

Garden bird feeding predicts the structure of urban avian assemblages

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ABSTRACT

Households across the developed world cumulatively spend many millions of dollars annually on feeding garden birds. While beneficial effects on avian assemblages are frequently claimed, the relationships between levels of garden bird feeding and local avian populations are unknown. Using data from a large UK city, we show that both avian species richness and abundance vary across different socioeconomic neighbourhood types. We examined whether patterns in bird feeding could explain this variation. The density of bird feeding stations across the urban environment was strongly positively related to avian abundance, after controlling for differences in habitat availability. This effect was almost exclusively driven by the abundance of those species known to utilize garden feeding stations frequently. In contrast, the density of feeding stations had no effect on avian species richness. We also examined variation in the proportion of households in different communities that provide food for birds, a factor that is not correlated with feeder density. The prevalence of bird feeding across different neighbourhoods declined as socioeconomic deprivation increased, and increased with avian species richness and abundance. Our results suggest that the provision of supplementary food for birds by multiple landowners across a city can impact the status of urban bird populations. The potential for harnessing these actions for conservation needs to be explored.

Keywords

Garden birds, human interactions, urban biodiversity, supplementary feeding.

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INTRODUCTION

Between one-fifth and one-third of households in Europe, North America, and Australia provide supplementary food for wild birds (Clergeau *et al.*, 1997; Rollinson *et al.*, 2003; Lepczyk *et al.*, 2004) and the global market for bird seed is currently growing at an estimated 4% per annum (Lin, 2005). In the USA, some 52 million people frequently feed garden birds, and the market is worth over US\$3000 million annually (United States Fish and Wildlife Service, 2001). In the UK, it has been estimated that more than 60% of households with a garden feed wild birds (DEFRA, 2002), and that 60,000 tonnes of food are presented annually to birds (Glue, 2006). The practice is sufficiently widespread that the level of bird feeding, among other 'wildlife-friendly' gardening practices, is a UK government indicator of the health of urban biodiversity (DEFRA, 2002, 2003).

Gardens represent a potentially vast resource for biodiversity, yet surprisingly few studies have considered their conservation significance (but see Savard *et al.*, 2000; Beebe, 2001; Rudd *et al.*, 2002; Thompson *et al.*, 2003; Gaston *et al.*, 2005a,b; Daniels & Kirkpatrick, 2006; Smith *et al.*, 2006). Some recent analyses

point to an important role of gardens in supporting avian populations of national conservation concern (Bland *et al.*, 2004; Chamberlain *et al.*, 2004, 2005, 2007; Cannon *et al.*, 2005), but conservation biology is yet to incorporate this resource into conservation planning exercises (Rudd *et al.*, 2002). Perhaps more fundamentally, the feeding of garden birds is a physical manifestation of a connection between people and nature. There is growing evidence that such connections are important to human well-being in urban environments (Kaplan & Kaplan, 1989; Bhatti & Church, 2001; Maller *et al.*, 2005), but also for nurturing interest in the natural world, and even inspiring the conservationists of the future (Pyle, 2003; Miller, 2005). Significant conservation outcomes, both locally and more diffusely, might therefore accrue with a better understanding of the dynamics and outcomes of such people–nature interactions.

Levels of 'wildlife-friendly' garden management in general, and bird feeding in particular, vary enormously across human society (Gaston *et al.*, 2007). The human behaviour of feeding garden birds presumably reflects a range of drivers, from economic and perceptual considerations, social context and garden size, to interest in wildlife and the amount of available time that

household members have (Francis & Hestor, 1990; Bhatti & Church, 2001; Gaston *et al.*, 2007). As such, it is likely to vary consistently among different kinds of human communities, which themselves show high levels of spatial organization (Harris *et al.*, 2005).

Providing supplementary food for birds will almost always increase the range of species and the number of individuals visiting an individual garden (Savard *et al.*, 2000; Daniels & Kirkpatrick, 2006; Parsons *et al.*, 2006). As such, the activity has been widely promoted as a means to enhance survival (Moss, 2003; Soper, 2006), and improve the conservation status (DEFRA, 2002) of urban bird populations. However, it remains an open question whether supplementary feeding increases avian species richness and abundance at the landscape level (Beebee, 2001; Lepczyk *et al.*, 2004; Cannon *et al.*, 2005).

Despite the clear evidence of the frequency and economic value of bird feeding, we know virtually nothing about the extent to which this activity actually relates to bird abundance and diversity. This paper has two principal aims: (1) to determine whether the amount of supplementary resource provision in domestic gardens predicts the diversity and abundance of urban birds, and (2) to determine whether the proportion of the human population that engages in bird feeding is associated with either their level of socioeconomic deprivation or the structure of the avian assemblage itself.

METHODS

Bird richness and abundance

The study focused on the urban area of Sheffield (53°22' N, 1°20' W), defined by the set of 1 × 1 km squares within the city boundary where cover by urban development exceeded 25%. Each of the 160 resulting 1 × 1 km squares was split into four 500 × 500 m cells, and a sampling point was randomly located within each, resulting in 640 survey points. Between 24 May and 1 July 2005, a point transect (see Buckland *et al.*, 2001) of 5-min duration was conducted at each survey point. Survey points were located in the field using a handheld GPS receiver. In 318 (49.7%) of the 640 cases, the exact randomly chosen point location was accessible. Where it was not, the observer stood at the nearest accessible point in the same habitat type. The identity and distance from the observer of each detected bird were noted. Birds in flight were excluded from all analyses, except in the case of aerial hunting raptors and insectivores. Given their rapid rates of movement, search effort was concentrated on these aerial species for the first few seconds of each point transect period. Distances were estimated in the field in 14 bands (0–4.9 m, 5–9.9 m, 10–14.9 m, 15–19.9 m, 20–24.9 m, 25–29.9 m, 30–39.9 m, 40–49.9 m, 50–59.9 m, 60–69.9 m, 70–79.9 m, 80–89.9 m, 90–99.9 m, 100 m+).

Because the probability of detecting birds declined with increasing distance from the observer, data were analysed using the PROGRAM DISTANCE software (version 5; Thomas *et al.*, 2005). Detection functions were generally calculated separately by species, although where insufficient detections were made of a

particular species, the detection probability of a species with similar detection characteristics was used as a surrogate (Appendix S1 in Supplementary Material; Buckland *et al.* 2001). To check whether the effective radius of detection declined with increasing urbanization (one potential source of bias in the resulting density and richness estimates), we estimated the detection function separately for each of 11 strata of values for the proportion of impervious surface, and plotted $r_{1/2}$ (the distance from a point at which the probability of detection of an object is 0.5) against the proportion of impervious surface within a 100-m buffer around each point. Because this approach requires sufficient sample sizes to generate independent detection functions for each stratum, the analysis was restricted to the 10 species with the greatest number of detections, and standardized mean values of $r_{1/2}$ across the 10 species were derived for each stratum of the proportion of impervious surface. There was no significant relationship between the mean of the standardized $r_{1/2}$ values and the proportion of impervious surface ($r = -0.413$, $n = 11$, $P = 0.206$). The number of species observed at each survey point was used directly as the measure of species richness (equivalent to species density of Gotelli & Colwell, 2001). As a measure of bird abundance, pointwise density estimates were calculated by applying the detection function for each species to the distance data from each survey point, and summing the density values across all species.

Using information from Cramp *et al.* (1977–94), species were classified into those that frequently take food provided artificially by humans ('supplementary feeders') and those that only rarely or never take such food ('non-supplementary feeders'; see Appendix S1 in Supplementary Material for the full list of species).

Land cover characteristics within a 100-m buffer around each survey point were determined in a GIS, based on the classification of surface cover polygons by Ordnance Survey within the MasterMap digital cartographic data set at a 1 : 1250 scale (Murray & Shiell, 2003). Cover by greenspace in each 100-m buffer was determined by summing the area of all polygons classified as natural surface or garden in the MasterMap data.

Neighbourhood classification

We used the Mosaic UK geodemographic database, developed by Experian's Business Strategies Division (see <http://www.business-strategies.co.uk>) to classify households across Sheffield into neighbourhood types. This classification is based on a hierarchical cluster analysis across 430 social, economic, and demographic variables chosen for their explanatory power (for details of the analyses used to build the classification see Farr & Webber, 2001; Webber, 2004; Harris *et al.*, 2005); 54% of the variables were derived from the 2001 census and the remainder from a variety of sources including the edited electoral roll, consumer credit activity, house price, and tax data. The cluster analysis identified 61 distinct neighbourhood types (Mosaic types), of which 47 occurred within our 160 km² study area, and each household within the study area was assigned to one of these.

To arrive at a generalized measure of deprivation for each neighbourhood type, we used the Index of Multiple Deprivation (see DETR, 2000), which integrates measures of income,

employment, health and disability, education, skills and training, housing, and geographical access to services.

We assigned each bird survey point to a neighbourhood type based on the Mosaic classification of the majority of households within a 100-m buffer around the point. In 179 cases, we were unable to match the survey point to a neighbourhood type, because, for example, there were no residential premises within the 100-m buffer. Data from these survey points were excluded from all analyses.

Bird feeding

Subsequent to building the Mosaic neighbourhood classification, Experian conducted a market research programme designed to examine the lifestyle characteristics of households comprising the various neighbourhood types. As part of this second study, a questionnaire was completed by 500,000 people across the UK. Respondents were asked to place a tick alongside any of a list of leisure activities in which they frequently engage. One of these activities was feeding birds in their garden. The data on bird feeding were therefore entirely independent of the data used to construct the Mosaic neighbourhood types, and the respondents were unlikely to be self-selecting based on their interest in wildlife, as this question formed a very small component of a much larger survey. We overlaid the results of this survey onto our neighbourhood classifications. The proportion of respondents in each neighbourhood type responding positively formed our measure of proportion feeding, the propensity of people in the neighbourhood type to feed birds. Then, to estimate the density of gardens in which birds are fed (feeder density), we multiplied proportion feeding by the number of households in the 100-m buffer around each survey point for each neighbourhood type. These two measures allow some potential separation of the effect of feeding on birds (if feeder density is related to bird abundance or diversity), and the possible effect of birds on people's likelihood of providing food (if bird abundance or diversity is related to proportion feeding).

Statistical analysis

All analyses were conducted at the level of neighbourhood type, using the subset of 35 neighbourhood types that contained three or more bird survey points. There were between three and 61 (mean = 12.63) bird survey points within each of the 35 neighbourhood types, a total of 442 bird survey points. Species richness was expressed as the mean number of species observed from the survey points falling within each neighbourhood type, and abundance was expressed as the mean number of individuals of all species per square kilometre calculated using distance sampling. The two variables were moderately positively correlated ($r = 0.355$, $n = 442$, $P < 0.001$).

To determine whether the amount of supplementary resource provision predicts bird diversity and abundance, we constructed regression models using feeder density and cover by greenspace as independent variables. Both variables were initially entered into the model, and backward stepwise selection

was used to eliminate terms satisfying the removal criterion ($P < 0.05$).

To investigate whether the proportion of the human population that engages in bird feeding is associated with socioeconomic deprivation and the structure of the avian assemblage, we used partial correlation to test for associations between the assemblage structure variables (species richness and abundance) and proportion feeding, while controlling for a measure of deprivation.

RESULTS

Variation in avian abundance and density

Avian populations were distributed non-randomly across the urban landscape with respect to the socioeconomic structure in human communities. There was significant variation among the 35 neighbourhood types in both avian species richness (ANOVA: $F_{34,407} = 2.436$, $P < 0.001$) and abundance ($F_{34,407} = 3.015$, $P < 0.001$). For example, species-rich samples tended to occur in neighbourhoods occupied by middle- or high-income residents in suburban settings. Samples with low species richness tended to be in economically disadvantaged neighbourhoods and also those near the city centre.

Does bird feeding predict avian assemblage structure?

There was significant variation in feeder density among the 35 neighbourhood types ($F_{34,407} = 3.068$, $P < 0.001$). However, proportion feeding was not strongly related to feeder density (Pearson's $r = 0.257$, $n = 35$, $P = 0.136$), indicating that household density, rather than the popularity of bird feeding is a key driver of spatial variation in feeder density. Therefore, to ensure that our results do not arise simply as result of a gradient of increasing urbanization (which might for example elevate bird densities through domination by abundant generalists or reduce species richness through habitat loss), we include greenspace coverage as an independent measure of urban form and habitat availability in models investigating the effect of feeder density. Greenspace coverage and feeder density were not correlated ($r = 0.064$, $n = 35$, $P = 0.714$). When feeder density and greenspace were used to model the avian assemblage data in multivariate models, greenspace was retained as a significant predictor of total avian species richness, the richness of 'non-supplementary feeders', and all three abundance measures (Table 1).

Among the 35 neighbourhood types, feeder density varied widely (mean = 925 feeders km⁻², range 53–1208). Feeder density did not predict total avian species richness (Fig. 1a), the richness of 'supplementary feeders', or the richness of 'non-supplementary feeders' (Table 1). In contrast, feeder density was strongly and positively related to total avian abundance (Fig. 1b) and to the abundance of 'supplementary feeders', although it was not related to the abundance of 'non-supplementary feeders' (Table 1). The density of feeders across the urban landscape was therefore a strong predictor of avian abundance, after accounting for the effect of greenspace.

Table 1 Results of regression models using greenspace coverage and the density of feeding stations in 35 neighbourhood types to predict avian species richness and abundance. Backward stepwise selection was used to remove non-significant terms from the full model, and only terms significant in the final model are shown. R^2 values are for the whole final model where there is only one predictor, and partial R^2 statistics where both predictors were retained in the final model. Asterisks indicate significance level ($P < 0.05$, $P < 0.01$, $P < 0.001$ for one, two and three asterisks, respectively).

Response	Greenspace			Feeder density		
	B	F	R^2	B	F	R^2
Richness (all species)	5.292	13.215**	0.286			
Richness (suppl. feeders)						
Richness (non-suppl. feeders)	3.123	24.757***	0.429			
Abundance (all species)	3759.169	14.836**	0.317	1.64	28.586***	0.472
Abundance (suppl. feeders)	2875.287	8.504**	0.21	1.59	26.301***	0.452
Abundance (non-suppl. feeders)	894.251	13.329**	0.288			

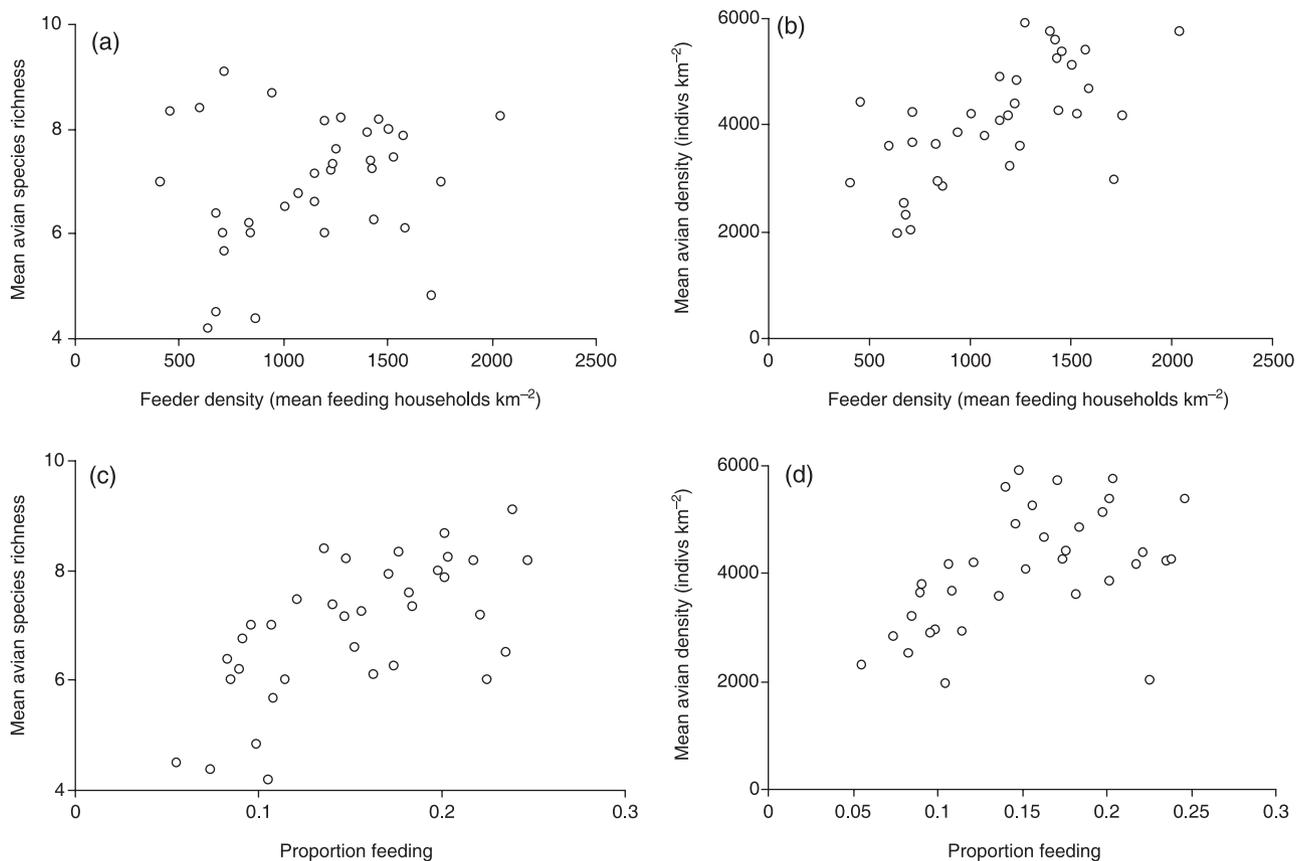


Figure 1 Relationships between levels of bird feeding and mean avian richness and abundance in 35 neighbourhood types containing at least three bird survey points across urban Sheffield. The density of households providing food for birds and two key parameters of avian assemblage structure (a) species richness and (b) abundance are shown, along with the proportion of households at which food is provided for birds in each of the 35 neighbourhood types and (c) species richness and (d) abundance. Species richness is the mean number of species recorded at point counts in areas within each neighbourhood type, and abundance is the mean number of individuals of all species per square kilometre calculated using distance sampling.

Socioeconomic deprivation, assemblage structure, and the prevalence of bird feeding

The proportion of households providing food for birds varied among the 35 neighbourhood types from 5.6% to 24.7% (mean = 15.3%). Proportion feeding declined with increasing

deprivation as measured by the IMD ($r_s = -0.63$, $n = 35$, $P < 0.001$; Fig. 2), hinting at social and economic aspects of the decision to feed birds.

Five of the six measures of bird species richness and abundance were positively associated with the prevalence of bird feeding in a given neighbourhood type (proportion feeding),

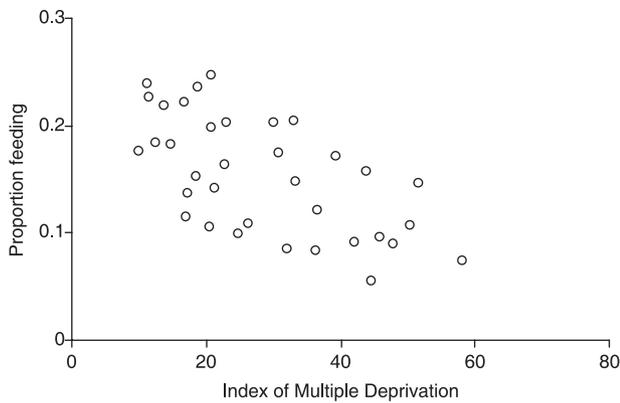


Figure 2 Relationship for the 35 neighbourhood types between the Index of Multiple Deprivation (IMD) and the proportion of households in each neighbourhood type where birds are fed. Higher values of IMD indicate greater socioeconomic deprivation.

Table 2 Results of partial correlations between the avian assemblage variables and proportion feeding, controlling for the Index of Multiple Deprivation in 35 neighbourhood types. Asterisks indicate significance level ($P < 0.05$, $P < 0.01$, $P < 0.001$ for one, two and three asterisks, respectively, ns = not significant).

Variable	Partial Pearson's r
Richness (all species)	0.609***
Richness (suppl. feeders)	0.547**
Richness (non-suppl. feeders)	0.412*
Abundance (all species)	0.629***
Abundance (suppl. feeders)	0.622***
Abundance (non-suppl. feeders)	0.216 ^{ns}

after accounting for the effects of deprivation (Table 2; Fig. 1c,d). So for a given level of socioeconomic deprivation, a smaller proportion of households fed birds in neighbourhoods where bird richness and abundance were low. The fact that feeder density did not predict any of the species richness measures suggests a separate relationship between ambient species richness and the prevalence of bird feeding in a given neighbourhood type.

DISCUSSION

Our results provide the first evidence that feeding garden birds influences the abundance of urban bird populations at a landscape scale. Supplementary feeding experiments have documented significant effects on abundance, condition, and reproductive output of birds on smaller scales (Grubb & Cimprich, 1990; Richner, 1992; Wilson, 2001; Doherty & Grubb, 2003), and it seems logical that widespread provision of supplementary food across the landscape in the form of garden bird feeding will enhance local avian abundance through elevated resource provision. Our results raise the intriguing possibility that garden bird feeding could be harnessed explicitly on a large scale to influence the conservation status of particular species

occurring within urban areas. While some urban specialist species within Europe are widely, and sometimes troublesomely, introduced beyond their native range (e.g. house sparrow *Passer domesticus* L. and European starling *Sturnus vulgaris* L.), their native populations have in some cases declined precipitously (Crick *et al.*, 2002). In such a situation, the existence of exotic populations elsewhere in the world in no way diminishes the importance of conservation efforts within their native range.

It is perhaps not surprising that we detected no effect on avian species richness of the density of bird feeders across the urban landscape. While supplementary feeding may elevate the abundance of birds already present in an area, it seems unlikely to attract species that would otherwise be unable to occupy the site. Variation in habitat quality and availability are likely to be much more important drivers of species richness patterns than resource availability, particularly in urban environments (Chamberlain *et al.*, 2004; Fernández-Juricic, 2004; Sandström *et al.*, 2006).

Our results suggest that provision of resources for biodiversity could form one part of a conservation strategy to enhance population levels of some urban-adapted species. The proportion of households in a neighbourhood feeding birds was unrelated to the density of feeding stations across the urban landscape. Variation in housing density was the key driver of variation in the density of gardens in which birds were fed, while the contribution of the proportion of households feeding was much smaller. This suggests that in spatial terms, bird feeding is being concentrated in relatively highly urbanized areas within city boundaries. Coupled with our finding that the proportion of households in a neighbourhood type that fed birds declined with increasing deprivation, these results hint at ways in which public policy and advocacy measures could be targeted to achieve maximum impact. However, supplementary feeding might not always have positive effects. Despite some evidence that artificially fed birds do not become dependent on the resource (Brittingham & Temple, 1992), investigation is required into the possible negative consequences of supplementary food provision in urban areas. These might include reliance on an unpredictable resource, a reduction in diet quality, loss of natural foraging behaviours (Brittingham & Temple, 1992), and subsidizing populations of exotic species (Daniels & Kirkpatrick, 2006).

The proportion of households that fed garden birds increased with the species richness and abundance of urban birds, when controlling for the socioeconomic status of households. There are at least two plausible classes of explanations for these relationships. First, both avian assemblage structure and the decision to feed birds might depend on one or more additional driving variables. For example, some households might be more likely to feed birds, as well as living in neighbourhoods that are more attractive to birds. Second, people might respond directly to richness and abundance when making decisions about feeding birds via some form of reward mechanism. It seems plausible that attracting large numbers and a wide variety of birds will increase the probability of persisting with bird feeding, given that the experience is being rewarded. Separating these mechanisms is not straightforward, and will require a better understanding

of the social dynamics of the decision by people to provide supplementary food for birds.

Our findings underline the close interplay between ecological and human social configurations in urban environments (Hostetler, 1999; Hope *et al.*, 2003), and demonstrate that the activities of people and biodiversity in cities are far more closely related than previously realized.

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REFERENCES

- Beebee, T.J. (2001) British wildlife and human numbers: the ultimate conservation issue? *British Wildlife*, **13**, 1–8.
- Bhatti, M. & Church, A. (2001) Cultivating natures: homes and gardens in late modernity. *Sociology*, **35**, 365–383.
- Bland, R.L., Tully, J. & Greenwood, J.J.D. (2004) Birds breeding in British gardens: an underestimated population? *Bird Study*, **51**, 96–106.
- Brittingham, M.C. & Temple, S.A. (1992) Does winter bird feeding promote dependency? *Journal of Field Ornithology*, **63**, 190–194.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001) *Introduction to distance sampling: estimating abundance of biological populations*. Oxford University Press, Oxford, UK.
- Cannon, A.R., Chamberlain, D.E., Toms, M.P., Hatchwell, B.J. & Gaston, K.J. (2005) Trends in the use of private gardens by wild birds in Great Britain 1995–2002. *Journal of Applied Ecology*, **42**, 659–671.
- Chamberlain, D.E., Cannon, A.R. & Toms, M.P. (2004) Associations of garden birds with gradients in garden habitat and local habitat. *Ecography*, **27**, 589–600.
- Chamberlain, D.E., Gosler, A.G. & Glue, D.E. (2007) Effects of the winter beechmast crop on bird occurrence in British gardens. *Bird Study*, **54**, 120–126.
- Chamberlain, D.E., Vickery, J.A., Glue, D.E., Robinson, R.A., Conway, G.J., Woodburn, R.J.W. & Cannon, A.R. (2005) Annual and seasonal trends in the use of garden feeders by birds in winter. *Ibis*, **147**, 563–575.
- Clergeau, P., Sauvage, A., Lemoine, A., Marchand, J.-P., Dubs, F. & Mennechez, G. (1997) Quels oiseaux dans la ville? Une étude pluridisciplinaire d'un même gradient urbain. *Les Annales de la Recherche Urbaine*, **74**, 119–130.
- Cramp, S., Simmons, K.E.L. & Perrins, C.M. (1977–94) *Handbook of the birds of Europe, the Middle East and North Africa*. Vols 1–9. Oxford University Press, Oxford, UK.
- Crick, H.Q.P., Robinson, R.A., Appleton, G.F., Clark, N.A. & Rickard, A.D. (2002) *Investigation into the causes of the decline of starlings and house sparrows in Great Britain*. BTO Research report no. 290. British Trust for Ornithology, Thetford, UK.
- Daniels, G.D. & Kirkpatrick, J.B. (2006) Does variation in garden characteristics influence the conservation of birds in suburbia? *Biological Conservation*, **133**, 326–335.
- Department of the Environment, Food and Rural Affairs (DEFRA) (2002) *Working with the grain of nature*. DEFRA Publications, London.
- Department of the Environment, Food and Rural Affairs (DEFRA) (2003) *A biodiversity strategy for England. Measuring progress: baseline assessment*. DEFRA Publications, London.
- Department of the Environment, Transport and the Regions (DETR) (2000) *Regeneration research summary 31: Indices of deprivation 2000*. DETR, London.
- Doherty, P.F. & Grubb, T.C. (2003) Relationship of nutritional condition of permanent-resident woodland birds with woodlot area, supplemental food, and snow cover. *The Auk*, **120**, 331–336.
- Farr, M. & Webber, R. (2001) MOSAIC: From an area classification system to individual classification. *Journal of Targeting, Measurement and Analysis for Marketing*, **10**, 55–65.
- Fernández-Juricic, E. (2004) Spatial and temporal analysis of the distribution of forest specialists in an urban-fragmented landscape (Madrid, Spain). Implications for local and regional bird conservation. *Landscape and Urban Planning*, **69**, 17–32.
- Francis, M. & Hestor, R.T., eds. (1990) *The meaning of gardens*. MIT Press, Cambridge, Massachusetts.
- Gaston, K.J., Fuller, R.A., Loram, A., MacDonald, C., Power, S. & Dempsey, N. (2007) Urban domestic gardens (XI): variation in urban wildlife gardening in the UK. *Biodiversity and Conservation*, **16**, 3227–3238.
- Gaston, K.J., Smith, R.M., Thompson, K. & Warren, P.H. (2005a) Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation*, **14**, 395–413.
- Gaston, K.J., Warren, P.H., Thompson, K. & Smith, R.D. (2005b) Urban domestic gardens (IV): the extent of the resource and its associated features. *Biodiversity and Conservation*, **14**, 3327–3349.
- Glue, D. (2006) Variety at winter bird tables. *Bird Populations*, **7**, 212–215.
- Gotelli, N.J. & Colwell, R.K. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters*, **4**, 379–391.
- Grubb, T.C. & Cimprich, D.A. (1990) Supplementary food improves the nutritional condition of wintering woodland birds: evidence from ptilochronology. *Ornis Scandinavica*, **21**, 277–281.
- Harris, R., Sleight, P. & Webber, R. (2005) *Geodemographics, GIS and neighbourhood targeting*. John Wiley and Sons Ltd, Chichester, UK.
- Hope, D., Gries, C., Zhu, W., Fagan, W.F., Redman, C.L., Grimm, N.B., Nelson, A.L., Martin, C. & Kinzig, A. (2003) Socioeconomics drive urban plant diversity. *Proceedings of the Academy of Natural Sciences of Philadelphia*, **100**, 8788–8792.

- Hostetler, M. (1999) Scale, birds, and human decisions: a potential for integrative research in urban ecosystems. *Landscape and Urban Planning*, **45**, 15–19.
- Kaplan, R. & Kaplan, S. (1989) *The experience of nature: a psychological perspective*. Cambridge University Press, Cambridge, UK.
- Lepczyk, C.A., Mertig, A.G. & Liu, J. (2004) Assessing landowner activities related to birds across rural-to-urban landscapes. *Environmental Management*, **33**, 110–125.
- Lin, E. (2005) *Production and processing of small seeds for birds*. Agricultural and Food Engineering Technical Report, Food and Agriculture Organization of the United Nations, Rome.
- Maller, C., Townsend, M., Pryor, A., Brown, P. & St. Leger, L. (2005) Healthy nature healthy people: 'Contact with nature' as an upstream health promotion intervention for populations. *Health Promotion International*, **21**, 45–54.
- Miller, J.R. (2005) Biodiversity conservation and the extinction of experience. *Trends in Ecology & Evolution*, **20**, 430–434.
- Moss, S. (2003) *The garden bird handbook: how to attract, identify and watch the birds in your garden*. New Holland, London.
- Murray, K.J. & Shiell, D. (2003) A new geographic information framework for Great Britain. *Photogrammetric Engineering and Remote Sensing*, **69**, 1175–1182.
- Parsons, H., Major, R.E. & French, K. (2006) Species interactions and habitat associations of birds inhabiting urban areas of Sydney, Australia. *Austral Ecology*, **31**, 217–227.
- Pyle, R.M. (2003) Nature matrix: reconnecting people and nature. *Oryx*, **37**, 206–214.
- Richner, H. (1992) The effect of extra food on the fitness of breeding Carrion crows. *Ecology*, **73**, 330–335.
- Rollinson, D.J., O'Leary, R. & Jones, D.N. (2003) The practice of wildlife feeding in suburban Brisbane. *Corella*, **27**, 52–58.
- Rudd, H., Vala, J. & Schaefer, V. (2002) Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces. *Restoration Ecology*, **10**, 368–375.
- Sandström, U.G., Angelstam, P. & Mikusiński, G. (2006) Ecological diversity of birds in relation to the structure of urban green space. *Landscape and Urban Planning*, **77**, 39–53.
- Savard, J.-P.L., Clergeau, P. & Mennechez, G. (2000) Biodiversity concepts and urban ecosystems. *Landscape and Urban Planning*, **48**, 131–142.
- Smith, R.M., Thompson, K., Hodgson, J.G., Warren, P.H. & Gaston, K.J. (2006) Urban domestic gardens (IX): composition and richness of the vascular plant flora, and implications for native biodiversity. *Biological Conservation*, **129**, 312–322.
- Soper, T. (2006) *Bird table book: the complete guide to attracting birds and other wildlife to your garden*, 8th edn. David & Charles, London.
- Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. & Marques, T.A. (2005) *Distance 5.0. Release Beta 5*. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK.
- Thompson, K., Austin, K.C., Smith, R.M., Warren, P.H., Angold, P.G. & Gaston, K.J. (2003) Urban domestic gardens (I): putting small-scale plant diversity in context. *Journal of Vegetation Science*, **14**, 71–78.
- United States Fish and Wildlife Service (2001) *2001 national survey of fishing, hunting and wildlife associated recreation*. Available at www.fws.gov.
- Webber, R. (2004) Designing geo-demographic classification to meet contemporary business needs. *Interactive Marketing*, **5**, 219–237.
- Wilson, W.H. (2001) The effects of supplemental feeding on wintering black-capped chickadees *Poecile atricapilla* in central Maine: population and individual responses. *Wilson Bulletin*, **113**, 65–72.

SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article:

Appendix S1 Classification into supplementary feeders and non-supplementary feeders of species recorded during the bird surveys.

This material is available as part of the online article from:
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