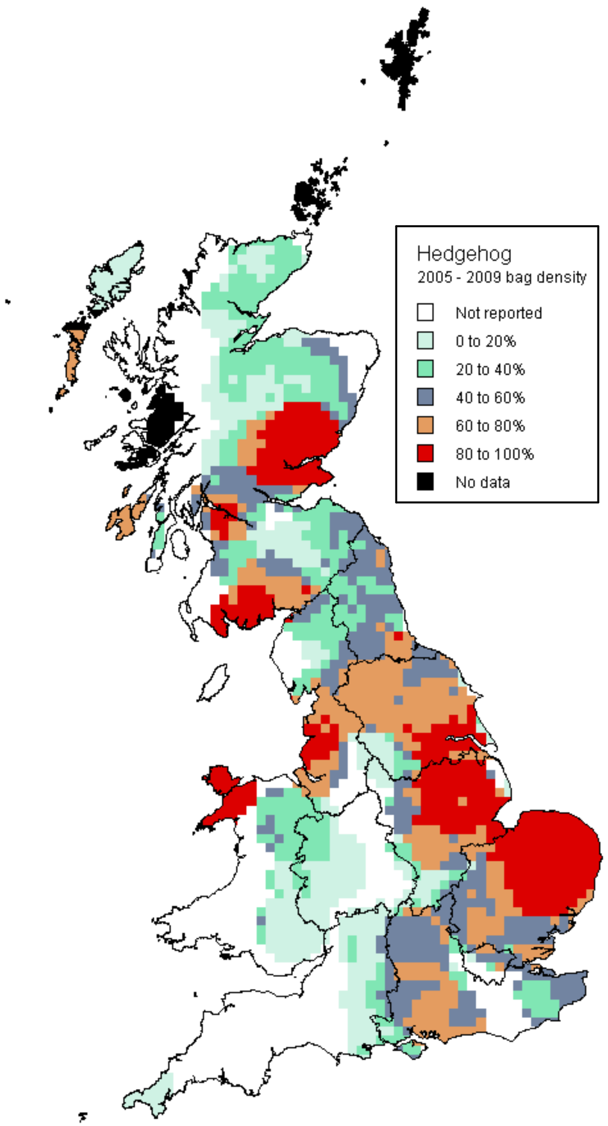
Hedgehog BBS Change



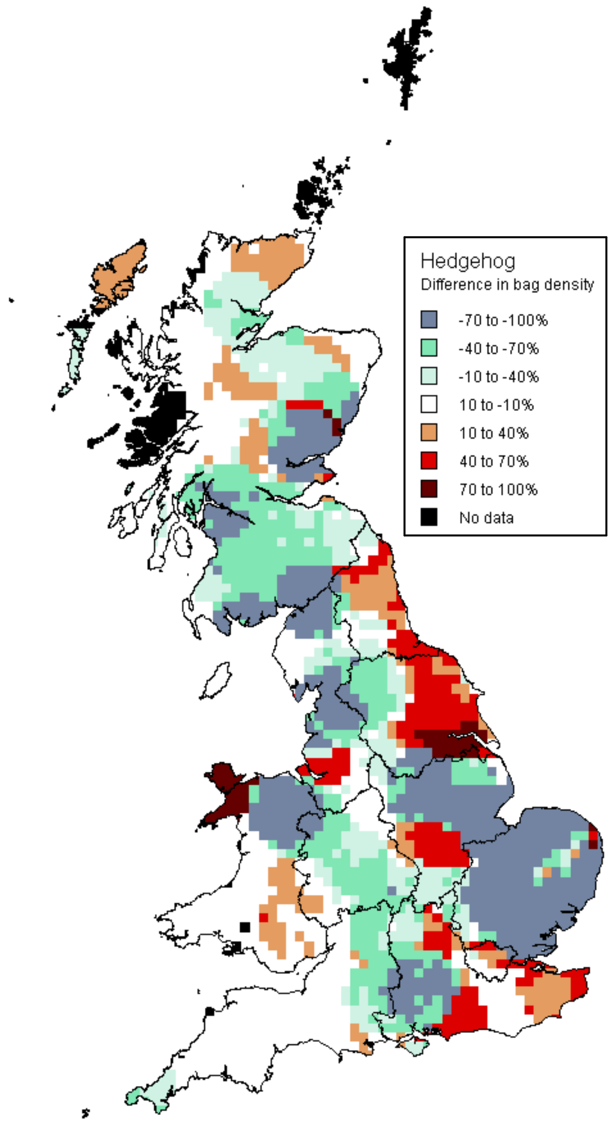
Hedgehog NGC 1995-1999



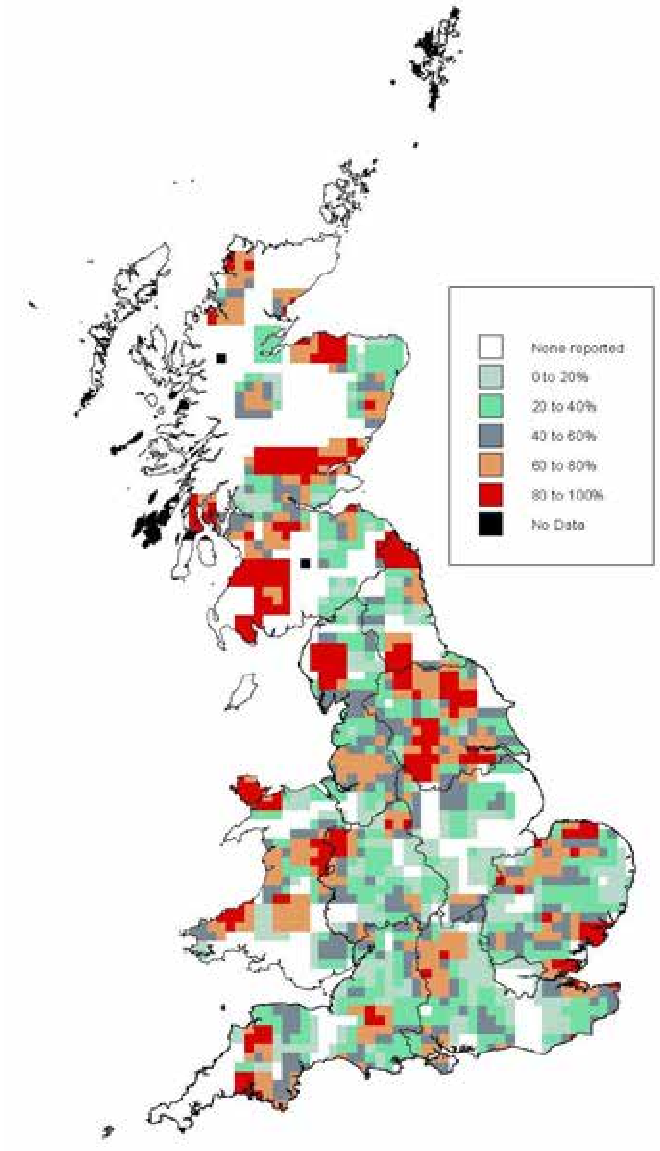
Hedgehog NGC 2005-2009



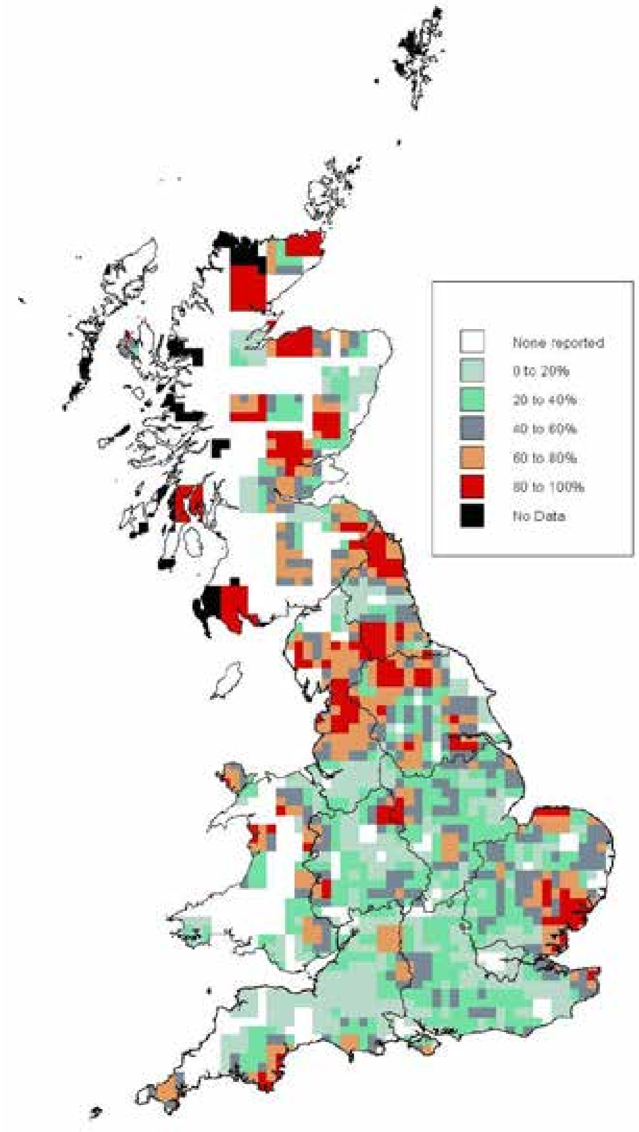
Hedgehog NGC Change



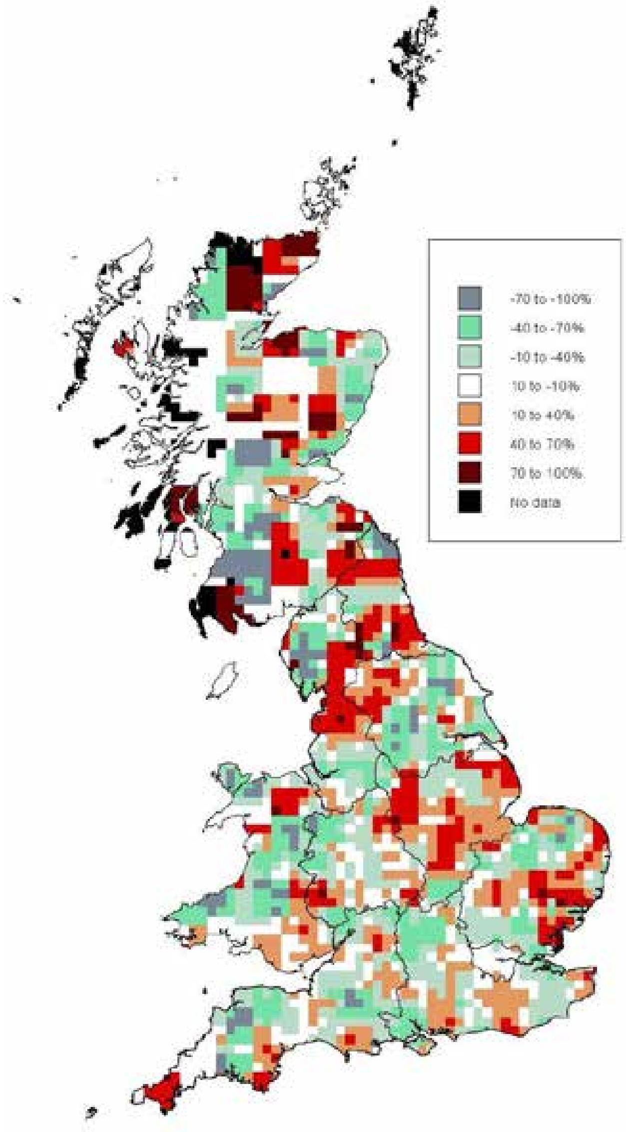
Stoat BBS 1995-1999

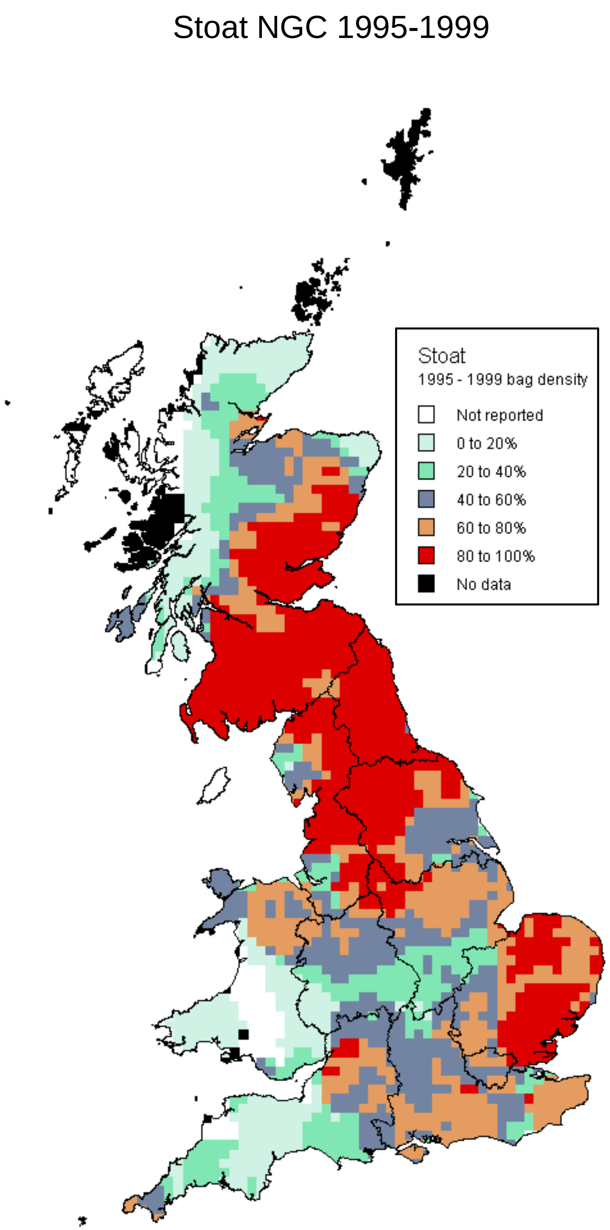


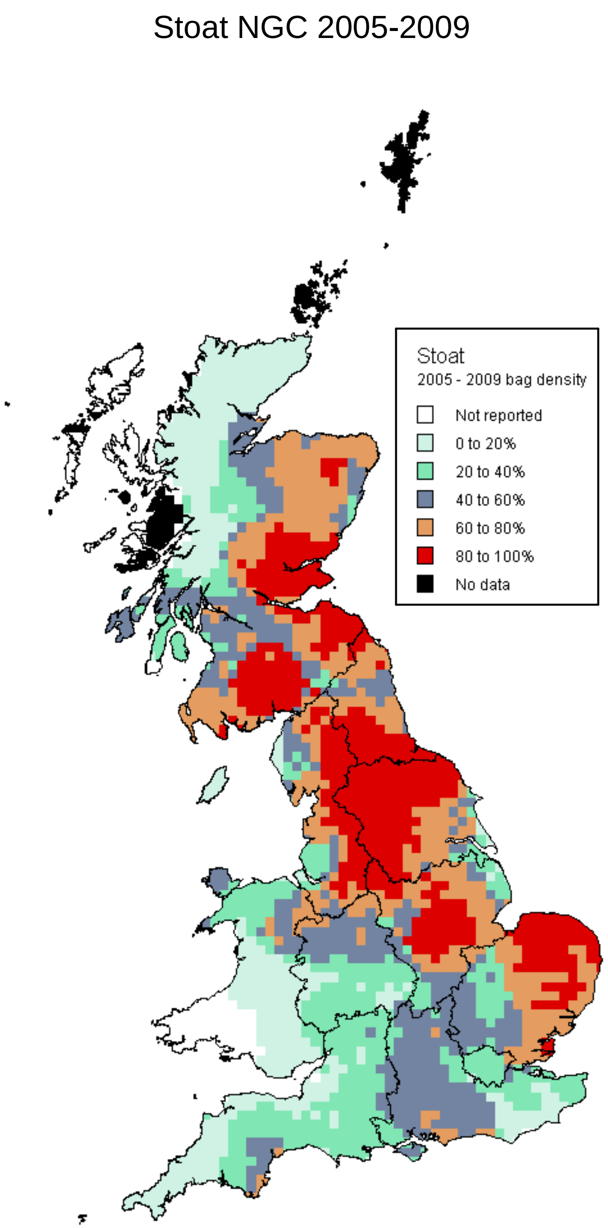
Stoat BBS 2005-2009

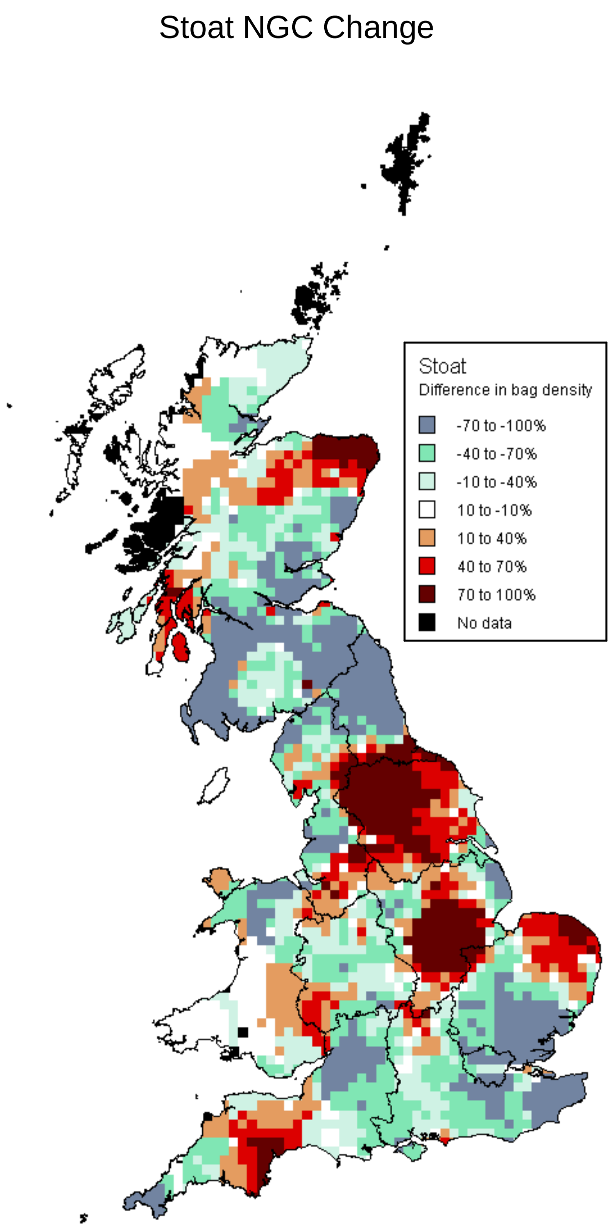


Stoat BBS Change

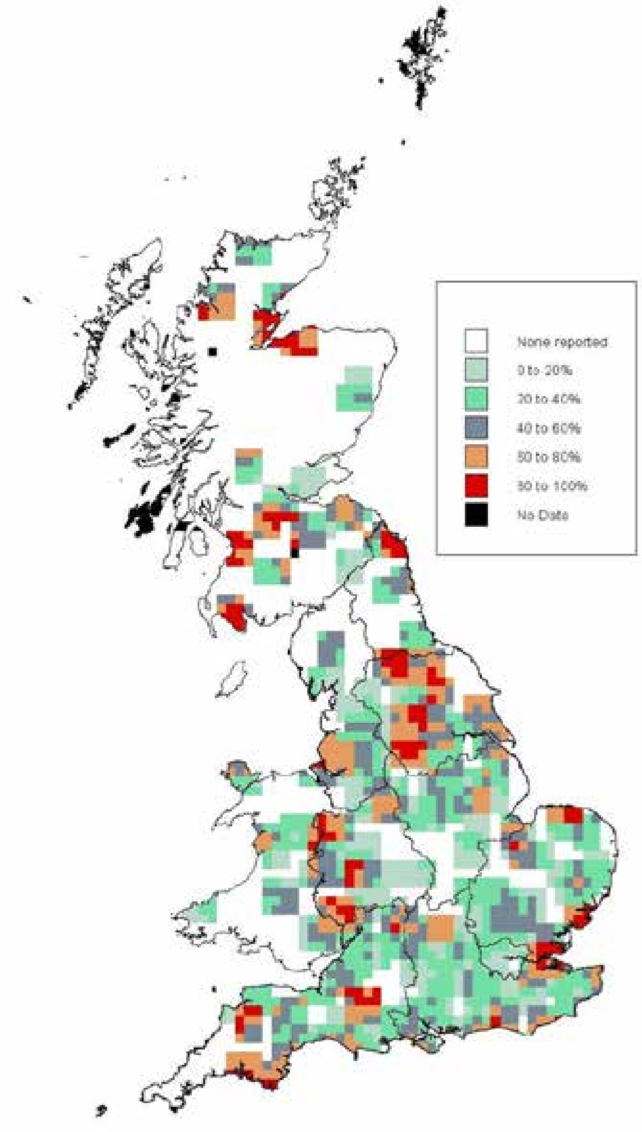



Stoat NGC 1995-1999
Stoat
1995 - 1999 bag density
Not reported
0 to 20%
20 to 40%
40 to 60%
60 to 80%
80 to 100%
No data

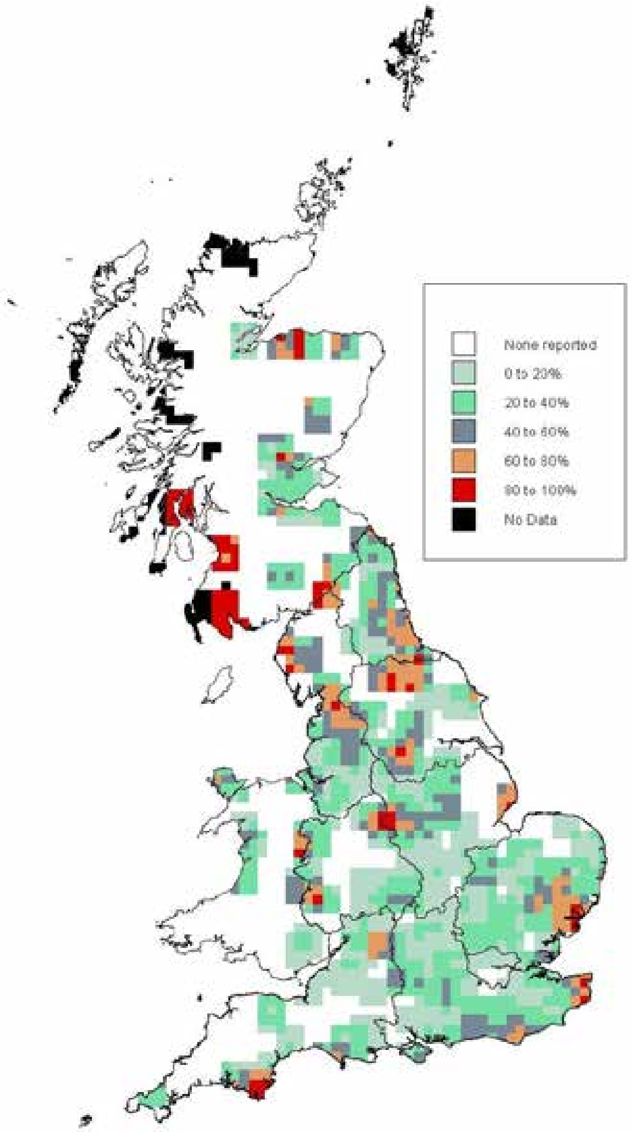

Stoat NGC 2005-2009
Stoat
2005 - 2009 bag density
Not reported
0 to 20%
20 to 40%
40 to 60%
60 to 80%
80 to 100%
No data


Stoat NGC Change
Stoat
Difference in bag density
-70 to -100%
-40 to -70%
-10 to -40%
10 to -10%
10 to 40%
40 to 70%
70 to 100%
No data

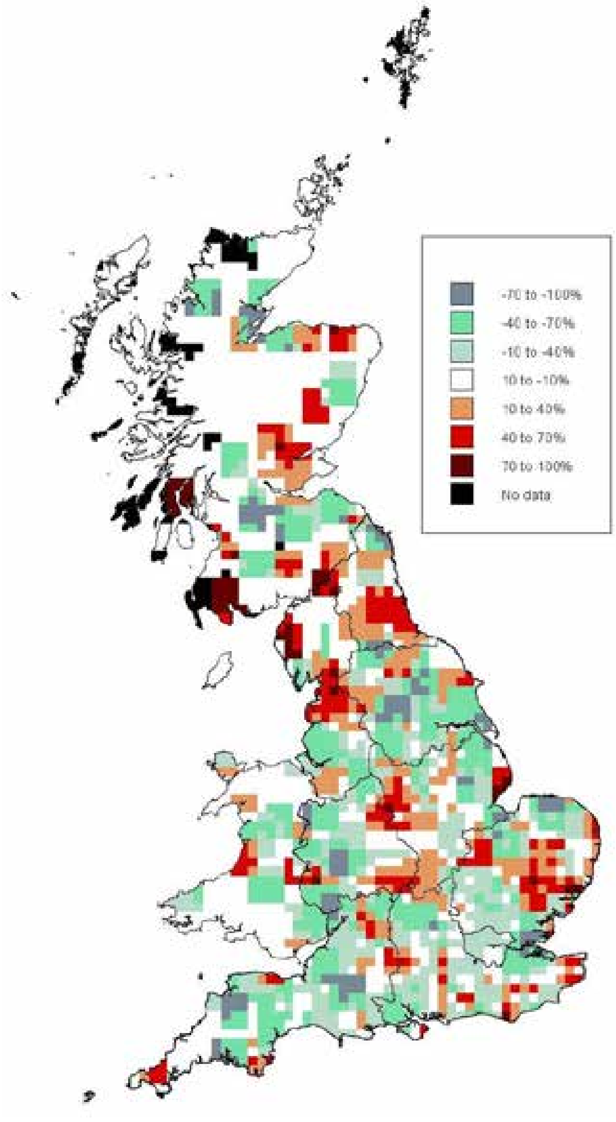
Weasel BBS 1995-1999



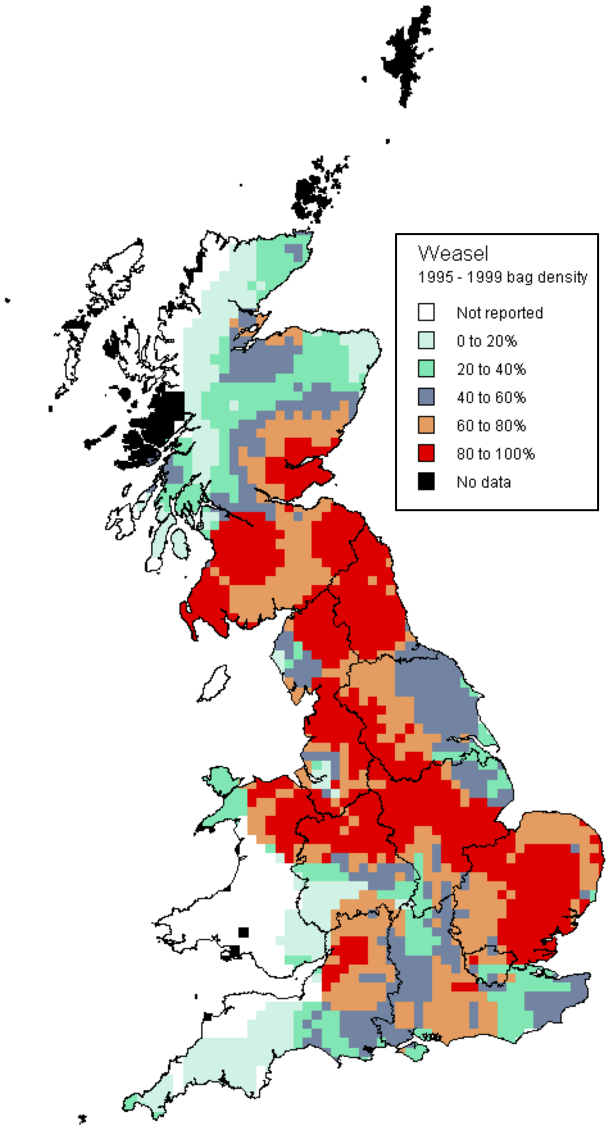
Weasel BBS 2005-2009



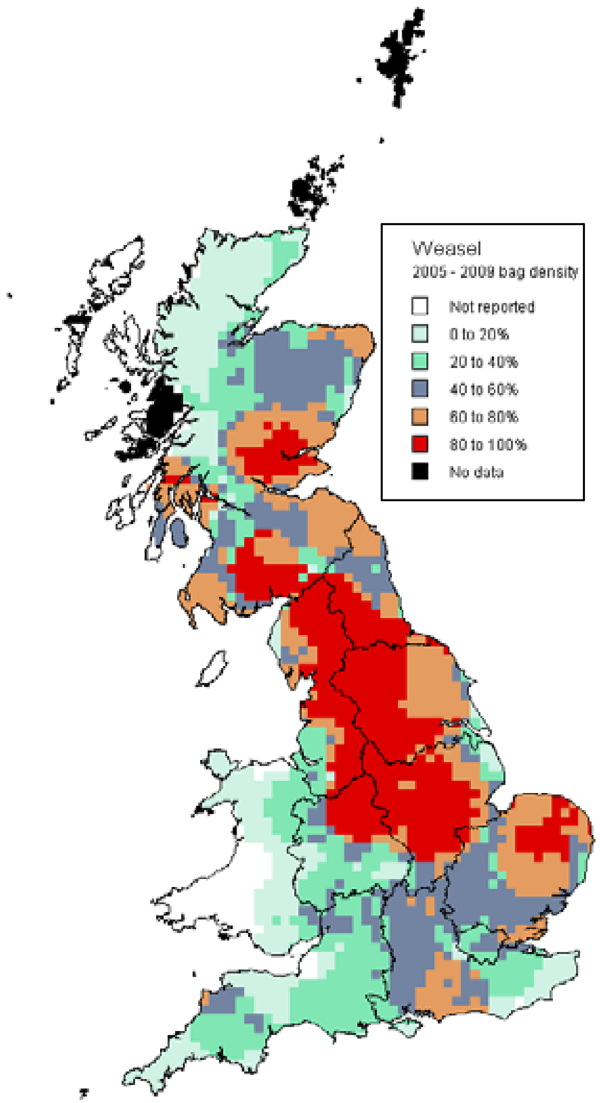
Weasel BBS Change



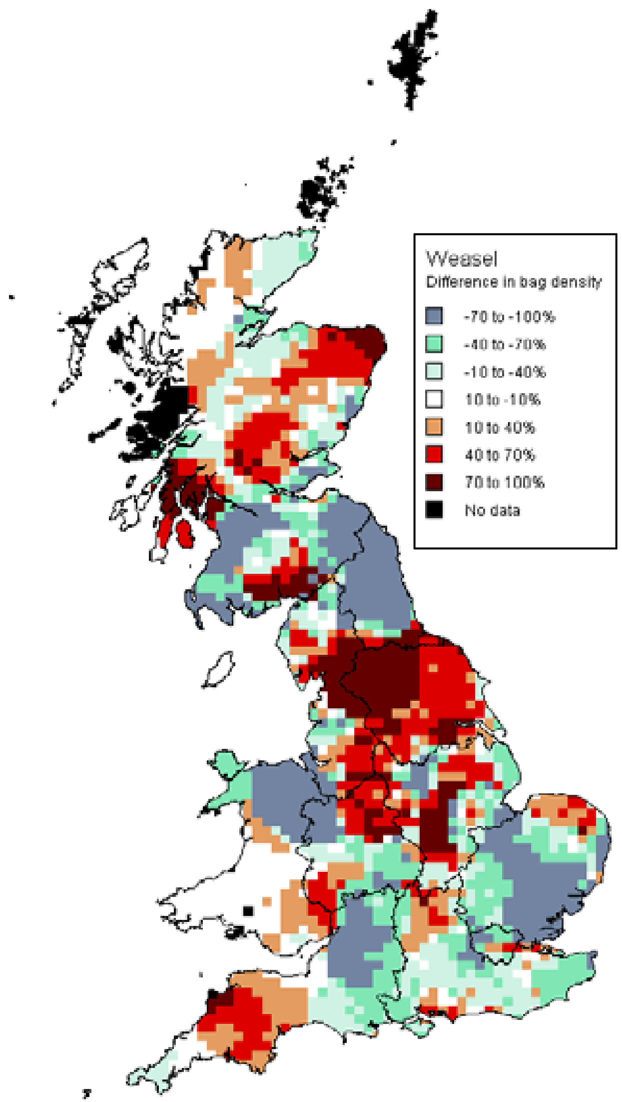
Weasel NGC 1995-1999



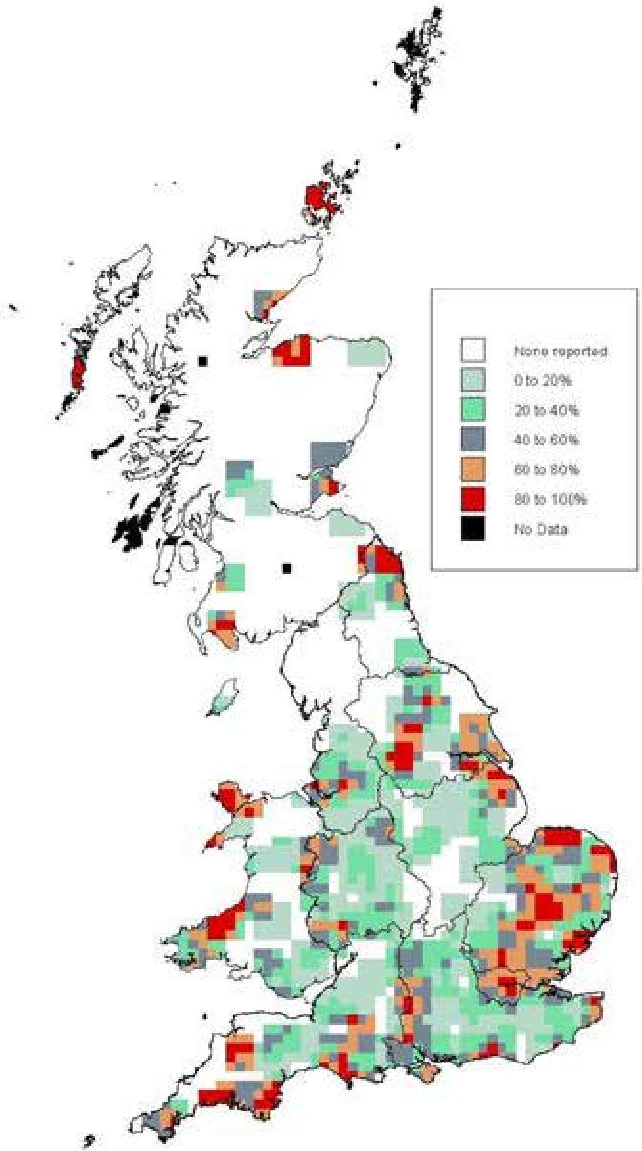
Weasel NGC 2005-2009



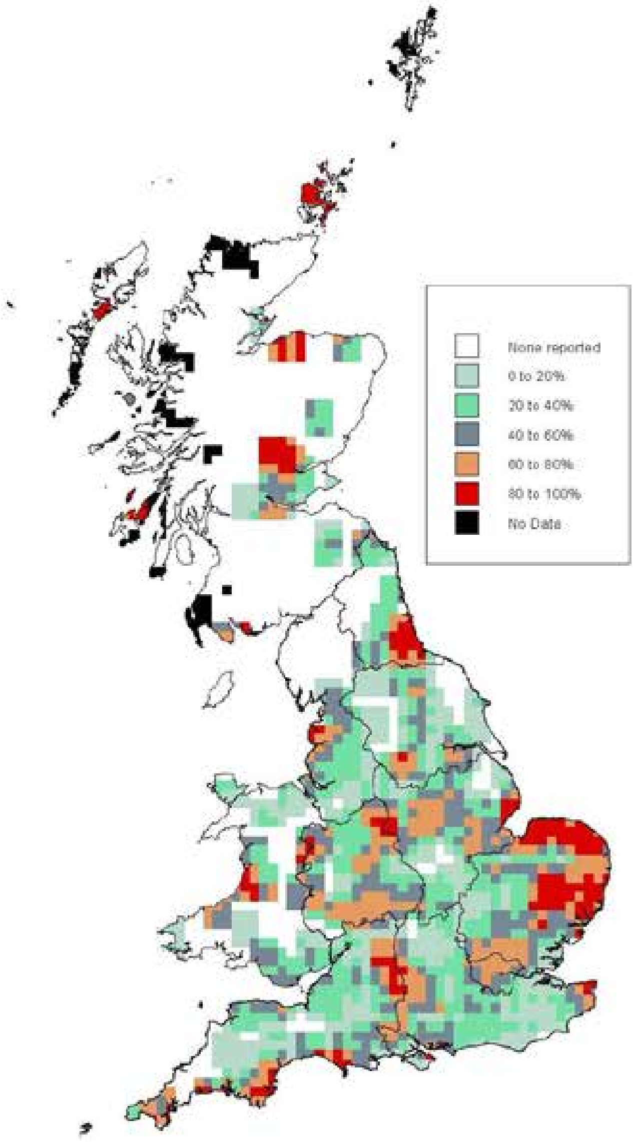
Weasel NGC Change



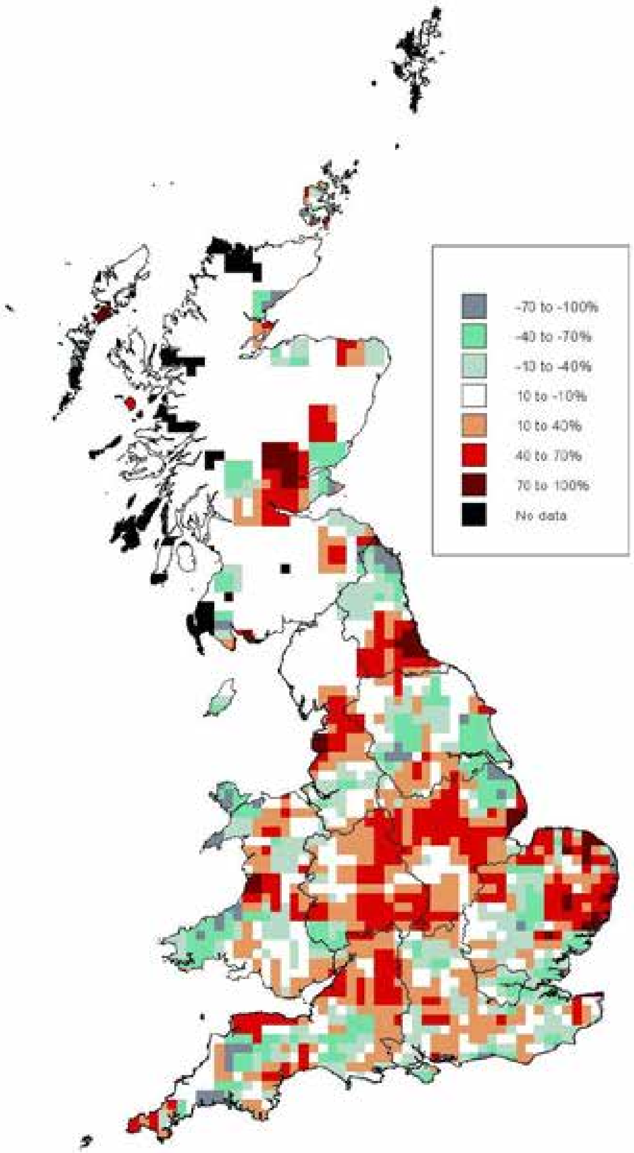
Brown Rat BBS 1995-1999



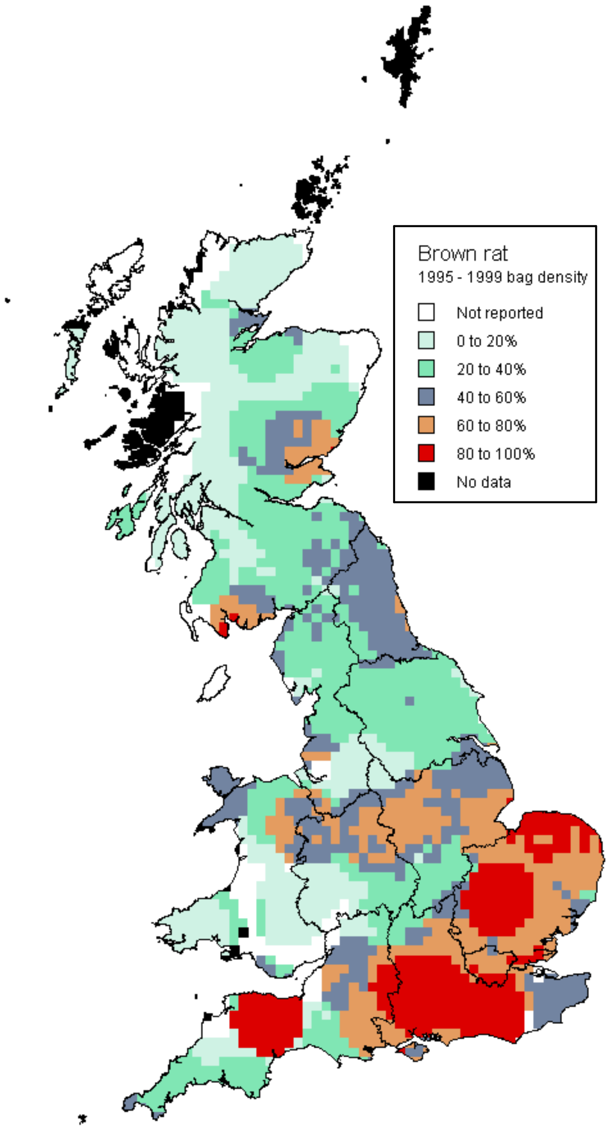
Brown Rat BBS 2005-2009



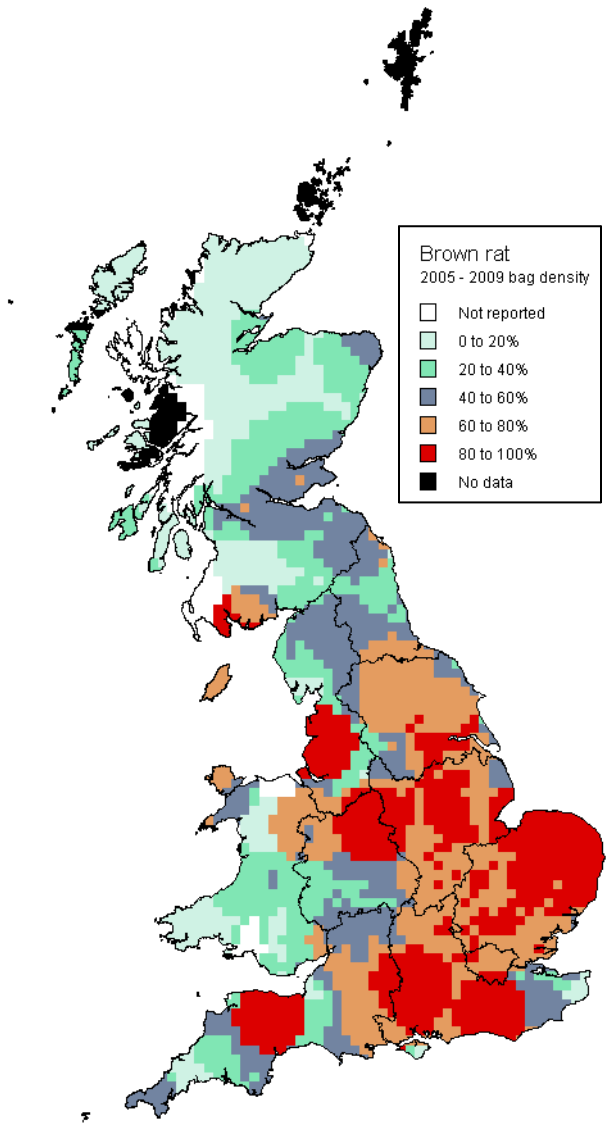
Brown Rat BBS Change



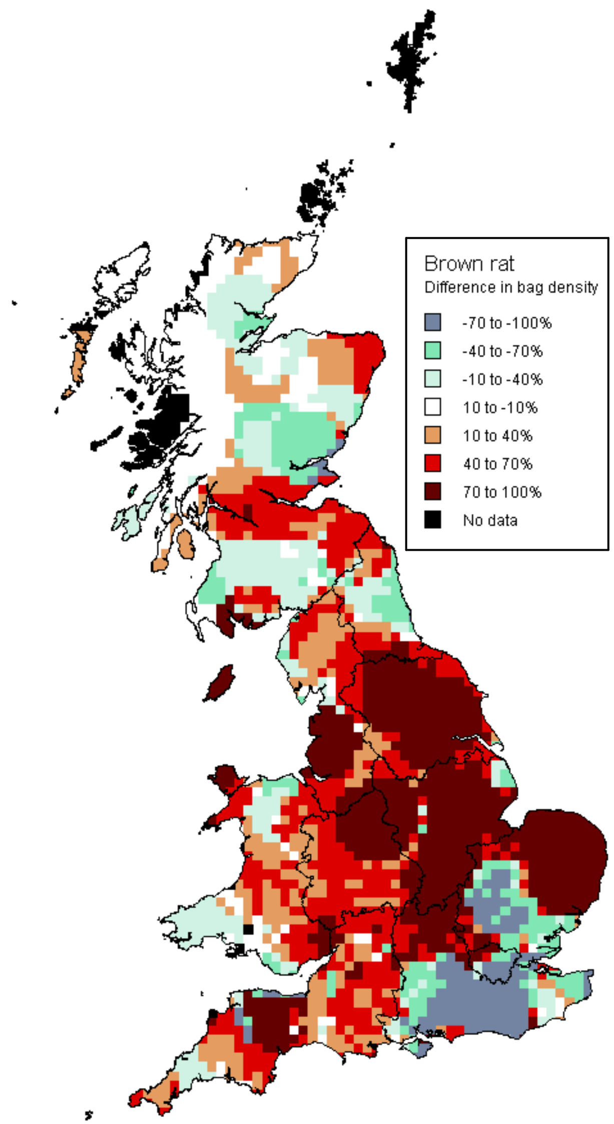
Brown Rat NGC 1995-1999



Brown Rat NGC 2005-2009

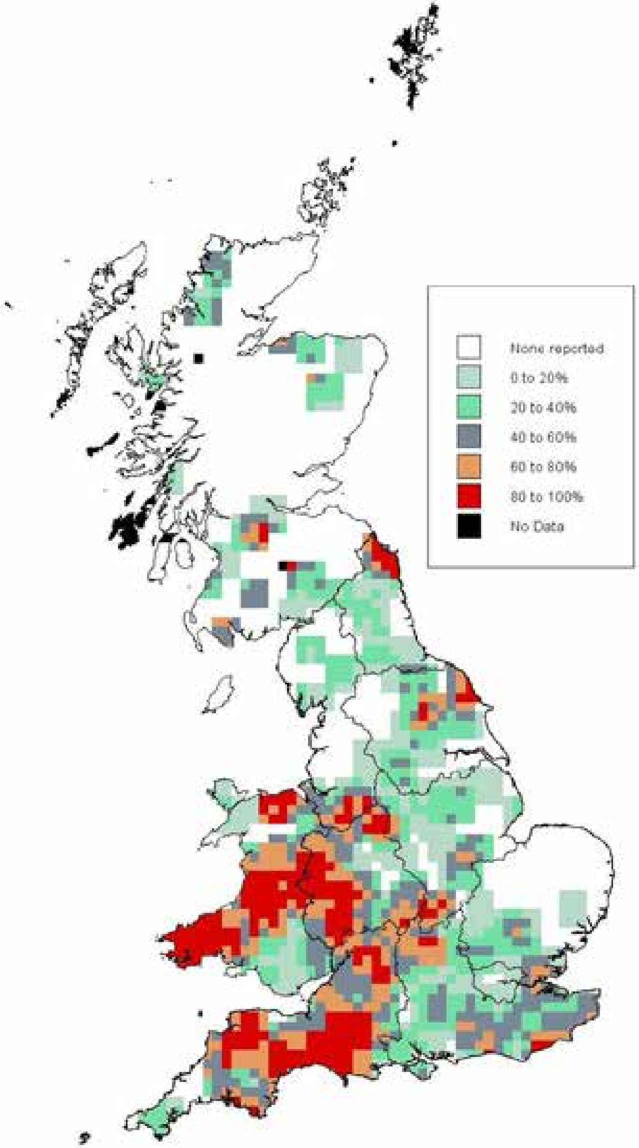


Brown Rat NGC Change

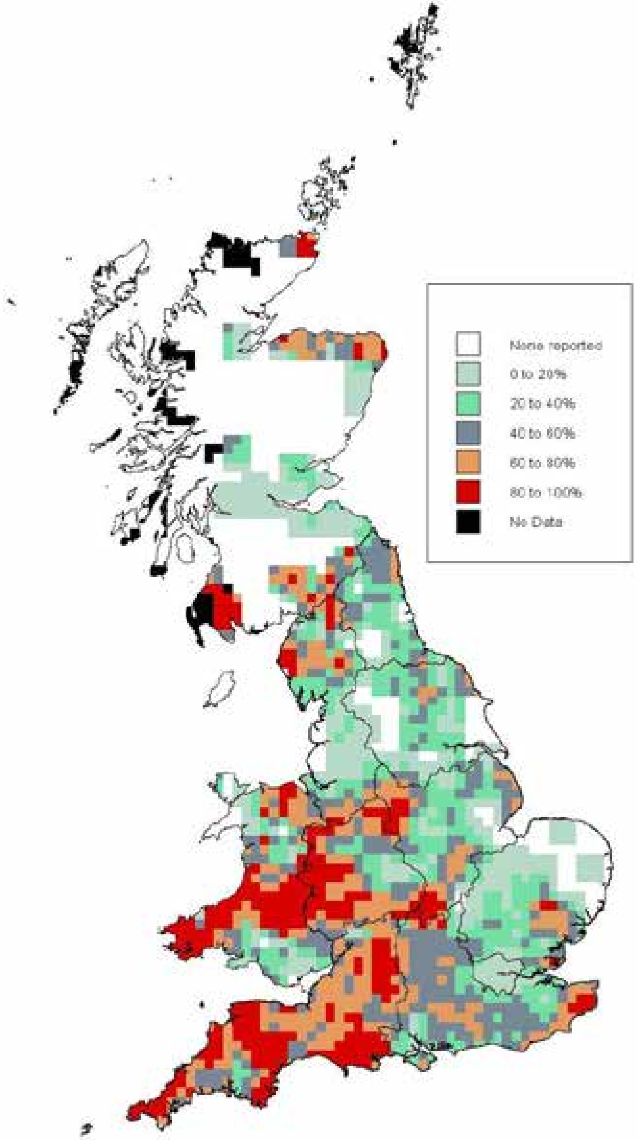


Appendix 1 (b) **Spatial maps of relative abundance based on BBS data (only) for one species Badger in each of two periods (1995-99 & 2005-09) and map showing change in relative abundance between these two periods.**

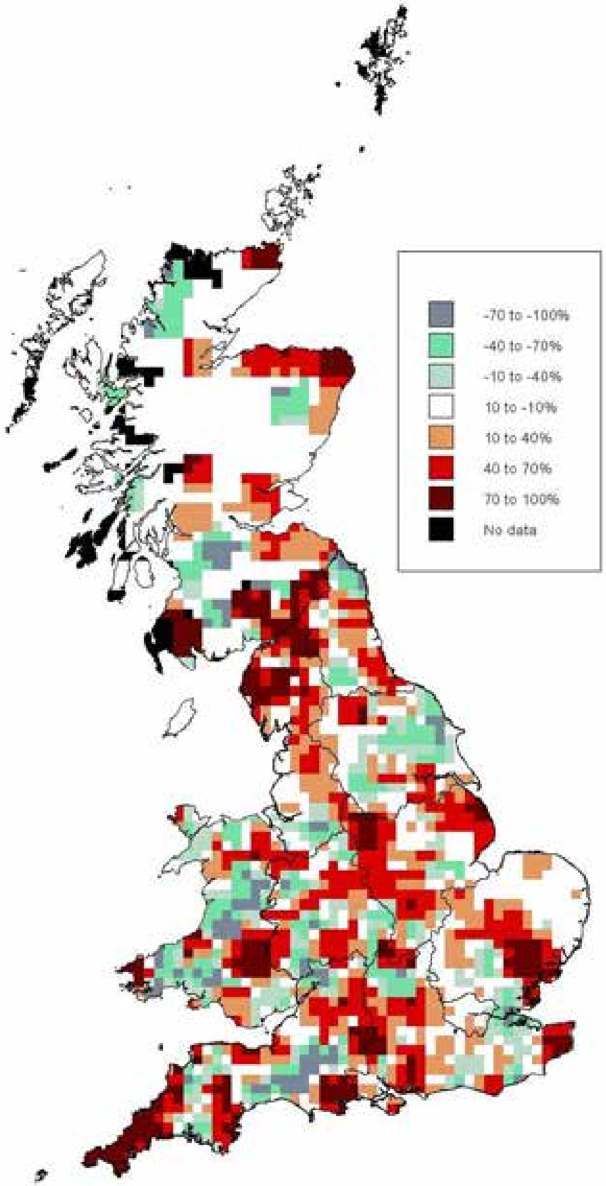
Badger BBS 1995-1999



Badger BBS 2005-2009

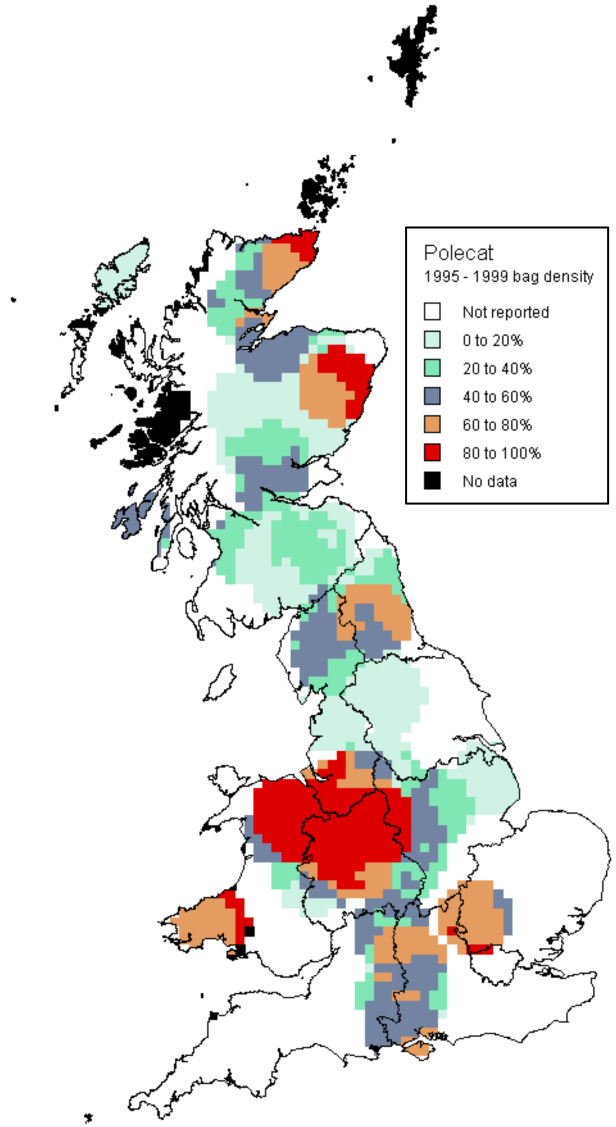


Badger BBS Change

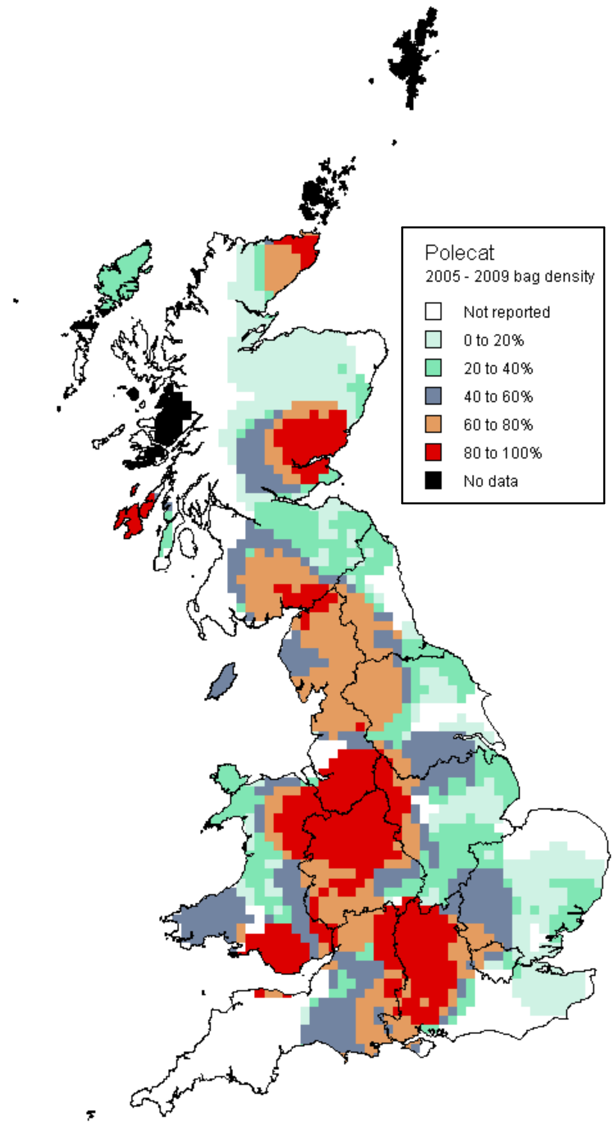


Appendix 1 (c) **Spatial maps of relative abundance based on NGC data (only) for four species (Polecat, Feral Cat, Sika Deer & American Mink) in each of two periods (1995-99 & 2005-09) and map showing change in abundance between these two periods.**

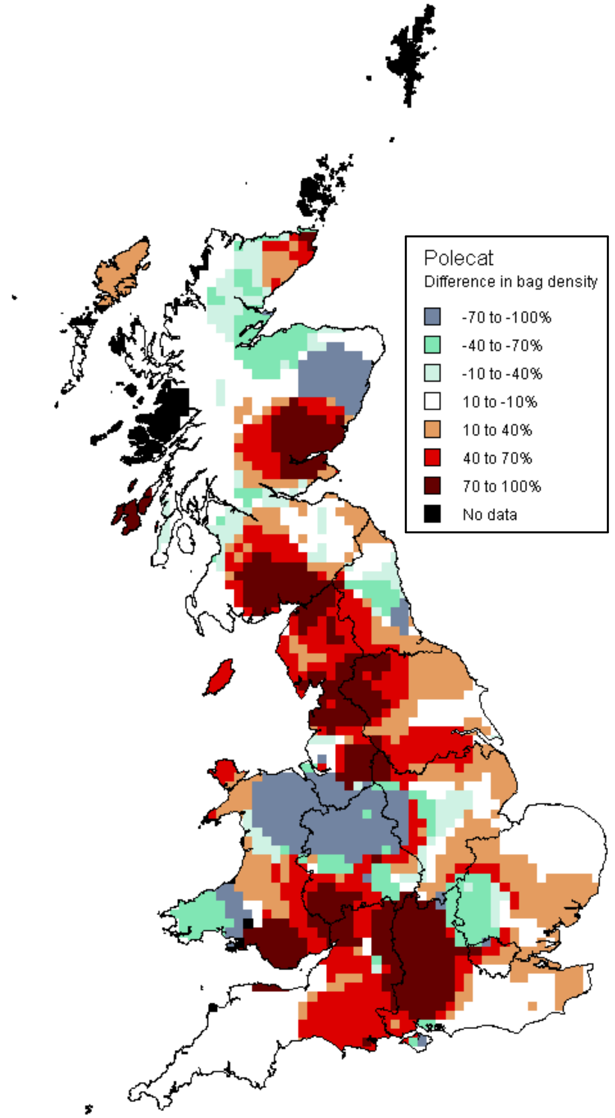
Polecat NGC 1995-1999

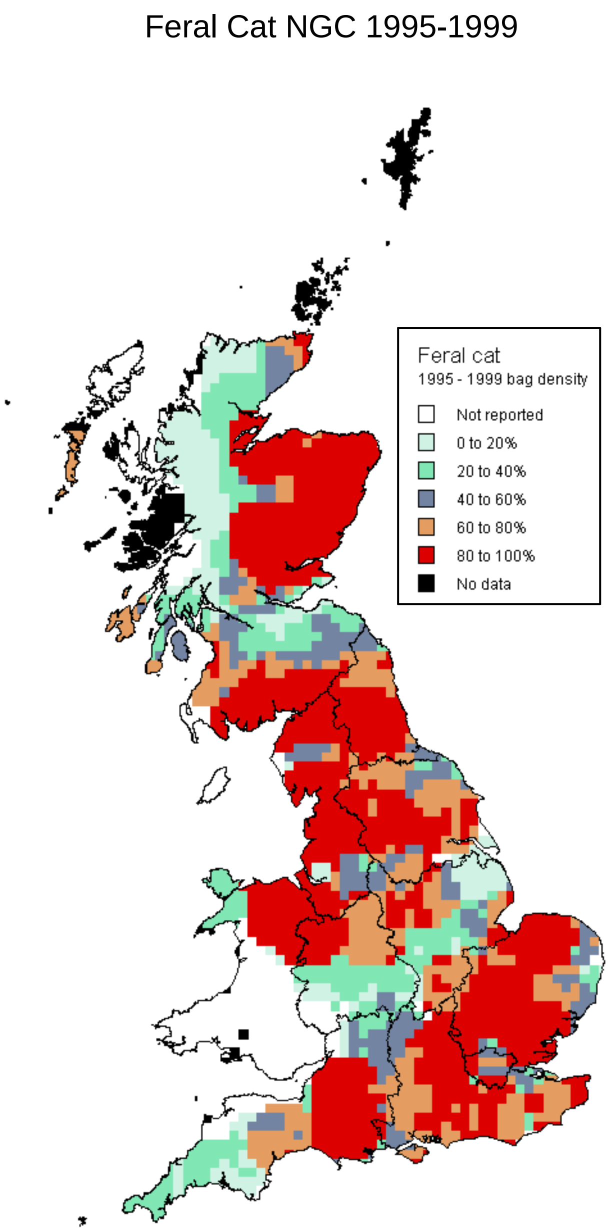


Polecat NGC 2005-2009

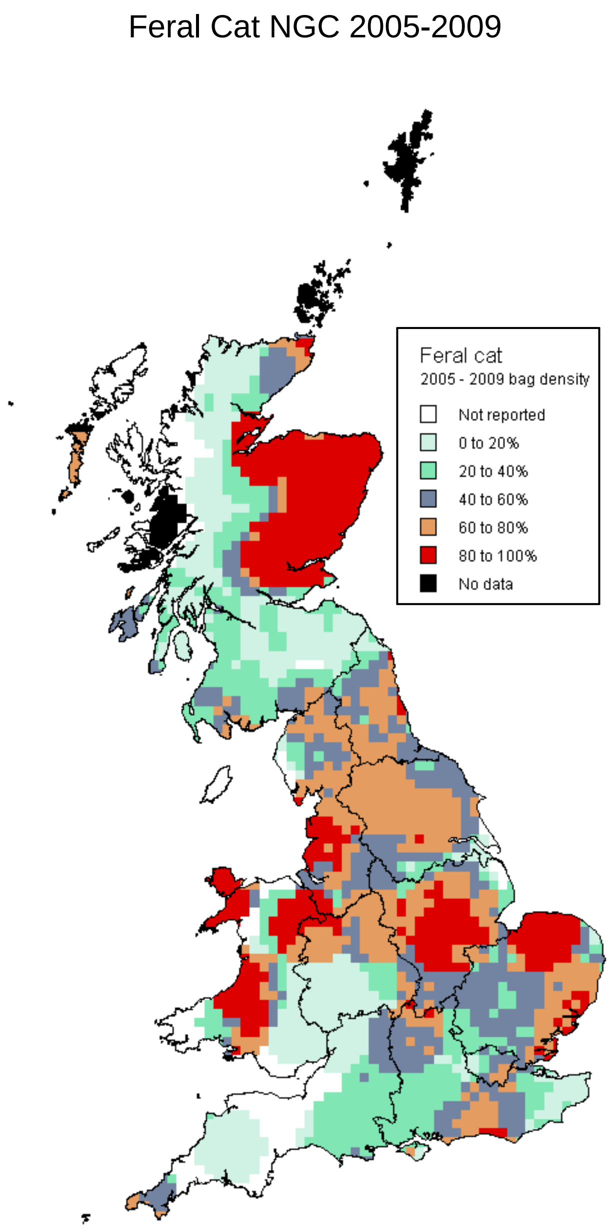


Polecat NGC Change

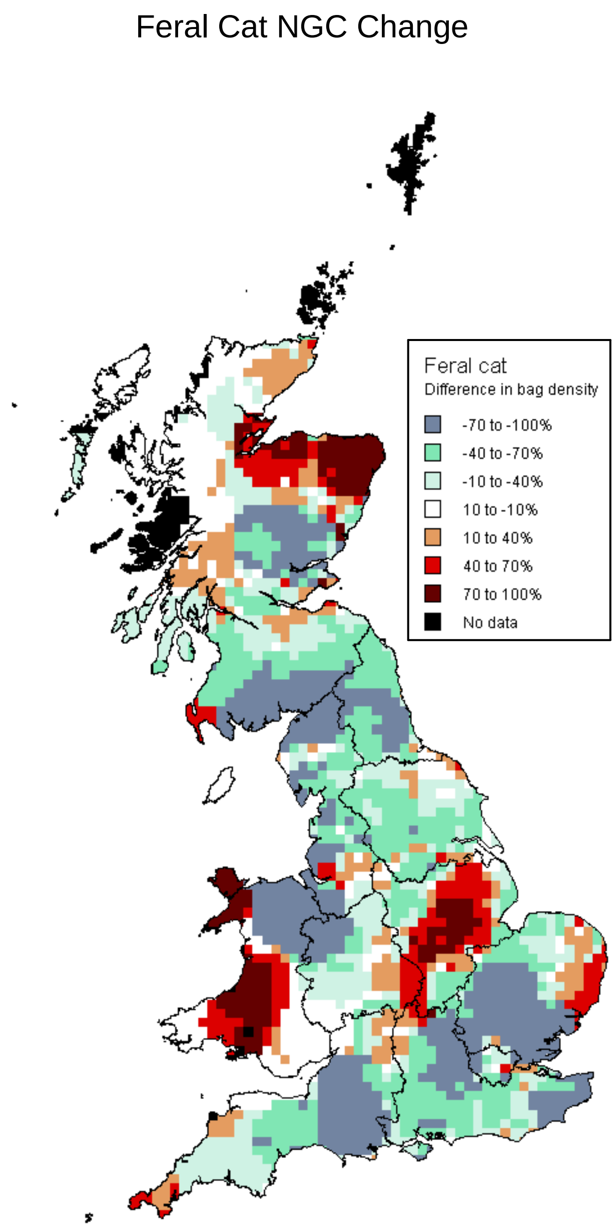




Feral Cat NGC 1995-1999
Feral cat
1995 - 1999 bag density
Not reported
0 to 20%
20 to 40%
40 to 60%
60 to 80%
80 to 100%
No data

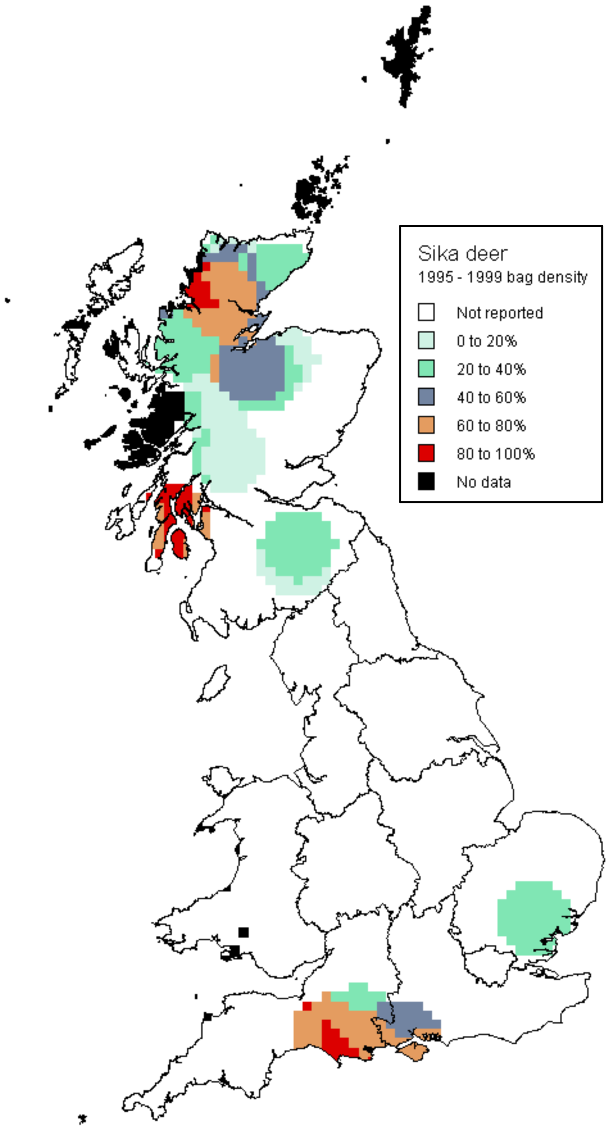


Feral Cat NGC 2005-2009
Feral cat
2005 - 2009 bag density
Not reported
0 to 20%
20 to 40%
40 to 60%
60 to 80%
80 to 100%
No data

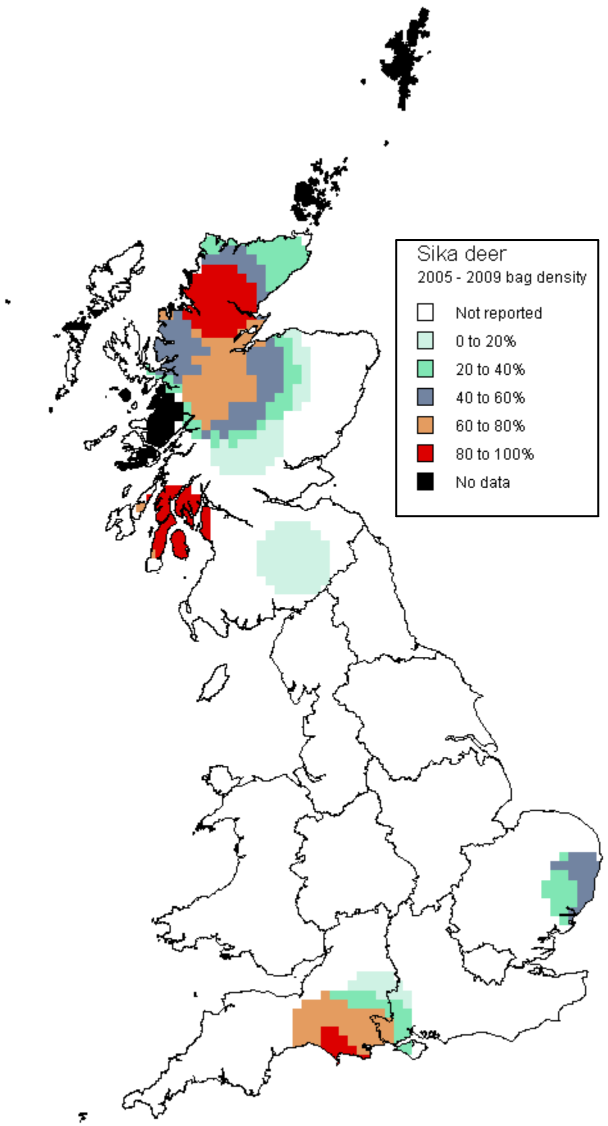


Feral Cat NGC Change
Feral cat
Difference in bag density
-70 to -100%
-40 to -70%
-10 to -40%
10 to -10%
10 to 40%
40 to 70%
70 to 100%
No data

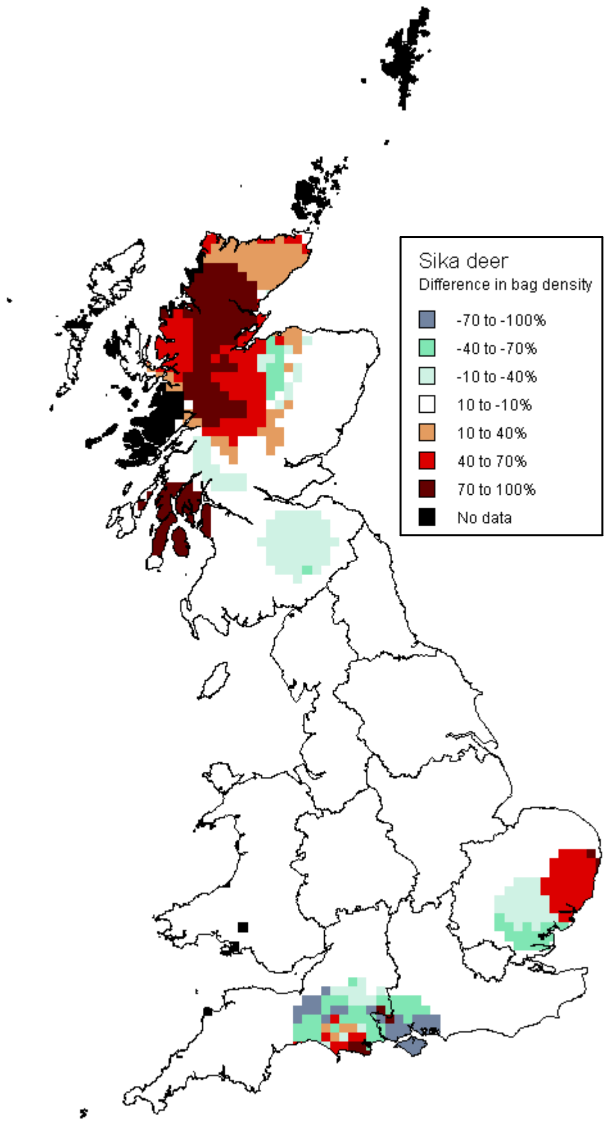
Sika Deer NGC 1995-1999



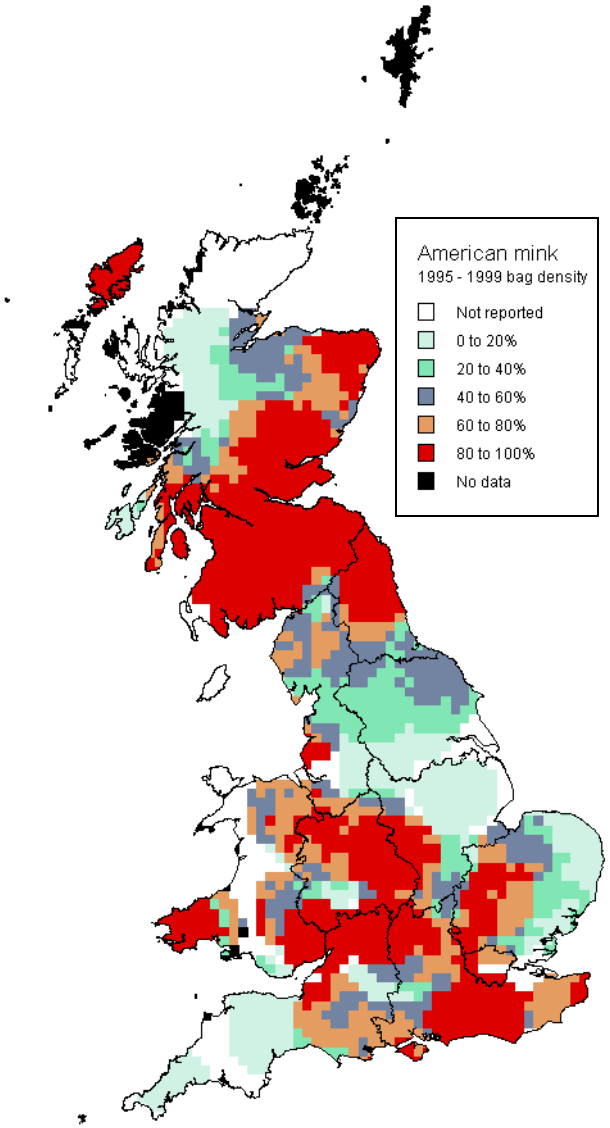
Sika Deer NGC 2005-2009



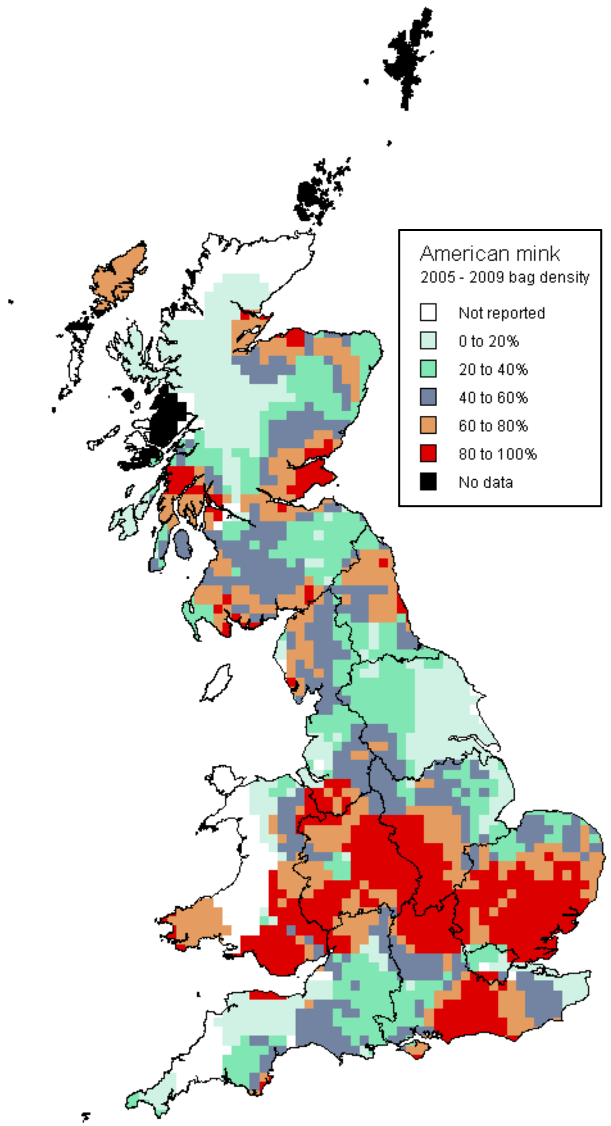
Sika Deer NGC Change



American Mink NGC 1995-1999



American Mink NGC 2005-2009



American Mink NGC Change