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Multi-species spatially-explicit indicators reveal spatially structured trends in bird communities

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ABSTRACT

Multi-species indicators are often used to assess biodiversity trends. By combining population trends across several species they summarise trends across a community. Composite indicators such as these are useful for examining general temporal patterns and may suggest important drivers of biodiversity change. However, they may also mask substantial spatial variation in population trends, particularly when they are calculated over large spatial regions. We produced spatially-explicit indicators for farmland and woodland bird communities in the UK and further separate these into trends for generalist and specialist species within each group. We found considerable spatial variation in the indicators, which is masked by indicators calculated at the national level. The farmland community indicator showed mostly positive trends in western areas and extensive declines in south-east England. The woodland community indicator showed a north–south divide, with increases in Scotland and northern England and stability in the southern regions. For both communities, indicator trends for specialist species were more negative than those for generalists. We found no significant difference in farmland community indicators between arable land and improved grassland. Woodland specialists had significantly more negative trends in broadleaf compared to coniferous woodlands, suggesting habitat-type is one of the drivers of changes in the woodland community. These spatial patterns in bird population trends may be used to highlight regional conservation priorities and identify where those may differ from the national scale. In combination with information about other environmental changes, they may also be used to develop hypotheses about potential drivers of change. We advocate that this approach is adopted for other taxa and geographical areas.

1. Introduction

Biodiversity indicators have been used for several decades to assess the state of biodiversity by summarising population trends of multiple species into a single metric (Landres et al., 1988). They can provide reliable and cost-effective means of tracking environmental changes that are otherwise difficult to measure directly (Fleishman and Murphy, 2009), as well as for reporting on progress of policy and conservation interventions. For example, biodiversity indicators were widely used to test the progress towards the target of reducing the rate of biodiversity loss by 2010, set at the 2002 World Summit of Sustainable Development and eventually to conclude that the target had not been met at the global level (Butchart et al., 2010; Secretariat of the Convention on Biological Diversity, 2010).

Birds are commonly used biodiversity indicators because they are subject to extensive citizen science monitoring, occupy high trophic levels and are sensitive to environmental change (Gregory et al., 2003; Mac Nally et al., 2004; Gregory et al., 2005). In the UK, bird indicators are calculated annually as an index of the health of various biological communities, which may highlight issues in the corresponding habitats. They are calculated as geometric averages of population indices of four communities of breeding birds: farmland birds, woodland birds, waterbirds and seabirds, and wintering waterbirds. The trends of these indicators have stimulated research and subsequent conservation action for declining species (Gregory et al., 2004; Grice et al., 2004).

The existing UK bird indicators are averaged across the whole of the United Kingdom and also over England, Scotland and further divided into nine regions within England (BTO, 2013). However, these summaries at the scale of administrative boundaries may mask significant spatial variation in trends and between habitats. For example, recent work summarising indicator trends at a 100-km resolution has highlighted significant gradients in these across Great Britain, with farmland and woodland bird

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communities showing predominantly declining trends in southern and eastern England (Harrison et al., 2014). Population trends of species that comprise the existing indicator suite also vary between habitats (Newson et al., 2009; Sullivan et al., 2015). As a result, there is a need to present indicator trends in a way which accounts for this spatial and habitat-based variation in trends, and to assess the importance of variation in land-cover or other spatial components in driving the observed patterns, the aim of this research.

Here, we have developed an approach to produce spatially-explicit indicators for farmland and woodland species suites, based upon the bird indicators already reported for the United Kingdom (DEFRA, 2013a). By modelling spatial variation in population trends accounting for both broad-scale geographical patterns (Harrison et al., 2014) and between-habitat variation (Newson et al., 2009; Sullivan et al., 2015), we are able to report on fine-grain variation in indicator trends across Great Britain. Identifying and reporting on such variation may help target locations for conservation effort, guide management and policy intervention within countries and regions, stimulate further research into the potential correlates of indicator trends in order to find the determinants of the trends themselves, and identify priority locations for field-based research to be conducted.

2. Methods

2.1. Data

This study used data from the BTO/JNCC/RSPB Breeding Bird Survey (BBS), an extensive volunteer survey used to monitor breeding bird populations in the United Kingdom every year since 1994. The BBS is undertaken on a stratified random sample of 1-km squares, where squares are stratified regionally (Risely et al., 2013). Each square is visited twice, once between April and mid-May (early visit), and once between mid-May and the end of June (late visit). Birds are recorded along two 1-km line transects with sightings classified into three distance bands (0–25 m, 25–100 m, 100 m+). Each transect is split into 200-m sections, in each of which habitat is recorded using a hierarchical coding system with nine broad categories (Crick, 1992).

In our study we focused on the farmland and woodland indicators, replicating their current species composition (Table 1), with the exception of Capercaillie (*Tetrao urogallus*), Common Crossbill (*Loxia curvirostra*), and Pied Flycatcher (*Ficedula hypoleuca*) which are too rare to be modelled in a spatially explicit way.

For the modelling process we first estimate the likely detectability of each species in each survey square. In the second stage we model observed species counts in a GAM as a function of spatial and habitat variables, using the estimated detectability from the first stage as the offset. One GAM is produced for two separate three-year periods. Using these models, species density is then predicted for each 1 km square in the UK, for each of the three-year periods, and used to calculate a trend in density for each species in each location. The last stage of the process produces fine-scale indicators, by calculating averages of the trends in each location, for all the species which comprise a given indicator and occur at that location. We describe these stages in further detail below.

2.2. Accounting for detectability

To account for heterogeneity in detectability across habitats and time of year (early or late visit during the breeding season), we used a distance-sampling approach (Buckland et al., 2001). We fitted half normal distributions to the BBS count data from the first two bounded distance bands (0–25 m and 25–100 m), for each species, using the 'mrds' package (Thomas et al., 2010) for R (R Development Core Team, 2014). We assumed that all birds on the transect line (zero distance) were detected. We also included as covariates visit and habitat (in the 200-m transect section in which each individual was recorded). We did not include year when modelling detectability as previous work has shown that the degree of such temporal variation is insufficient to affect long-term trends, such as those reported here (Newson et al., 2013). Detectability estimates were produced for each species, BBS square and visit (early or late). However, in the subsequent analyses, we only used the visit at which the maximum number of individuals was detected across the two visits, for each square and for each species. The detectability estimated from this model was used as an offset in the following model.

Table 1
Species included in the indicator sets (adapted from DEFRA, 2013a).

	Farmland	Woodland
Generalists	Greenfinch (*Chloris chloris*) Jackdaw (*Corvus monedula*) Kestrel (*Falco tinnunculus*) Reed bunting (*Emberiza schoeniclus*) Rook (*Corvus frugilegus*) Woodpigeon (*Columba palumbus*) Yellow wagtail (*Motacilla flava*)	Blackbird (*Turdus merula*) Blue tit (*Cyanistes caeruleus*) Bullfinch (*Pyrrhula pyrrhula*) Chaffinch (*Fringilla coelebs*) Dunnock (*Prunella modularis*) Great tit (*Parus major*) Lesser whitethroat (*Sylvia curruca*) Long-tailed tit (*Aegithalos caudatus*) Robin (*Erithacus rubecula*) Song Thrush (*Turdus philomelos*) Tawny owl (*Strix aluco*) Wren (*Troglodytes troglodytes*)
Specialists	Corn bunting (*Emberiza calandra*) Goldfinch (*Carduelis carduelis*) Grey partridge (*Perdix perdix*) Lapwing (*Vanellus vanellus*) Linnet (*Carduelis cannabina*) Skylark (*Alauda arvensis*) Starling (*Sturnus vulgaris*) Stock dove (*Columba oenas*) Tree sparrow (*Passer montanus*) Turtle dove (*Streptopelia turtur*) Whitethroat (*Sylvia communis*) Yellowhammer (*Emberiza citrinella*)	Blackcap (*Sylvia atricapilla*) Chiffchaff (*Phylloscopus collybita*) Coal tit (*Periparus ater*) Garden warbler (*Sylvia borin*) Goldcrest (*Regulus regulus*) Great spotted woodpecker (*Dendrocopos major*) Green woodpecker (*Picus viridis*) Hawfinch (*Coccothraustes coccothraustes*) Jay (*Garrulus glandarius*) Lesser redpoll (*Carduelis cabaret*) Lesser spotted woodpecker (*Dendrocopos minor*) Marsh tit (*Poecile palustris*) Nightingale (*Luscinia megarhynchos*) Nuthatch (*Sitta europaea*) Redstart (*Phoenicurus phoenicurus*) Siskin (*Spinus spinus*) Sparrowhawk (*Accipiter nisus*) Spotted flycatcher (*Muscicapa striata*) Tree pipit (*Anthus trivialis*) Treecreeper (*Certhia familiaris*) Willow tit (*Poecile montanus*) Willow warbler (*Phylloscopus trochilus*) Wood warbler (*Phylloscopus sibilatrix*)

2.3. Modelling density across Great Britain

BBS count data from all squares surveyed during the initial period (years 1994–1996) and later period (2007–2009) were used to build two separate models (one for each period) for each species in the indicator sets. For each 1-km square of the British National Grid (Ordnance Survey, 2013), species abundance was modelled using Generalised Additive Models (GAMs), specifying a logarithmic link function and quasi-Poisson error structure. Covariates were the percentage cover in the 1-km square of seven land cover classes (broadleaved/mixed woodland, coniferous woodland, mountain/heath/bog, improved grassland, semi-natural grassland, arable land, and built up area) from the Land Cover