BTO Research Report No. 286

Determining Greylag and Canada Goose Habitat Associations During the Breeding Season

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A report by the British Trust for Ornithology

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CONTENTS

Page No.

List of Tables

Page No.

List of Figures

Page No.

List of Appendices

Page No.

1. EXECUTIVE SUMMARY

- Surveys conducted during 1999 and 2000 by the British Trust for Ornithology indicated that the feral populations of Canada and Greylag Geese in Britain have continued to increase unabated since the previous complete survey undertaken during 1989-91.

- Increases in population size were due largely to local expansion into marginal habitats rather than an expansion of the geographic range.

- The results of these analyses indicated that, within their core range, the presence of inland freshwaters and lowland grassland were important factors for explaining the current distribution of both species. Additionally Canada Geese were associated with suburban areas and farmsteads.

- The results also suggest that the two species occupy slightly different habitats within the lowland grasslands. Canada Geese were more strongly associated with pasture, amenity turfs, meadows and cropped swards whilst Greylag Geese were more strongly associated with marsh and rough grassland.

- Both species were negatively associated with arable land during the breeding season.

- Generalised linear models, based on these habitat associations, explained 54% of the variation in Canada Goose numbers and 36% of the variation in Greylag Goose numbers.

- No associations were found between changes in numbers of either species between the 1989-91 survey and the 1999 & 2000 surveys and the habitat variables.

- These models, based on data from within the core range of each species, were used to derive maps of predicted relative goose abundance for the whole of Britain in order to envisage how goose populations might expand. This routine suggested that there are considerable tracts of land from which geese are largely absent that contain suitable habitat.

- Understanding the relationships between goose numbers and habitat could enable informed judgements to be made as to how these populations may increase and spread in the future.

2. BACKGROUND

Canada Geese, first introduced into Britain in 1665, were widespread and numerous in Great Britain at the time of surveying for "The New Atlas of Breeding Birds in Britain and Ireland: 1988-91" (Gibbons *et al*. 1993), hereafter referred to as the "1988-91 survey", when the British population was estimated to be 59,500 adults. The rate of growth of the population was estimated at 8% per annum between 1962 and 1976 and 8.3% per annum between 1976 and 1991. The same survey estimated that there were 22,000 adult Greylag Geese *Anser anser*. A reanalysis of the 1988-91 survey data, refined by the use of a habitat stratification (Appendix A), resulted in revised population estimates of 53,000 and 19,500 for Canada Goose and Greylag Goose, respectively.

A feral goose survey organised by the Wildfowl & Wetlands Trust in 1991 specifically targeted Canada and Greylag Geese. That survey was undertaken in the late summer, a period when flightless moulting birds aggregate on large waterbodies so as to be relatively safe from predators (Delany 1993). That survey reported 43,871 adult Canada Geese and 11,737 adult Greylag Geese, fewer birds than estimated by the 1988-91 survey probably because it was restricted to sites where geese congregated to moult. Consequently, that survey would have missed the adults accompanied by unfledged young that were unable to join the large moult flocks.

During 1999 a smaller scale survey was undertaken by the British Trust for Ornithology (BTO) to assess the relative change of the goose populations since the 1988-91 survey (Rehfisch *et al*. 2002). Although it was not possible to sample all habitats used by geese during the 1999 survey, there were strong indications that the numbers of Canada Goose and Greylag Goose had increased substantially during the past decade in particular habitats. During 2000, however, the BTO collected a much larger data set and extended coverage to habitats that had to be excluded from the 1999 survey on practical grounds. Both these surveys were based on a stratified random sample of tetrads (2 km × 2 km grid square) chosen from the 61,509 in Great Britain. Tetrads were classified into strata based on urbanisation, water cover and geographic location. Full details of the methodology are given by Austin *et al*. (2001). Although the published results for the 1988-91 survey were summarised by Ordnance Survey 10 km grid square, that survey had also collected the raw data at the tetrad level (although the 42,736 tetrads covered had not been randomly selected). The original tetrad data from the 1988-91 survey were those used for comparisons between that and subsequent BTO surveys (Austin *et al*. 2001, Rehfisch *et al*. 2002).

The 2000 survey identified considerable population increases for both species since the 1988-91 survey. During the breeding season, it was estimated that there were 93,400 Canada Geese and 35,100 Greylag Geese in Great Britain in 2000. Thus the rate of Canada Goose population growth remained high at 8.6% per annum between the 1989-91 survey and the 2000 survey and that for Greylag Geese was 10.5% per annum over the same period.

The function of the habitat stratification (Appendix 1) used for the 1999 and 2000 surveys had been to improve the precision of the population estimates obtained rather than to specifically investigate habitat related population distribution and growth. However, despite the broad classification used, the analysis revealed that the increases in the numbers of either species of goose have not been consistent across all habitats (Tables 1 & 2). Most of the increase in Canada Goose numbers has occurred in habitats that had held low numbers of these birds in 1988-91. Two habitats in particular, the no-water and medium-water lowland strata, had absorbed most of the numerical increase (Table 1). Although the southern no-water lowland stratum still held geese at relatively low densities in 2000 (1.64 geese per tetrad in 2000, up from 0.65 geese per tetrad in 1988-91), this habitat, that covers 52% of Britain, supported about 56% of the British Canada Goose population. There had been little change in the urban and high water strata, suggesting that either successful control measures had been implemented in these habitats or that without further habitat creation there had been no scope for the population to increase since the 1989-99 survey. The increases in Greylag Geese numbers in the various habitats had overlapped but not paralleled those of Canada Geese. Like Canada Geese the numbers of Greylag

Geese had increased considerably in the medium water lowland stratum, but they had also increased greatly in the "no" water upland stratum (Table 2).

Clearly, both species are still expanding in population size and distribution in Britain and there is no evidence that the population rate of growth is decreasing for either. Given that the degree of change appears to be associated with habitat it is prudent to further investigate these associations with the aim of understanding how the populations of both species have increased in number and extended their geographic range. This would enable informed predictions to be made as to where further increase in numbers and geographic range may occur.

3. OBJECTIVES

1) To use generalised linear models to describe the relationships between goose numbers and habitat.

2) To extrapolate those relationships to the whole of Britain and thus identify areas with suitable habitat mosaics to support further increases in goose numbers and geographic range.

4. METHODOLOGY

The analysis sought to describe the relationships between goose numbers and changes in goose numbers observed between the 1989-91 survey and the 1999 and 2000 surveys, and habitat. Analyses were based on data from the "core area" of each species range the rational being that within these areas goose distributions would strongly reflect any associations they have with habitat, whereas towards edges of their geographic ranges suitable habitat may as yet remain unoccupied or occupied well below carrying capacity. To have included all of Britain or peripheral areas in the analyses would have thus reduced the chances of detecting any underlying goose / habitat associations. The core area for each species were defined to the nearest whole 100 km Ordnance Survey grid square with reference to the distribution maps from Gibbons *et al*. (1993), the core area for Greylag Goose being restricted to those regions occupied by the resident feral population (Table 3).

Bird counts in general have a highly squewed distribution best described as a "zero inflated poisson" due the high incidence of zeros. While many statistical software packages allow a poisson link function to be specified this inadequately describes many bird count datasets. Various data transformations were explored with the aim of normalising the goose numbers data (Figure 1) in order to facilitate analysis using parametric statistical methods. Although none of the transformations dealt well with the high number of zero counts, a double square-root transformation was considered to have dealt best with the upper tail of the frequency distribution. Thus double square-root transformed goose numbers were used in all subsequent analyses. No transformations were used for changes in goose numbers because numbers may decrease giving a negative change and negative numbers do not lend themselves to transformations. However, the distribution of change in goose numbers was considered to be at least reasonably symmetrical.

For each species, associations between both the numbers (transformed) of geese found on tetrads surveyed during the 1999 and 2000 surveys, and change in numbers on those tetrads since the 1989-91 survey, and habitat were first explored by the use of simple correlation statistics. Combining the 1999 and 2000 surveys served to increase the sample size, data from the latter being chosen in preference where tetrads had been surveyed in both years. Habitat data for each tetrad was based on the area in hectares of each of a suite of land cover classes, obtained from the Centre for Ecology and Hydrology's (CEH) remotely sensed "*Land Cover Map of Great Britain: one-kilometre summary data*". Only those habitat classes likely to be of relevance to goose distribution and numbers (Table 4, with full descriptions given in Appendix 2) together with the geographical variables easting and northing referenced to the Ordnance Survey were considered in the data analyses. The CEH's data set was also used to exclude tetrads containing seawater, intertidal flats and saltmarsh from the core area. These habitats would have been too rare within the sample of tetrads to have been incorporated into the modelling process and the tetrads in which they occurred could have contributed small values for other variables to the models due to small land area rather than relative area of the habitats within those tetrads.

A stepwise approach was then used to construct generalised linear models (GLMs: McCullagh and Nelder 1989, SAS Institute Inc 2001) the response variable being either Canada Goose or Greylag Goose numbers or change, the explanatory variables in each case being the subset of those variables described above that best explained the variation in the response variable in question. Goose numbers were modelled without an intercept term to prevent negative values being predicted for the response variable. Changes in goose numbers were modelled with an intercept to allow decreases as well as increases to be predicted. Given that changes in goose numbers had not been consistent across all the broad habitat strata previously used to derive population estimates (Austin *et al*. 2001, Rehfisch *et al*. 2002) those changes were modelled for both all habitat strata combined and each habitat stratum separately. During model development variables with positive parameter estimates were given precedence over those with negative parameter. Negative associations identify habitats that do not hold geese or support only small numbers but do not distinguish between those habitats which are unsuitable for geese *per se* (e.g. forestry which does not offer resources needed by the birds) from habitats that may be actively avoided (e.g. habitats where geese encounter high disturbance or high densities of predators). The latter are less useful for predictive purposes. For example, a hypothetical negative relationship between arable farmland and geese, if used in a predictive model would push the estimated goose numbers towards high values in areas dominated by unfavourable habitats, such as forestry plantations or montane areas, where there was also little arable land, and towards low numbers in areas where there was substantial areas of arable land admixed with habitats favoured by geese such as wetlands.

The resulting models, based on species core areas, were then used to predict values of each response variable for all tetrads in Britain and these were mapped using a Geographic Information System (GIS; ArcView v8, ESRI 2001). The intention of this exercise was to give an indication of how the pattern of relative abundance might develop throughout Britain should these species continue to spread and fill habitats according to the current associations as determined for the core areas. Given that other factors besides land cover may be limiting the expansion of the goose populations it was not intended that these alone should be used as a predictive tool of future goose numbers, only as a guide to possible increases in the geographical distribution. The distribution of predictive habitat variables that significantly explained variation in the response variables were also mapped (Figures 2 to 5) to aid interpretation of the models, as were the numbers of each species counted on each tetrad during the 1989-91 survey (Figures 6 & 7).

5. RESULTS

5.1 Correlations Between Goose Numbers and Land Cover

Numbers of both Canada Geese and Greylag Geese were significantly correlated with many of the selected habitat variables, although the strength of these associations varied considerably (Table 5).

In the case of Canada Geese the strongest positive correlations were with the land cover classes Inland Freshwater, Suburban & Farms, Urban & Industrial and Combined Lowland Grassland, whilst there were strong negative correlations with Arable Land and Combined Cultivated. In the case of Greylag Geese the strongest positive correlations were with the land cover classes Inland Freshwater, Marsh & Rough Grass and Ruderal Weeds.

5.2 Correlations Between Changes in Goose Numbers and Land Cover

Neither the change in numbers of either Canada Geese nor Greylag Geese were significantly correlated with any of the land cover variables considered.

5.3 Modelling Goose Numbers in Relation to Land Cover

The geographic variables Easting and Northing were useful in explaining the east to west and south to north decrease in the numbers of geese which are apparent within their core areas as well as nation-wide. However, to have included these variables in the models would not have allowed assessment of goose abundance outwith the core area based on habitat. This is because land cover also displays geographic trends and thus land cover is itself correlated with the two geographic variables. Thus, when they were included they displaced the habitat variables from the model. The resulting models dominated by the geographic variables would, therefore, have tended to do no more than extrapolate the south to north and east to west decreases in current goose numbers observed in the core areas across all of Britain with little recognition of habitat. Consequently the land cover variables were retained in the models in preference to the geographical variables.

Modelling Canada Goose numbers

There were 756 tetrads in the Canada Goose core area that were covered by either the 1999 or 2000 survey. The best model obtained, explaining 53% of the variation in Canada Goose numbers, was a three variable model based on Combined Lowland Grassland, Freshwater and Suburban Areas & Farms (Table 6). Other variables that had showed strong associations with Canada Goose numbers were not retained during the stepwise modelling procedure due to inter-correlations with retained variables. Arable Land, for example, was also a useful predictor of Canada Goose numbers when it was substituted for Lowland Grassland (with which it was inversely correlated).

When this model was used to derive a map of predicted relative Canada Goose abundance for the whole of Britain (Figure 8) this suggested that there are considerable areas in the west of Britain as far north as the Central Lowlands of Scotland that, based on the abundance of the key habitats represented in the model, could hold much higher densities of Canada Geese than they do at present.

Modelling Greylag Goose numbers

There were 647 tetrads in the Greylag Goose core area that were covered by either the 1999 or 2000 survey. The best model obtained, explaining 36% of the variation in Greylag Goose numbers, was a three variable model based on Combined Lowland Grassland, Freshwater and Marsh & Rough Grass (Table 7). Other variables that showed strong associations with Greylag Goose numbers but which were not retained during the stepwise modelling procedure due to inter-correlations with retained variables included Ruderal Weeds (highly correlated with Marsh & Rough Grass) and Arable Land (highly inversely correlated with Combined Lowland Grassland).

When this model was used to derive a map of predicted relative Greylag Goose abundance for the whole of Britain (Figure 9) this suggested that there are considerable areas in the west of Britain that, based on the abundance of the key habitats represented in the model, could hold much higher densities of Greylag Geese than they do at present. These areas include much of lowland Wales and southwest England.

5.4 Modelling Changes in Goose Numbers Between the 1989-91 Survey and the 1999 and 2000 Surveys

There were 554 tetrads in the Canada Goose core area and 465 tetrads covered by the Greylag Goose core area that were covered by both the 1989-91 survey and either the 1999 or 2000 survey. None of the habitat variables significantly explained any of the variation in the change in the numbers of either species between the two survey periods either when considering the whole core area or when considering the change separately for each habitat stratum.

6. DISCUSSION

This analysis has identified a number of key land cover types associated with the distribution of both Canada Geese and Greylag Geese within the core of their British distributions. The surveys on which these analyses were based were conducted during the breeding season when geese are more evenly distributed within their range than at other times of the year. Outwith the breeding season geese may come together into large concentrations, initially to moult at sites offering security during the flightless period in June and July. Thereafter flocks generally persist until late winter. At these other times of year habitat associations may be different to those identified during the breeding season. However, the British feral populations of both species are relatively sedentary, although they may forage over a considerable local area on a daily basis. Much of the historic spread of both species has been attributed to the natural spread of birds from sites of deliberate introductions by landowners and wildfowling clubs (Owen *et al*. 1986, Gibbons *et al*. 1993). The sedentary nature of these species suggests that the breeding season distribution of geese will be a good predictor of the year-round distribution. Comparisons of winter and summer distributions (Lack 1986, Gibbons *et al*. 1993) shows that this was the case during the 1980s for both Canada Geese and Greylag Geese (allowing for geographic separation of feral and migratory wild Greylags). Although a small proportion of the Canada Goose population are know travel considerable distances to moult this will not be the case for successful breeders and most non-breeders and failed breeders. In fact the median distance travelled by Canada Geese that have been ringed, mostly during the moult period, and later recovered dead (over 9,000) is only 11 km (Austin *et*. *al*. 1996, Wernham *et*. *al*. in press). It therefore follows that problems associated with large concentrations of feral geese such as the risk of airstrike, agricultural damage, fouling of amenity land, damage to natural vegetation and impacts on native bird species, are likely to be confined to areas within the breeding range and in proportion to the breeding densities.

6.1 Relationships Between Goose Population Increase and Habitat

Comparisons between the 1998-91 survey and the 1999 and 2000 surveys (Austin *et al*. 2001, Rehfisch *et al*. 2002) found that both Canada Geese and Greylag Geese had shown greatest increases in particular habitat strata. It may, therefore, seem surprising that none of the habitats considered here significantly explained population increase for either Canada Greylag Geese. However, the two results are not contradictory. The stratification used by the 1999 and 2000 surveys had aimed to minimise the variance of the data collected and thus reduce the level of uncertainty of the resulting population estimates, by separating, for example, tetrads in habitats holding very high numbers of Canada Geese (e.g. over one hundred geese in a typical "high water, high urban, lowland" tetrad) from those in habitats holding very small numbers of Canada Geese (e.g. less than one goose in a typical "no water lowland" tetrad). Habitats with particularly high numbers of Canada Geese are rare in comparison with those holding small numbers of geese for example, under the survey stratification, 34,282 British tetrads were classified as "no water lowland" whereas only 97 were classified as "high water, high urban lowland". Consequently, even if Canada Geese had increased at a higher rate in the high density habitats the contribution to the numerical increase in the country-wide population from those high density habitats would still be relatively small.

6.2 Relationships Between Goose Numbers and Habitat

Not surprisingly the presence of fresh water is a useful predictor of the abundance of both species. There is a tendency for Canada Geese to be associated with suburban areas and farms. This may be related to the provision, both intentional and unintentional, of artificial food and the abundance of pools, ponds and reservoirs found in such areas. Also deliberate introductions in the past were probably biased towards public amenity areas. As would be expected for grazing species, both were associated with managed grassland although there were small differences between the species. Canada Geese were most strongly associated with the more intensively managed grassland types including pasture, amenity turf, meadows and cropped swards, while Greylag Geese were most strongly associated with less intensively managed grassland including marsh and rough grassland and ruderal weeds including set-aside land. This may reflect either true differences in habitat preference between the two species of inter-specific competition whereby the large Canada Geese are excluding Greylag Geese from the richer grasslands. Competitive exclusion of Greylag Geese could also explain their negative association with suburban areas and farms although possibly Greylag Geese are more sensitive to human disturbance. The numbers of both species were negatively associated with arable land. This is probably due to the absence of suitable nesting sites and food supply during the breeding season in arable land and explains the relatively low abundance of both species in the eastern coastal counties of England away from waterbodies and towns.

6.3 Predictions of Potential Relative Abundance Across Britain

When the models were used to predict relative abundance across the whole of Britain the resulting maps (Figures 8 & 9) identified many areas in the west of the country where, given the availability of these key habitats, goose densities higher than those in the east would be expected. Currently both Canada Geese and Greylag Geese densities in the west are considerably lower than those in the east and thus there is considerable scope for numbers of both species to increase substantially in the west.

Figures 8 and 9 give an indication of how the pattern of relative abundance might develop throughout Britain should these species continue to spread and fill habitats according to the current associations as determined for the core areas. However, the models on which they are based only explain 56% and 36% of the variation in the numbers of Canada Geese and Greylag Geese respectively. They should not, therefore, be used in isolation as a predictive tool of future goose numbers, only as a guide to possible increases in the geographical distribution and relative numbers. Other factors, not included in the models may also influence future distributions in a manner that substantially modify these predictions. Future work might seek to extend these models by the inclusion of other factors such as weather and population control measures.

6.3.1 Predictions of potential relative abundance for Canada Geese

Canada Geese are currently at their most abundant within a broad band running from the southeast of England through the Midlands reaching to south Lancashire and Yorkshire. At the time of the 1989-91 survey they were sparsely distributed in Wales and south-west England and northern Britain and relatively so in the east of Britain away from towns and major water bodies (Figure 6 & Gibbones *et. al*. 1993). (The 10 km square summary maps presented in Gibbons *et al*. (1993) tend not to differentiate well between high and low densities and the smoothing algorithm used to produce the abundance maps may have been biased by particularly large moulting flocks towards the end of the recording season.). The predicted abundance maps suggest that there is habitat that could support high densities of Canada Geese in southwest England, lowland Wales, the lowlands of northwest England and the central-belt of Scotland. Indeed from our models some of these areas could support densities as high as those observed in the present core range.

There are various reasons why this predicted relative abundance across Britain may not be reached. The models on which these predictions were made explained 56% of the variation in Canada Goose numbers and thus there other factors not considered by these models could that influence the realised abundance. In some northern areas snow-lie during the winter and early spring and freezing conditions could depress population growth but it could equally cause Canada Geese to move to habitats frequented by migratory geese bringing them into direct competition with those species. Also, given that deliberate introductions and translocation of birds in the 1950s and 1960s, ironically often in an attempt to limit local population growth and agricultural damage, which in the past assisted the expansion of Canada Geese, are now fewer (Kirby *et al*. 1999), it might also be expected that range expansion will slow. However, with population size still increasing unabated (Austin *et al*. 2001, Rehfisch *et al*. 2002) natural range expansion may accelerate in response to density related pressures.

6.3.2 Predictions of potential relative abundance for Greylag Geese

The feral population of Greylag Geese is less widespread than that of Canada Geese. Currently feral Greylag Geese are most abundant in the east of England extending into the east Midlands with local population centres also on the Cheshire Plane, Anglesey and northwest England (Figure 7). The predicted abundance maps suggest that there is habitat that could support high densities of Greylag Geese in southwest England, lowland Wales, the lowlands of northwest England and the central-belt of Scotland.

Potential relative abundance across Britain may not be reached for the same reasons as described for Canada Geese. As for Canada Geese, the past expansion of Greylag Geese is believed to have been aided by deliberate introductions and similarly, in the absence of such assistance, range expansion may be less rapid than realised in recent decades. However, the Greylag Goose population is also still increasing in size unabated (Austin *et al*. 2001, Rehfisch *et al*. 2002) and so natural range expansion can be expected.

6.4 Consequences of Expanding Goose Distributions

Based on the availability of suitable land cover there is clearly scope for both species to expand into new areas or increase in areas where numbers are relatively low. This could prove to be a cause of concern for a number of interest groups including farmers, amenity landowners and conservationists. They are also a proven risk to aircraft (Allan *et al*. 1999, Richardson & West 2000). They can contribute to eutrophication of water-bodies, and are a risk to human health (Allan *et al*. 1995, Dawson & Evans 1996, Manny *et al*. 1994, Watola *et al*. 1996). The main concern to farmers relates to damage to arable crops particularly cereals, both in the spring when young crops are growing and in the autumn when cereals are ripening (Gibbons *et al*. 1993). In extreme cases goose grazing can lead to total loss of root crop and cereal yield but more normally 50% or less is lost (Owen *et al*. 1986) although these statistics do not relate to feral geese in Britain. In pastoral areas they could also damage silage, their trampling possibly reducing the efficiency of harvesting. When large concentrations of geese build up on amenity grasslands they are generally perceived to be a nuisance, although if only small numbers colonise such areas they are often appreciated by the public and tolerated by landowners thus making control at an early stage difficult. Large geese, particularly Canada Geese, can be very aggressive during the breeding season and may displace less dominant species of smaller native waterbirds and being aggressive in nest defence, have killed ducks, Moorhen and Coot (Lever 1987, Blair *et al*. 2000). Their aggressive defence of nests and young can also be intimidating to humans. Canada geese tend to dominate the wetlands where they are common and have also been found to be responsible for water eutrophication and ground erosion (Allan *et al*. 1995).

If the feral populations of Canada and Greylag Geese were to expand considerably into the southwest of Scotland they may come into competition with migratory populations of Bean Geese *Anser fabalis*, Pink-footed Geese *Anser brachyrhynchus*, Greylag Geese and Barnacle Geese *Branta leucopsis* during the winter. The populations of feral geese would probably take advantage of the artificial methods adopted to benefit these wild populations such as the provision of supplementary feeding and refuge areas, for example at Caerlaverock NNR. In the case of Greylag Geese there may also be a problem for the conservation of the pure native populations in the north and west of Scotland if these were to interbreed with birds of feral origin. The southwest of Scotland and Wales are also areas used extensively by military aircraft for low-level flight training. Increased numbers of feral geese in these areas could considerably increase the year-round risk of airstrikes to military aircraft.

6.5 Conclusion

In conclusion, the habitat associations identified by this analysis suggest that there may be considerable potential for both Canada Geese and Greylag Geese to increase their geographical range within Britain. Currently both species are patchily distributed in the west and north of Britain and yet these areas would seem to contain much suitable habitat. The population growth rates that continue unabated in the south and east of Britain suggest that such a range expansion should it occur could do so rapidly.

Recommendations for further work would include extending the habitat-based models developed here to consider factors not considered by this analysis such as weather and control measures that might be used to check population growth. Within the time constraints of this project it was only possible to make use of the available habitat data in a simple manner, treating each habitat class as a single variable. An alternative approach would be to describe the habitat with one km squares based on a principle components analysis and then using the resulting factors in the general linear models. This would take more account of the habitat mosaics within each one km square. Alternatively GIS modelling could also be used to search for goose associations with habitat mosaics. The latter would have the advantage of being spatially aware and thus not treating each tetrad as independent of those in its neighbourhood as does the generalised linear model approach. Furthermore, models derived from statistical or GIS based models based on habitat associations could be coupled with dispersal information derived from ringing recoveries data for Canada Geese and Greylag Geese to produce simulations of population spread by using GIS cellular automata tools.

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Table 1 Percentage change in estimated numbers of Canada Geese by habitat (from Austin *et al*. 2001). A description and derivation of the habitat stratification is given in Appendix 1.

	Canada Goose Population Change		
Stratum	**1988-91**	**2000**	**Change**
high urban, high water, lowland	3,691	3,101	-16%
low urban, high water, lowland	4,135	3,750	-9%
“no” urban, high water, lowland	3,088	1,060	-66%
high water, upland (northern)	23	0	-
high water, upland (southern)	1,217	1,003	-18%
Medium water, lowland (northern)	66	63	-5%
Medium water, lowland (southern)	17,403	26,019	50%
Medium water, upland (northern)	15	0	-
Medium water, upland (southern)	1,219	4,199	244%
“no” water, lowland (northern)	54	0	-
“no” water, lowland (southern)	21,044	52,697	150%
“no” water, upland (northern)	199	0	-
“no” water, upland (southern)	861	1,443	68%

Table 2 Percentage change in estimated numbers of Greylag Goose by habitat (from Austin *et al*. 2001). A description and derivation of the habitat stratification is given in Appendix 1.

	Greylag Goose Population Change		
Stratum	**1988-91**	**2000**	**Change**
high urban, high water, lowland	605	827	37%
low urban, high water, lowland	2,266	2,450	8%
“no” urban, high water, lowland	916	1,342	47%
high water, upland	1,398	2,725	95%
Medium water, lowland	5,704	10,821	90%
Medium water, upland	1,717	1,905	11%
“no” water, lowland	4,576	4,670	2%
“no” water, upland	2,269	10,253	352%

Table 3 Core areas used for model development referenced to 100 km Ordnance Survey grid square.

Species	Core Area - Ordnance Survey 100 km grid squares, arranged geographically			
Canada Goose	SD	SE	TA	
	SJ	SK	TF	TG
	SO	SP	TL	TM
		SU	TQ	TR
		SY	SZ	TV
Greylag Goose	SE	TA		
	SK	TF	TG	
		TL	TM	
	SU	TQ	TR	
	SZ	TV'		

Table 4 Habitat classes, from the CEH remotely sensed "*Land Cover Map of Great Britain: one-kilometre summary data*" selected for the modelling process (full descriptions for classes used are given in Appendix 2).

Class	Derivation from Land Cover Map class
Inland Freshwater	2
Lowland Grass & Heath	5
Pasture & Amenity Turf	6
Meadows & Cropped Sward	7
Marsh & Rough Grass	8
Arable land	18
Ruderal Weeds	19
Suburban & Farms	20
Urban & Industrial	21
Combined Lowland Grassland	6 + 7
Combined Cultivated	18 + 19

Table 5 Correlations between numbers of Canada Geese and Greylag Geese and selected variables from the CEH remotely sensed "*Land Cover Map of Great Britain: one-kilometre summary data*". Goose numbers were normalised using a double square-root transformation.

Habitat Variable	**Canada Goose numbers** n=754 (rho, P)	**Greylag Goose numbers** n=645 (rho, P)
Easting	-0.067 NS	0.182 <0.0001
Northing	-0.118 0.0011	-0.053 NS
Inland Freshwater	0.218 <0.0001	0.241 <0.0001
Lowland Grass & Heath	-0.025 NS	-0.026 NS
Pasture & Amenity Turf	0.075 0.0387	-0.004 0.NS
Meadows & Cropped Sward	0.092 0.0119	0.084 0.0319
Marsh & Rough Grass	-0.047 NS	0.190 <0.0001
Arable Land	-0.259 <0.0001	-0.085 0.0303
Ruderal Weeds	0.093 0.0108	0.170 <0.0001
Suburban & Farms	0.117 0.0013	-0.055 NS
Urban & Industrial	0.101 0.0056	0.020 NS
Combined Lowland Grassland	0.102 0.0049	0.053 NS
Combined Cultivated	-0.253 <0.0001	-0.074 NS

Table 6 Details of the generalised linear model describing the relationship between Canada Goose numbers and land cover. Goose numbers were normalised using a double square-root transformation. Data from 756 tetrads were used in model development.

Variable	**Parameter Estimate**	**Partial R^2**	**Model R^2**	**$F_{2,645}$**	**P**
Combined Lowland Grassland	0.0107	0.4021	0.4021	506.3	<0.0001
Inland Freshwater	0.0052	0.0849	0.4870	124.5	<0.0001
Suburban & Farms	0.0058	0.0525	0.5395	85.7	<0.0001

Table 7 Details of the generalised linear model describing the relationship between Greylag Goose numbers and land cover. Goose numbers were normalised using a double square-root transformation. Data from 647 tetrads were used in model development.

Variable	**Parameter Estimate**	**Partial R^2**	**Model R^2**	**$F_{2,645}$**	**P**
Combined Lowland Grassland	0.0030	0.2422	0.2422	205.8	<0.0001
Inland Freshwater	0.0085	0.0884	0.3306	85.0	<0.0001
Marsh & Rough Grass	0.0145	0.0338	0.3644	34.2	<0.0001

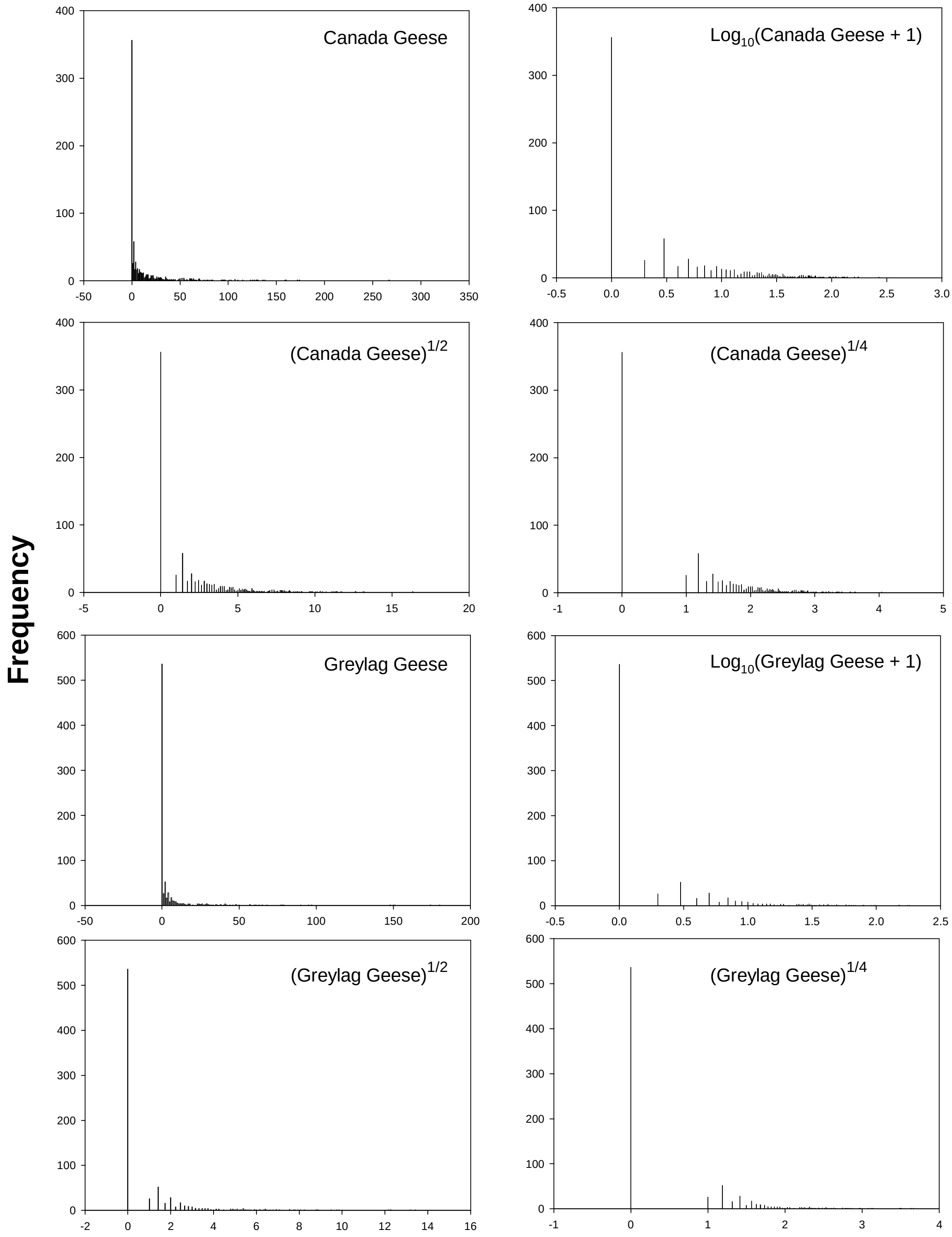

Figure 1 Frequency distributions of goose counts under various transformation. For each species the plots show, in order, untransformed counts, $\log_{10}$(count+1), square-root transformed counts and double square-root transformed counts.

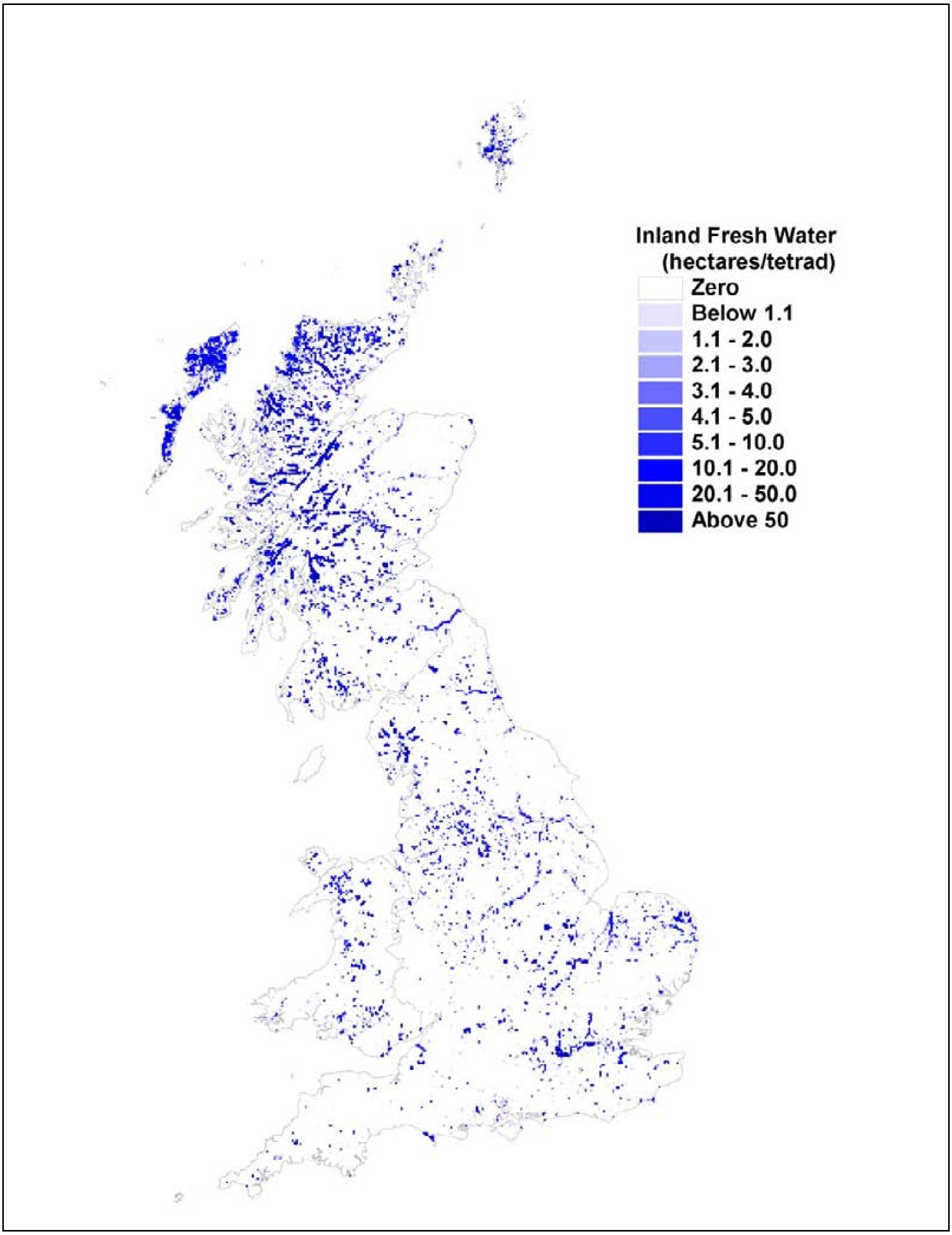

Figure 2 Distribution of inland fresh water from the CEH *"Land Cover Map of Great Britain: one-kilometre summary data"* (class 2).

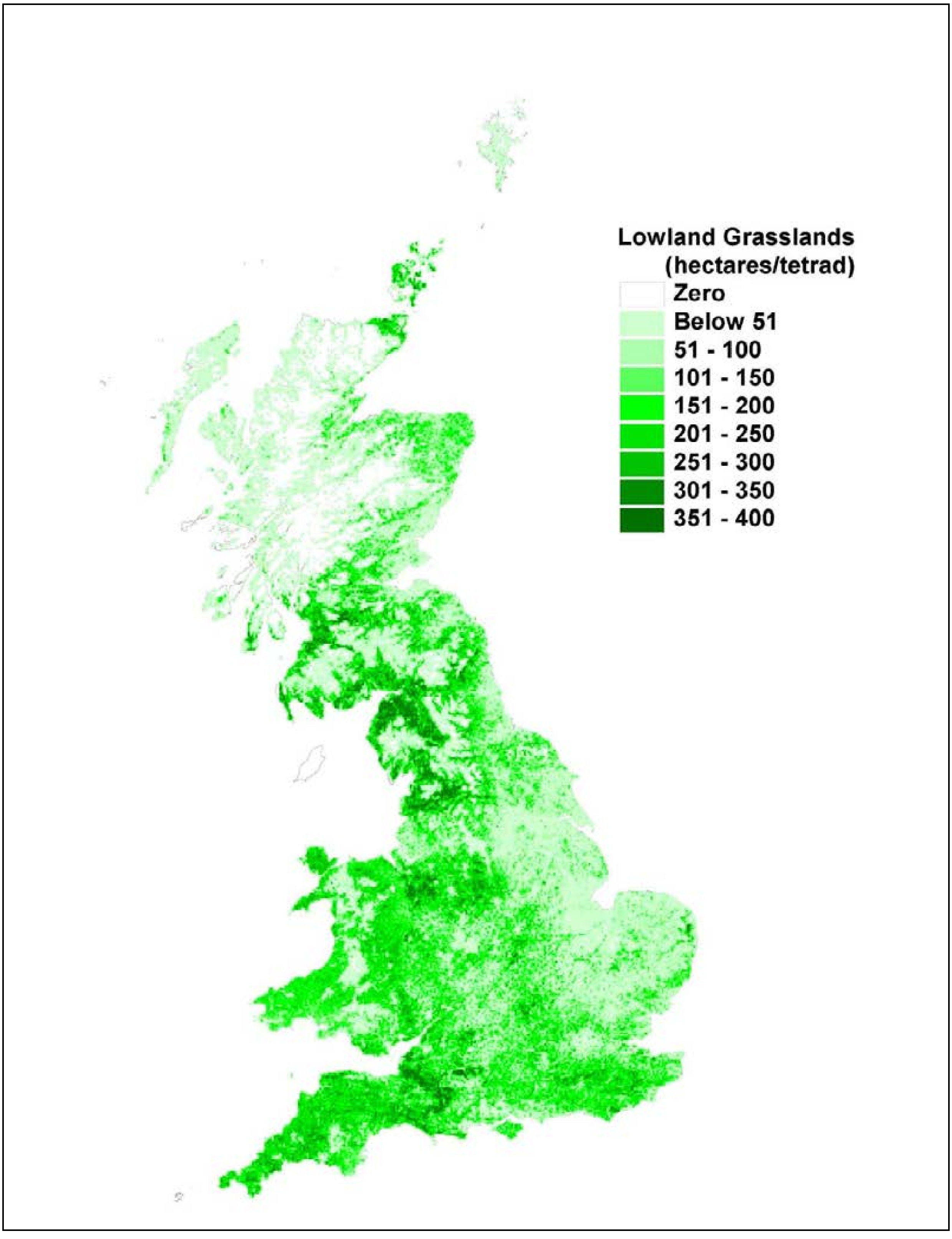

Figure 3 Distribution of Lowland grassland from the CEH *"Land Cover Map of Great Britain: one-kilometre summary data"* (classes 6 + 7).

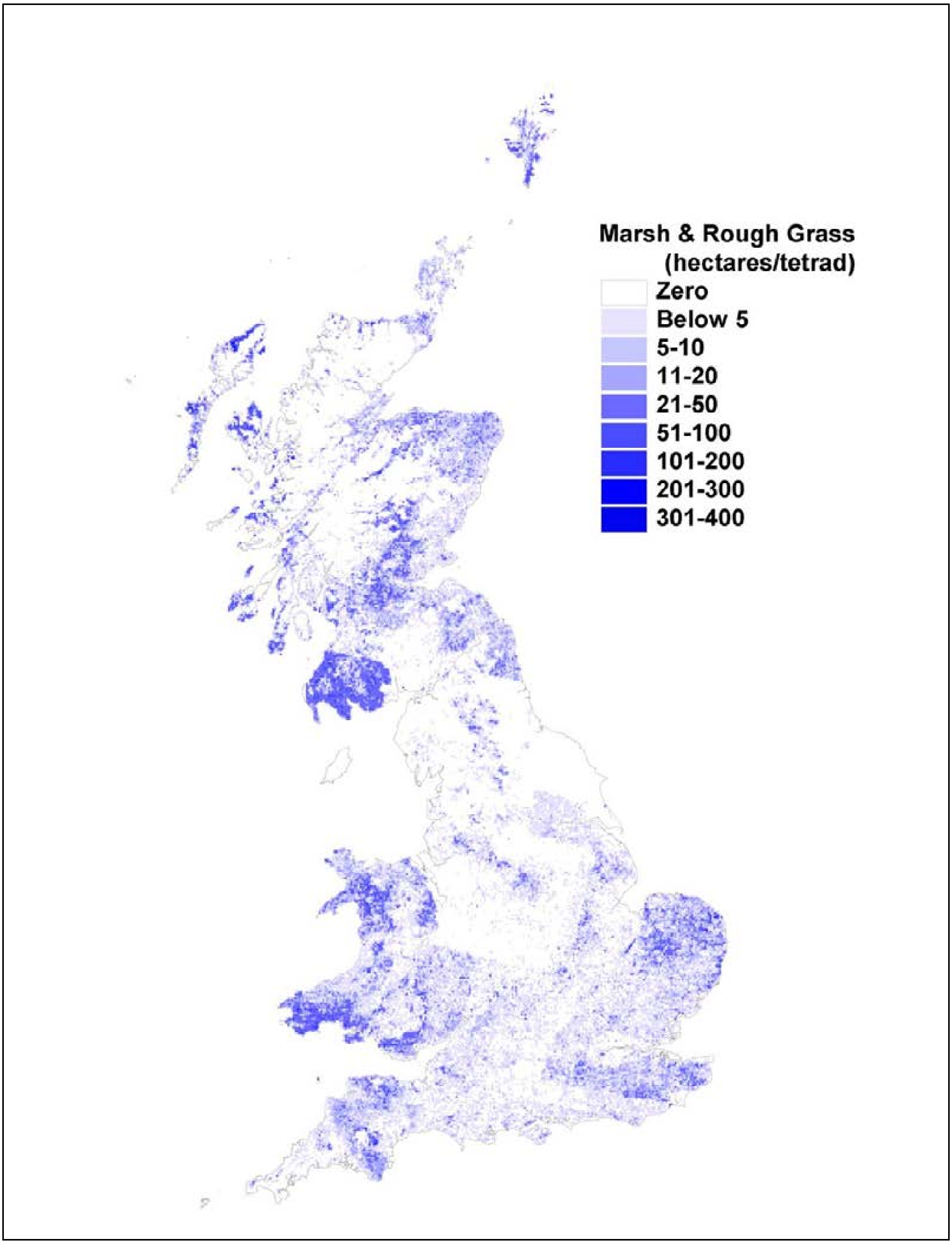

Figure 4 Distribution of Marsh & Rough Grass from the CEH *"Land Cover Map of Great Britain: one-kilometre summary data"* (class 8).

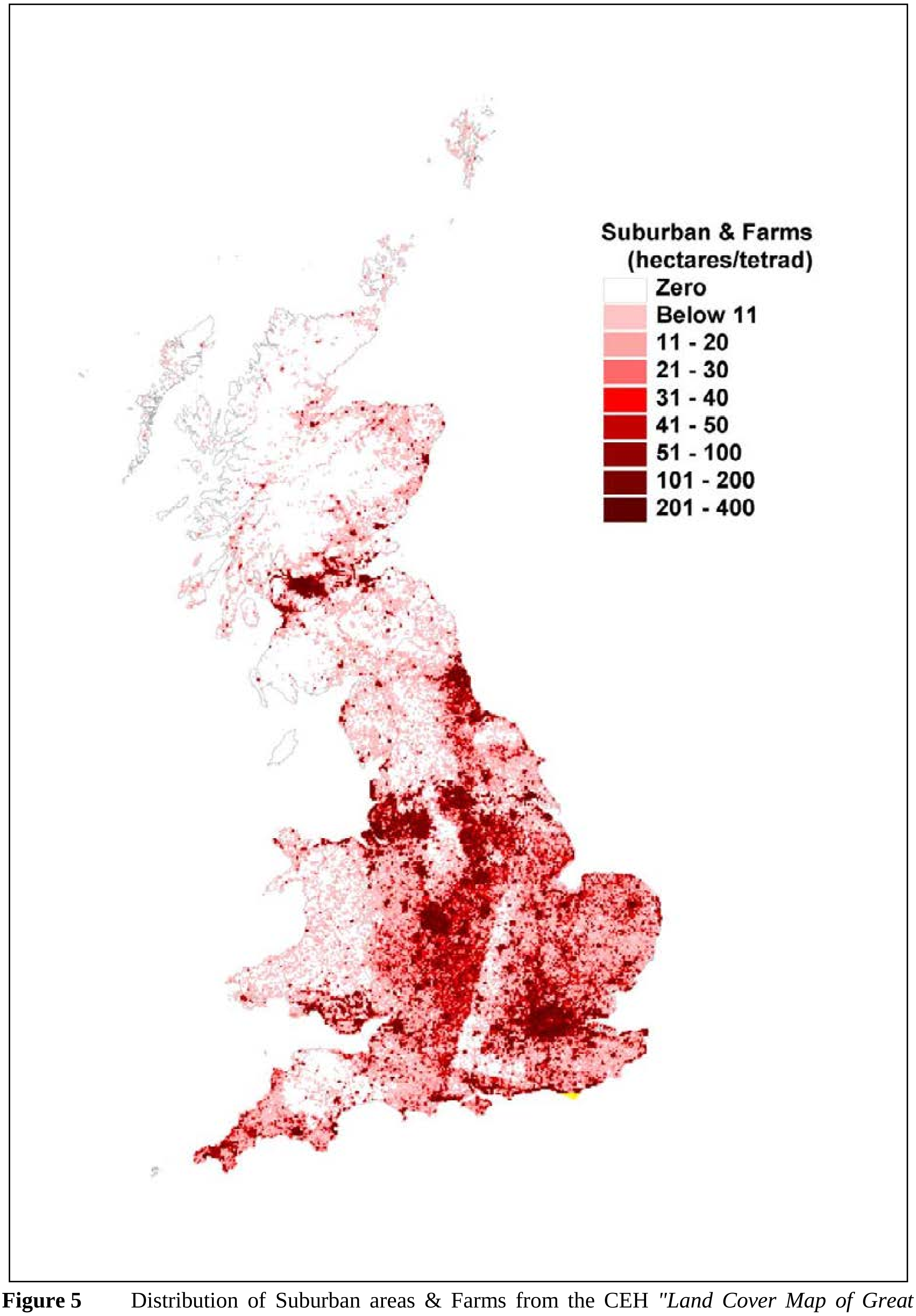

Figure 5 Distribution of Suburban areas & Farms from the CEH *"Land Cover Map of Great Britain: one-kilometre summary data"* (class 20).

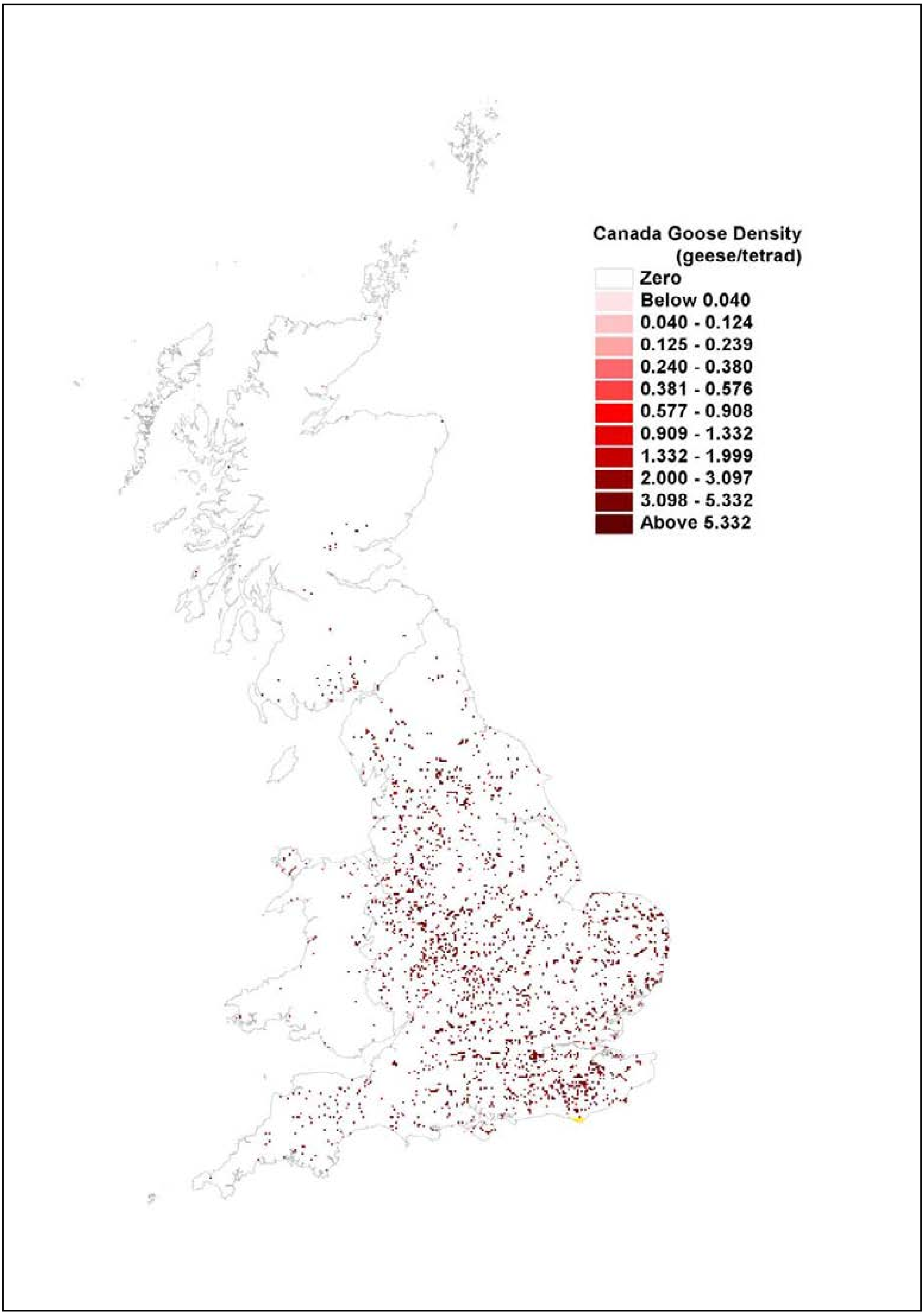

Figure 6 Canada Goose numbers from tetrads visited during the 1989-91 survey.

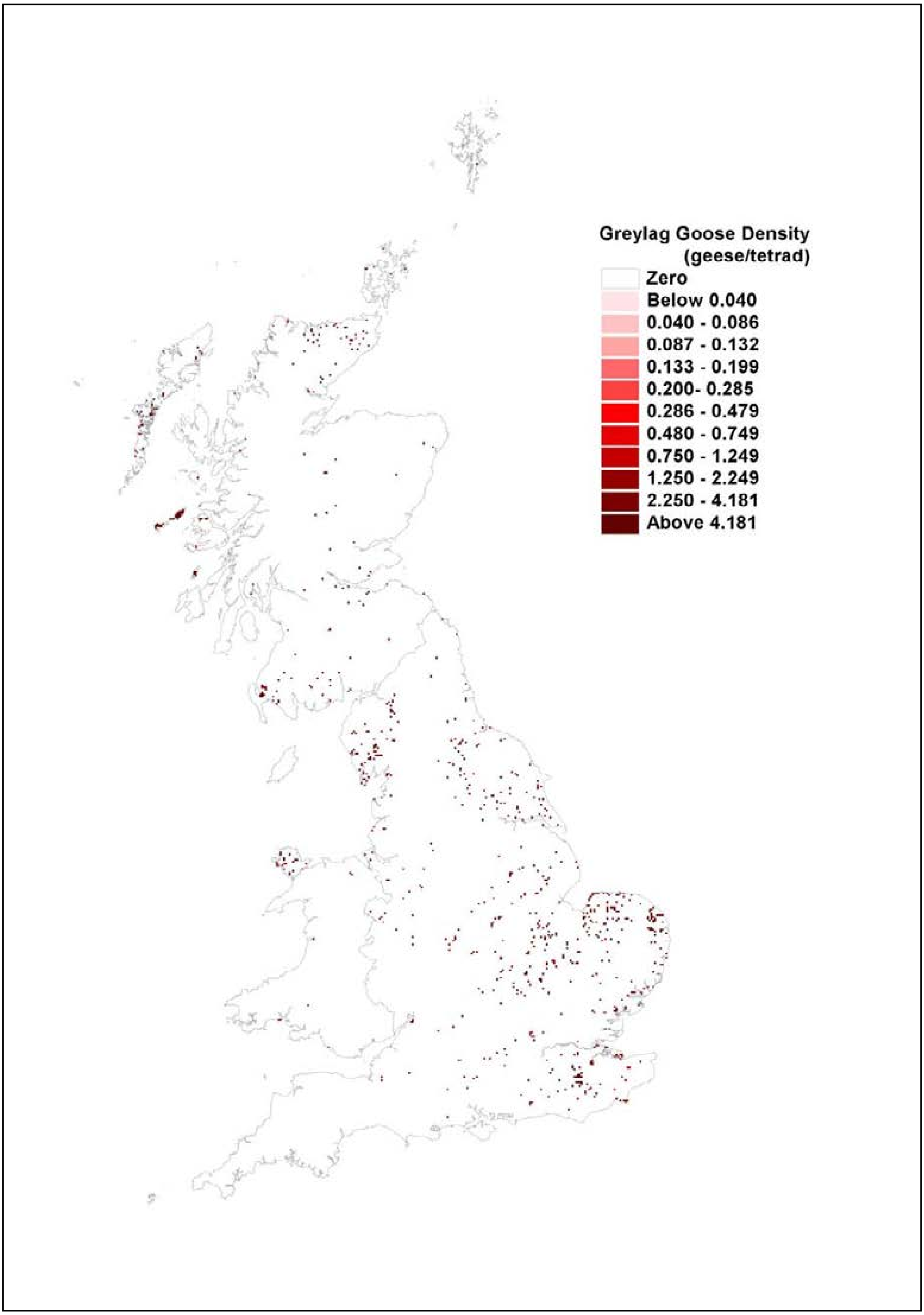

Figure 7 Greylag Goose numbers from tetrads visited during the 1989-91 survey.

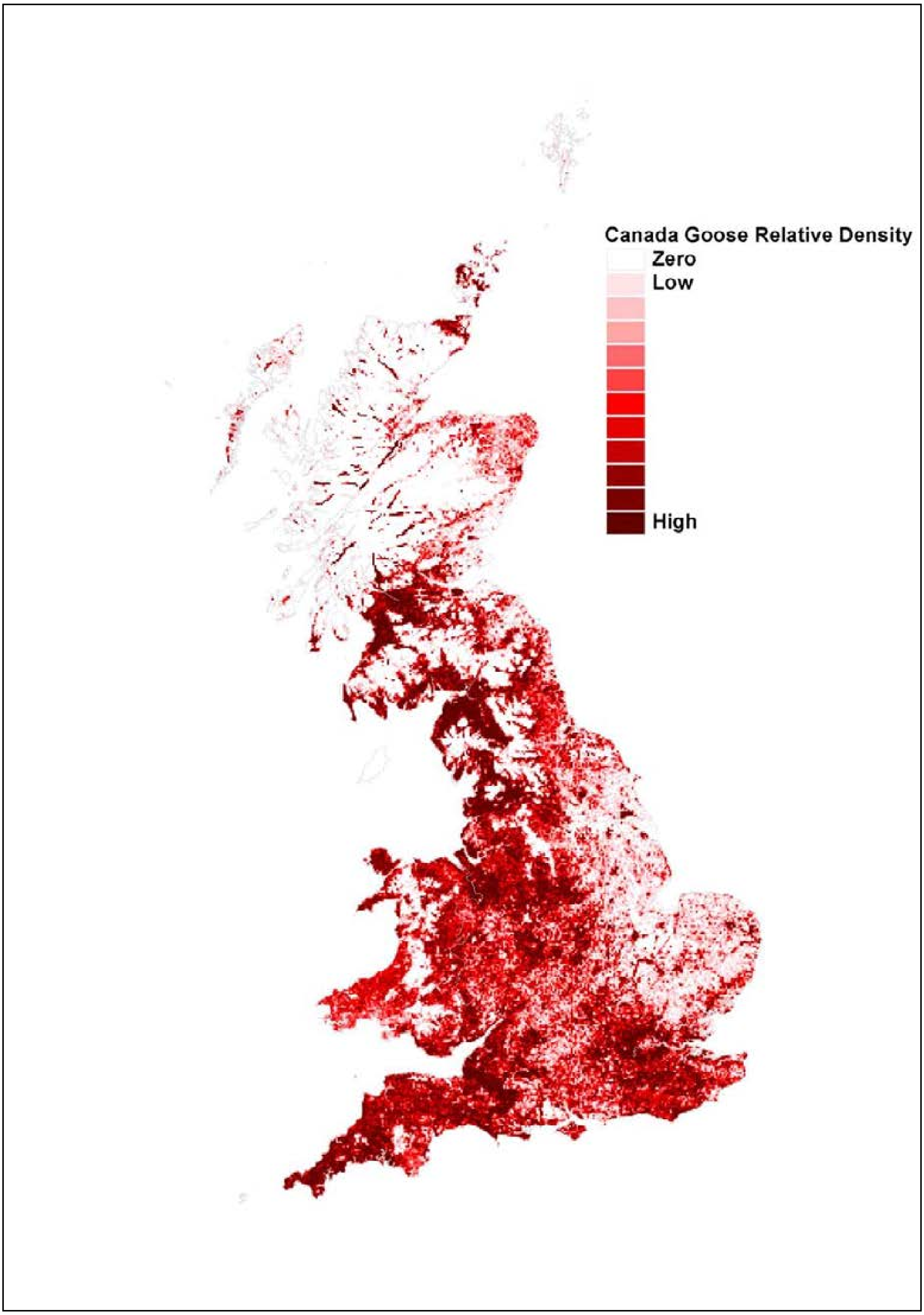

Figure 8 Predicted relative abundance of Canada Geese obtained by extrapolation from the model for the species core area to the whole of Britain.

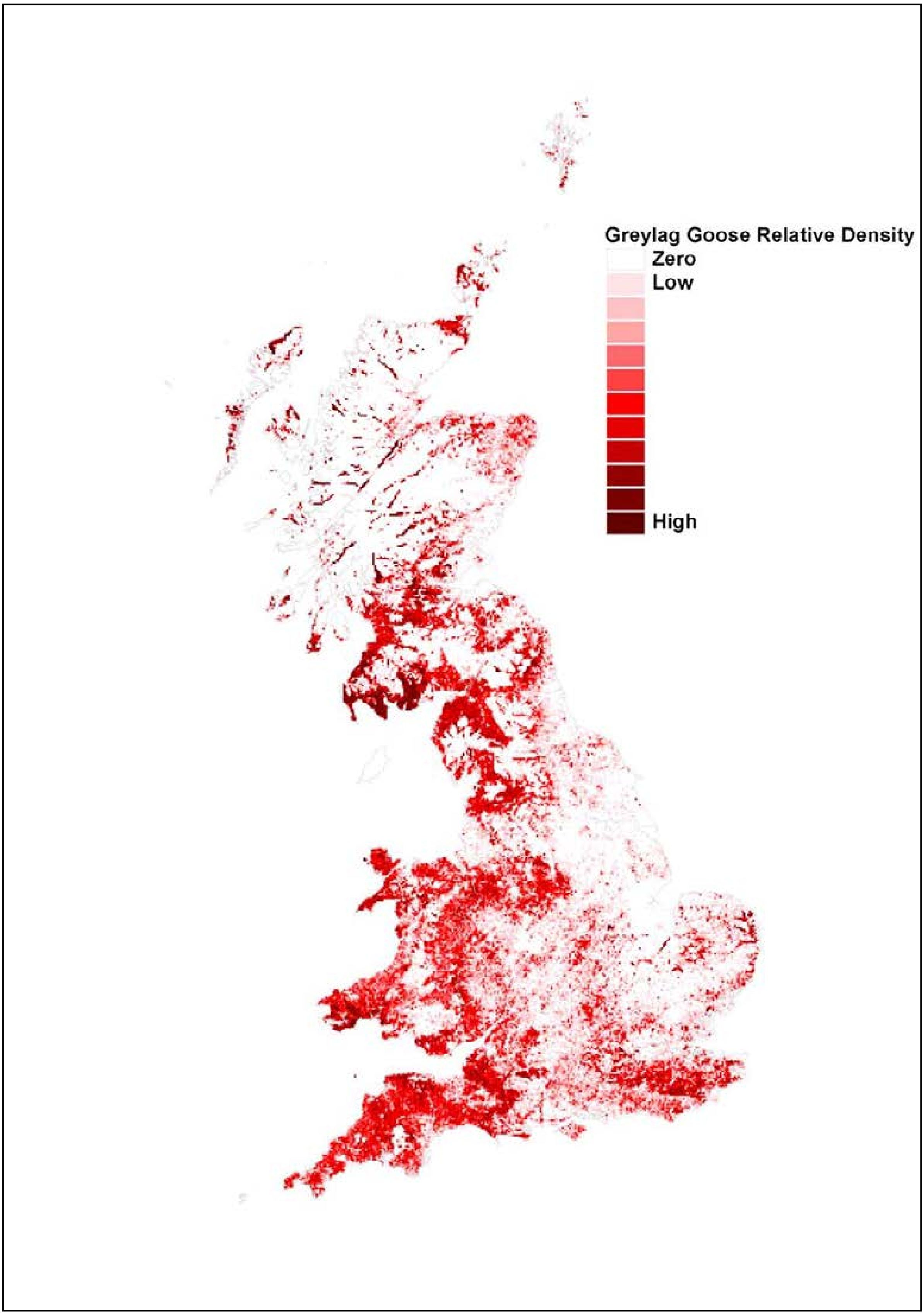

Figure 9 Predicted relative abundance of Greylag Geese obtained by extrapolation from the model for the species core area to the whole of Britain.

APPENDIX A

Survey Stratification Used for 1999 and 2000 Feral Goose Surveys

The habitat stratification used for the 1999 and 2000 feral goose surveys (Rehfisch *et al*. 2002, Austin *et al*. 2001) was based on proportional cover of urbanisation, fresh water, upland / lowland character and a north / south divide.

Classification of the Degree of Urbanisation and Water Cover

Urban and water cover classifications were based on the Centre for Ecology and Hydrology (CEH) remotely sensed "*Land Cover Map of Great Britain: one-kilometre summary data*", a 25-class system last updated in April 1997. The pixel resolution corresponds to a 25-metre grid cell. Each record contains the percentage cover for each of 25 land cover classes for a one-kilometre Ordnance Survey grid square.

Urban cover was based on category 21 (Appendix B). This information was used to derive three levels of urban cover for our tetrad stratification:

high urban ≥ 5% urban
low urban < 5% urban
"no" urban 0 % urban

Water cover was based on category 2 (Appendix B). This information was used to derive three levels of water cover for our tetrad stratification:

high water ≥ 5% water
medium water < 5% water
"no" water 0 % water

Classification of Upland / Lowland Character

The division between upland and lowland character was based on the ITE LANDCLASS stratification (Benefield and Bunce, 1982) under which each 1-km grid square of Britain is classified into one of 32 landclass types. This information was used to derive two categories of land type for this survey, "primarily upland" and "primarily lowland" (Table A):

Table A Landclass types used to assign tetrads to lowland and upland categories. See Benefield and Bunce (1982) for detailed descriptions of landclass types.

Land type classification for the 2000 survey	ITE Landclass Type
Lowland Landclass Types	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,25,26,27
Upland Landclass Types	17,18,19,20,21,22,23,24,28,29,30,31,32

Landclass descriptions for tetrads were derived from these as follows:

Upland > 25% (2 to 4) of 1-km squares in the tetrad classified as upland landclass types
Lowland ≤ 25% (0 to1) of 1-km squares in the tetrad classified as upland landclass types

Overlaying the urbanisation, water cover and land type classifications derived the final habitat stratification. The water cover and land type classifications were completely cross-tabulated to give six categories. The urbanisation classification was only cross-tabulated with one of the resulting six categories: high water lowland. This resulted in nine categories for the stratification. Urbanisation was vary rare in the five categories other than high water lowland and consequently a saturated threeway cross tabulation would have resulted in 18 categories many of which would have contained no or virtually no tetrads.

Classification of Northern and Southern Regions

In order to optimise the effort of the counters, the survey Britain was sub-divided into "northern" and "southern" sub-samples for all but the three high water lowland strata, for these areas of high water were the areas most likely to be colonised first during any range expansion. The southern sub-divisions were sampled to a higher degree than the northern sub-divisions. The southern sub-divisions correspond to that part of Britain covered by the 1999 survey with the exception that all of Wales was included. The northern and southern sub-divisions were based on Ordnance Survey 100 km grid squares:

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Northern	southernmost 100km grid squares are NL, NM, NN, NO (*i.e.* north of central lowlands of Scotland)
Southern	northernmost 100km grid squares are NR, NS, NT, NU (*i.e.* central lowlands of Scotland southwards)

Overlaying the existing habitat strata, other than high-water lowland strata, with this geographic stratification results in a 13-class stratification (Table B).

Table B Coverage obtained during the 2000 Canada goose survey. All tetrads visited during the second visit period had been visited during the first visit period.

Stratum	**Total in Britain**
high urban, high water, lowland	97
low urban, high water, lowland	195
“no” urban, high water, lowland	215
high water, upland (northern)	1,071
high water, upland (southern)	282
medium water, lowland (northern)	196
medium water, lowland (southern)	2,788
medium water, upland (northern)	2,691
medium water, upland (southern)	924
“no” water, lowland (northern)	2,152
“no” water lowland (southern)	32,130
“no” water, upland (northern)	9,304
“no” water, upland (southern)	9,464
Total Tetrads	61,509

APPENDIX B

Details of classes from the CEH remotely sensed "*Land Cover Map of Great Britain: one-kilometre summary data*" used in this report

These data are a 25-class system last updated in April 1997. Each record contains the area in hectares for each of 25 land cover classes for a one-kilometre Ordnance Survey grid square.

Category 2, Inland Water: "*Inland fresh waters and estuarine waters above the first bridging point or barrier. Inland water includes all map-able fresh waters and any estuarine waters which are excluded in category1 (Sea/Estuary). The maps record only those areas which are water-covered on both the winter and summer images. Thus, reservoirs with summer draw-down, or winter-flooded meadows are classified to the summer class (i.e. bare or grassland in these examples)*".

Category 6, Pasture / Meadow / Amenity Grass: "*Pastures and amenity swards, mown or grazed, to form a turf throughout the growing season. Agricultural grasslands comprise many types, from newly sown leys, of single species, to largely unimproved swards of indigenous species*". … "*It characteristically forms a cropped sward, comprising finer grass species (e.g. Festuca, Agrostis, Lolium and Poa spp.) often with many other grasses and herbs. The sward is maintained by mowing and/or grazing, such that coarser species of grass, herbs and scrub cannot become dominant*".

Category 7, Meadows, Verges and Seminatural Cropped Swards: "*Meadows, verges, low intensity amenity grasslands and semi-natural cropped swards, not maintained as a short turf. Meadows and verges include grasslands which are managed, but mostly at a lesser intensity than the previous class*". "*The swards are characterised by Festuca rubra and ovina, Agrostis stolonifera, A. tenuis and/or A. canina, often with substantial quantities of rushes (Juncus spp.), sedges (Carex spp.) and broadleaved plants. Alternatively, the seminatural grasslands may be agriculturally non-productive swards which are managed by occasional cutting to prevent excessive weed or scrub growth, e.g. roadside verges, country parks, golf course semi-rough areas*".

Category 8, Marsh/Rough Grassland: "*Lowland marsh/rough grasslands, mostly uncropped and unmanaged, forming grass and herbaceous communities, of mostly perennial species, with high winter-litter content. This class includes lowland herbaceous vegetation of fens, marshes, upper saltmarshes, and rough or derelict ground. The characteristic feature of this category is that the swards are not significantly cropped by mowing or grazed by stock. In fact most are unenclosed grasslands, abandoned from economic use. The result is that they have a high standing crop of vegetation, most of which dies back in winter, leaving a dense plant litter*".

Category 18, Arable land: "*Arable and other seasonally or temporarily bare ground. Tilled land includes all land under annual tillage, especially for cereals, horticulture etc. It also includes leys in their first year, i.e. if they were bare at the time of the winter imagery. Other land, vegetated at the time of summer imagery but bare soil during the winter, is also included in this land cover type: hence any temporarily bare ground (e.g. from scrub-clearance, development, mining or soil tipping) would be classified in this category*".

Category 19, Ruderal weed: "*Ruderal weeds colonising natural and man-made bare ground. The ruderal weed cover-type is generally bare ground being colonised by annual and short- lived perennial plants, usually with a considerable remnant of bare ground, especially in winter. The ground may be naturally bare, e.g. shingle beaches, or abandoned arable land, e.g. set-aside, or derelict industrial works such as demolished factories, gravel pits etc*".

Category 20, Suburban: "*Suburban and rural developed land comprising buildings and/or roads but with some cover of permanent vegetation. The suburban/rural development category includes all land where the pixels of the Landsat image have recorded a mixture of built-up land and permanent vegetation. Most suburban and rural developments, where the buildings and associated car-parks etc. remain small enough that they do not fill all of each pixel, are included in this cover-type. Small rural industrial estates, glasshouses, railway stations, larger rural roads, villages, small retail sites are all included in this class*".

Category 21, urban: "*Industrial, urban and any other developments, lacking permanent vegetation: The urban development category covers all developments which are large enough to completely fill individual pixels, to the exclusion of any significant quantities of permanent vegetation. It includes cities, large town centres, major industrial and commercial sites, major areas of concrete and tarmac, plus permanent bare ground associated with these developments, such as car-parks and tips*."