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Trends in abundance and biomass of widespread European farmland birds: how much have we lost?

PETR VOŘÍŠEK,[1]* FREDERIC JIGUET,[2] ARCO VAN STRIEN,[3] JANA ŠKORPILOVÁ,[1] ALENA KLVAŇOVÁ[1] & RICHARD D. GREGORY[4]

[1]*Pan-European Common Bird Monitoring Scheme, Czech Society for Ornithology, Na Bělidle 252/34, CZ-150 00 Prague 5, Czech Republic*
[2]*UMR 7204 MNHN-CNRS-UPMC, CP 51, 55 rue Buffon, 75005 Paris, France*
[3]*Statistics Netherlands, PO Box 24500, 2490 HA The Hague, The Netherlands*
[4]*Royal Society for the Protection of Birds, The Lodge, Sandy, Beds. SG19 2DL, UK*

*Corresponding author.
Email: euromonitoring@birdlife.cz

Analysis of an extensive European dataset confirms the large decline of widespread farmland birds across Europe. Common farmland birds have on average fallen in number by nearly half – the most severe decline of the bird groups considered. Among the 36 species that were classified as characteristic of farmland, 20 have declined, seven have increased, four have remained stable and trends of five were classified as uncertain. In parallel with the index of abundance, we show for the first time that an overall index of biomass of farmland birds in Europe has more than halved during the last 27 years. Differences between trends of farmland birds in four European regions are not significant, but trends in New EU Member States have been less negative than those in Old EU Member States. Long-distance migrants among the farmland birds have less negative trends than those that are short-distance migrants or residents in Europe. A wide range of studies suggest that changes in land and crop management have been the main cause of farmland bird declines, although population declines in arable landscapes of south and central-eastern Europe may be linked to land abandonment and afforestation. In contrast, populations of all common species taken together, or common forest species from within that group, have declined modestly over the last 27 years. Similarly, overall biomass of these two groups has declined slightly, although biomass of both has inceased over the last 5 years. The pattern of changes in bird abundance and biomass detected in European farmland birds suggests a considerable loss of European biodiversity and a likely loss of ecosystem function and services.

Key words: Monitoring, population, biomass, indicators, agriculture, biodiversity

The decline of many farmland birds over recent decades, including formerly very abundant and widespread species as well as the rare and localized, has been reported from many European countries (e.g. Aebischer *et al.* 2000, Chamberlain *et al.* 2000, Chamberlain & Vickery 2002, Vickery *et al.* 2004b, Fox 2004, Newton 2004, Wretenberg *et al.* 2006, Reif *et al.* 2008a, Sudtfeldt *et al.* 2008, Baillie *et al.* 2009). Although much of the quantitative information comes from western European countries, there is growing evidence to suggest that the decline of farmland birds is a continent-wide phenomenon (Donald *et al.* 2001, 2006). Results from the Pan-European Common Bird Monitoring Scheme (PECBMS), an initiative to pool trend information from national breeding bird surveys across Europe, have provided further and detailed evidence for the overall decline of common farmland birds (Gregory *et al.* 2005, 2008, PECBMS 2008, Jiguet *et al.* 2009). Population trends of common European birds (with standard errors) have been updated regularly. The PECBMS dataset is the largest and probably most precise dataset documenting population trends of common birds in Europe. At the same time, it is important to recognize that the decline of common farmland birds is not a homogeneous one, as species trends vary between farmland birds and the trends themselves vary between countries and regions (Newton 2004, Gregory *et al.* 2005, 2008). Although more work is required, it seems clear that different drivers are in play in different parts of Europe (Donald *et al.* 2002, 2006, Reif *et al.* 2008, Sirami *et al.* 2008, Bas *et al.* 2009).

The best available evidence suggests that we may be witnessing an unprecedented decline of bird species on farmed land in Europe, including those once considered common. Information on other taxa, when and where it is available, e.g. butterflies (van Swaay *et al.* 2006), suggests that such trends are not unique to birds, but arguably part of a broader pattern of biodiversity loss that may differ in timing and scale between taxa, but is nonetheless a general phenomenon (see Gregory *et al.* 2005). However, change in abundance alone is only part of the picture of describing and understanding how the environment is changing for these birds. Other characteristics of bird populations are also important for our understanding of what is happening in European farmland and other habitats. For example, data on breeding success or adult over-winter mortality can shed critical light on the potential causes of species declines and thereby help to inform conservation actions designed to remedy the situation (e.g. Thomson *et al.* 1997, Siriwardena *et al.* 1998).

Furthermore, recent work has emphasized the importance of common species to ecosystem functioning and suggested that the depletion of their populations may have been underestimated and overlooked (Gaston & Fuller 2008). Even relatively small proportional declines in the abundance of common species could result in large absolute losses of individuals and biomass and it is suggested that it might significantly disrupt ecosystem structure, function and services. In this context, biomass may be seen as a way of estimating ecosystem production in birds and trends in biomass might well be different from trends in abundance. Large species for example might face more severe threats than small species, as shown in mammals (Cardillo *et al.* 2005). Following Gaston and Blackburn (1995) and Owens and Bennett (2000), one might predict that larger-bodied birds would contribute most to the decline of species groups in Europe, including birds of farmland. However, we have recently shown the opposite pattern in European birds covered by the PECBMS (Gregory *et al.* 2009).

More generally, we might predict that different drivers of change might be acting on large- and small-bodied species, and even where the same drivers are in action, their impact on populations may differ because of the different life histories of these species and their ability to respond numerically to such threats (Peters 1983, Gaston & Blackburn 1995, Owens & Bennett 2000). One can imagine situations in which the trends of biomass and population might differ. A population index for a group of species could decline when an index of biomass was stable or even increasing (if heavier species were doing relatively well compared with lighter species) and vice versa. Such opposing trends mean that species are reacting disproportionately, and this we suggest deserves attention. Obviously, there may be a need to monitor depletion events covering information not only on relative changes in numbers, but also in biomass. The only paper on bird biomass we are aware of in Europe (Dolton & Brooke 1999) suggests that farmland species have contributed most to a decrease in biomass detected in birds in the UK. At the time of the study (period 1968–1988), Common Wood Pigeon *Columba palumbus*, Rook *Corvus frugilegus*, Common Starling *Sturnus vulgaris* and Grey Partridge *Perdix perdix* stood out as contributing most strongly to the declining trends in biomass of birds in the UK.

Presenting data from the PECBMS, we aim to summarize recent knowledge on bird population trends in Europe and in its regions, to show how populations are changing, to summarize what is known about the likely causes and drivers of the trends and to stimulate further research. Specifically, we examine trends in European bird abundance in different habitats with the strong expectation that grouped species trends will differ by habitat, by region and by migratory status of the species following our previous work (Gregory *et al.* 2005, 2007, 2008). We focus our attention on widespread farmland birds, but to provide context, we also present trends for all the species monitored by the PECBMS and trends for common forest birds too. There is compelling evidence from the PECBMS, and many independent studies, to demonstrate that farmland birds as a group have declined disproportionately compared with other bird groups in Europe. There is also evidence to suggest that on average long-distance migrant birds have declined to a greater degree than other species, at least in some recent periods and habitats (Sanderson *et al.* 2006, Gregory *et al.* 2007).

Our predictions for the likely changes in bird biomass in Europe are more uncertain. Among the widespread species monitored by the PECBMS, the body size of the birds varies by two orders of magnitude (see Table 2), from small passerines weighing tens of grams, to large non-passerines weighing several hundred or several thousands of grams. Clearly, if the factors driving trends in numbers either up or down were independent of body size, indices of abundance and biomass would exhibit parallel trends. However, any asymmetry in effects would result in diverging trends in these indices. Following Dolton and Brooke's (1999) findings, we predict that farmland species will have contributed most to any decline in biomass trends that we are able to establish at a European level.

METHODS

Data

We use national generic sample bird surveys in the breeding season as a source of our trend data. Birds are counted annually within the national surveys by skilled volunteer counters using standardized field methods. Although the field methods vary country by country (Table 1), such differences have little impact on the resulting composite indices and indicators because our methods combine standardized national species indices (see below). These sample surveys record all birds heard or seen, but because their relative sampling intensity is low, they are unlikely to monitor trends of nationally rare or localized species adequately.

We use data from 21 European countries: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Netherlands, Norway, Poland, Portugal, Republic of Ireland, Spain, Sweden, Switzerland and United Kingdom. The data come from varying time periods (Table 1). Although national bird indices are available from 1966 for the UK, most schemes started much later. The European indices used in this paper are computed for the period from 1980, a time when data from multiple country schemes became available. For more details on national monitoring schemes, see http://www.ebcc.info/pecbm.html.

Producing national indices

For each species per country, yearly abundance indices were calculated using Poisson regression (log-linear models (McCullagh & Nelder 1989)), as implemented in TRIM-software (TRends and Indices for Monitoring data (Pannekoek & van Strien 2001)). The estimation method in TRIM is based on generalized estimating equations (GEE; see Liang & Zeger 1986, McCullagh & Nelder 1989). The basic model has fixed site and year effects, but national coordinators may add covariates for the year effects to improve model fit. Based on this model, any missing species counts for particular sites in a country were estimated ('imputed') from the changes in all other sites, or sites with the same characteristics if covariates were used. In addition, serial correlation and over-dispersion from Poisson distribution were taken into account in TRIM, following Liang and Zeger (1986).

Table 1. National breeding bird monitoring schemes contributing data to the analysis. Countries were grouped into regions and missing values were imputed using the results within the same region (see Methods). The regional index for Southeast Europe was not produced because it is based on one country and very short time series.

Region	Country	First year	Last year	Field method
West Europe	Austria	1998	2006	point counts
	Belgium-Brussels	1992	2005	point counts
	Belgium-Wallonia	1990	2005	point counts
	Denmark	1976	2006	point counts
	Germany West	1989	2006	point counts, line transects & territory mapping
	Netherlands	1990	2006	territory mapping
	Republic of Ireland	1998	2006	line transect
	Switzerland	1999	2006	territory mapping
	United Kingdom	1966	2006	line transect & territory mapping
North Europe	Finland	1975	2006	point counts
	Norway	1995	2006	point counts
	Sweden	1975	2006	point counts & line transect
South Europe	France	1989	2006	point counts
	Italy	2000	2006	point counts
	Portugal	2004	2006	point counts
	Spain	1996	2006	point counts
Central & East Europe	Czech Republic	1982	2006	point counts
	Estonia	1983	2006	point counts
	Germany East	1991	2006	point counts, line transects & territory mapping
	Hungary	1999	2006	point counts
	Latvia	1995	2006	point counts & line transect
	Poland	2000	2006	line transect
Southeast Europe	Bulgaria	2004	2006	line transect

Producing supranational indices and trends

To produce supranational indices, we combined the national all-sites totals per species as assessed in the national monitoring schemes. The national European monitoring schemes started in different years, leading to missing national all-sites totals. Again, we used TRIM to estimate the missing country totals, in a way equivalent to imputing missing counts for particular sites. This procedure was trialed in van Strien *et al.* (2001) and has been applied subsequently by Gregory *et al.* (2005, 2007, 2008). We combined the all-sites totals in five regional groupings (see Table 1). Any missing year totals were then estimated from other countries in the same region on the assumption that those countries shared similar population changes and were subject to similar environmental pressures. Furthermore, we have prevented any estimation of missing year totals in the original 15 European Union countries (Old EU Member States) using information from the 12 new EU countries (those joining in 2004 or 2007) by applying a hierarchical procedure to estimate missing years. First, we assessed separate yearly totals for North, West, South, and Central & East Europe. Then, the regions North, West and South were combined to impute remaining missing yearly totals. Finally, missing years for Central & East Europe were estimated from the combination of North, West and South Europe (for details see http://www.ebcc.info/index.php?ID=362).

In addition, the all-sites totals were weighted to allow for the fact that different countries hold different proportions of the European population. The yearly scheme totals were first converted into yearly national population sizes, using the latest information on national population sizes from BirdLife International (2004). We used the geometric mean of minimum and maximum values of national population sizes reported by BirdLife International (2004). These population sizes were assumed to reflect the situation in or around the year 2000. A weighting factor was calculated as the national population size divided by the average of the estimated yearly scheme total for 1999–2001. This weighting factor was applied to all other years of the scheme to obtain yearly national population sizes for each year. This means a change in a larger national population has greater impact on the overall trend than a change in a smaller population. The alternative, of weighting national population trends equally, makes little sense in this context because changes in small, insignificant populations could dominate and obscure the genuine European trend.

As summary statistics, overall trends in yearly indices were computed, taking into account the uncertainty of the indices (Pannekoek & van Strien 2001). These trends were expressed as multiplicative slopes, i.e. as yearly multiplication factors (1 = stable) and were classified into the following categories according to statistical significance and magnitude:

(1) Strong increase – increase significantly more than 5% per year and thus the lower limit of the confidence interval of the slope estimate is >1.05;
(2) Moderate increase – significant increase, but not significantly more than 5% per year, and thus the lower limit of the confidence interval is >1.0 but <1.05;
(3) Stable – no significant increase or decline, and it is certain that trends are less than 5% per year; thus the confidence interval encloses 1.00 but the lower limit is >0.95 and the upper limit is <1.05;
(4) Uncertain – no significant increase or decline, but not certain if trends are less than 5% per year; thus the confidence interval encloses 1.00 but the lower limit is <0.95 or the upper limit is >1.05;
(5) Moderate decline – significant decline, but not significantly more than 5% per year; thus the upper limit of the confidence interval is >0.95 but <1.00;
(6) Strong decline – decline significantly more than 5% per year; thus the upper limit of the confidence interval is <0.95.

Producing supranational multi-species indicators

The individual European species indices were combined (averaged) to create composite multi-species supranational indicators for Europe and European regions, and for three groups of species: forest, farmland and all common species. We averaged indices rather than bird abundance in order to give each species an equal weight in the resulting indicators. If more species decline than increase each at the same rate, then the mean should go down and vice versa for an increasing trend. We used geometric means rather than arithmetic means because we consider an index change from 100 to 200 to be equivalent, but opposite, to a decrease from 100 to 50. For some species (Table 2), the available time series started later than 1980. To prevent bias in the indicator assessment, we first estimated these missing species indices using the chaining method (e.g. Marchant *et al.* 1990), assuming that the average change in all other species of the indicator reflects the parts of the time series that were missing.

Data quality

Data quality was controlled at a level of a species indices as well as at the level of multi-species indices (indicator). In order to produce a European species index, the data should be available from countries representing at least 50% of a species European population. Because of practicalities, Europe in this case is considered to be countries contributing actively to the PECBMS or expected to contribute in the near future.

Thus, this criterion excludes species populations in countries that do not have well-developed bird monitoring schemes for their territories. Then each national species trend is inspected to assess whether it might reliably reflect population changes at that level. This procedure involves assessing statistical characteristics, such as the species slope value and its standard error, the index value and its standard error, and the proportion of each species national population covered by the monitoring scheme. It may also involve consultation with the coordinators of the national monitoring schemes to seek their expert view. In some cases, the coverage of species populations and thus the representativeness of the data may be lower at the beginning of the time series, i.e. data in the early years of time series come from countries holding smaller proportion of a species European population than 50%. Such species are indicated in Table 2. Because the most extreme trends tend to correspond with less precise estimates (Link & Sauer 1996), species with indices judged to be less reliable in the early years are not included in the presentations of the most extreme changes in numbers or biomass. For information on the time span and the list of countries contributing their data for individual species, see http://www.ebcc.info/index.php?ID=358.

Table 2. Population trends of common birds in Europe. Trend is multiplicative slope reflecting average percentage change per year. For trend classification and characteristics of migratory status see Methods. Long-term trends are given for the period 1980–2006, and short-term for the period 1995–2006.

Species	Long-term trend (SE) Trend classification	Short-term trend (SE) Trend classification	Habitat	Migratory status	Body mass (g)
Eurasian Sparrowhawk *Accipiter nisus*	1.0035 (0.0090) Stable	1.0078 (0.0238) Uncertain	forest	short-distance/residents	204.0
Great Reed Warbler [1, 5] *Acrocephalus arundinaceus*	1.0354 (0.0172) Moderate increase	1.057 (0.0158) Moderate increase	other	long-distance	27.2
Marsh Warbler *Acrocephalus palustris*	1.0029 (0.0031) Stable	0.9956 (0.0048) Stable	other	long-distance	11.9
Eurasian Reed Warbler *Acrocephalus scirpaceus*	0.9939 (0.0024) Moderate decline	0.9859 (0.0041) Moderate decline	other	long-distance	11.2
Sedge Warbler *Acrocephalus schoenobaenus*	1.0007 (0.0043) Stable	0.9872 (0.0083) Stable	other	long-distance	12.3
Common Sandpiper *Actitis hypoleucos*	0.9828 (0.0045) Moderate decline	0.9827 (0.0101) Stable	other	long-distance	51.7
Long-tailed Tit *Aegithalos caudatus*	1.0059 (0.0042) Stable	1.0203 (0.0154) Uncertain	other	short-distance/residents	8.2
Eurasian Skylark *Alauda arvensis*	0.9801 (0.0010) Moderate decline	0.9757 (0.0016) Moderate decline	farmland	short-distance/residents	37.2
Mallard [6] *Anas platyrhynchos*	1.0098 (0.0029) Moderate increase	1.0051 (0.0037) Stable	other	short-distance/residents	1028.5
Tawny Pipit [3] *Anthus campestris*		1.0505 (0.0840) Uncertain	farmland	long-distance	28.0
Meadow Pipit *Anthus pratensis*	0.9816 (0.0029) Moderate decline	0.9860 (0.0047) Moderate decline	farmland	short-distance/residents	18.4
Tree Pipit *Anthus trivialis*	0.9714 (0.0011) Moderate decline	0.9946 (0.0026) Moderate decline	forest	long-distance	25.1
Common Swift *Apus apus*	0.9934 (0.0038) Stable	1.0302 (0.0128) Moderate increase	other	long-distance	37.6
Grey Heron *Ardea cinerea*	1.0444 (0.0070) Moderate increase	1.0296 (0.0133) Moderate increase	other	short-distance/residents	1433.0
Eurasian Stone-curlew [2] *Burhinus oedicnemus*		1.0377 (0.0153) Moderate increase	farmland	short-distance/residents	450.0
Common Buzzard *Buteo buteo*	1.0228 (0.0032) Moderate increase	0.9785 (0.0076) Moderate decline	other	short-distance/residents	806.5
Greater Short-toed Lark [2] *Calandrella brachydactyla*		0.9570 (0.0167) Moderate decline	farmland	long-distance	23.0
Common Linnet *Carduelis cannabina*	0.9765 (0.0030) Moderate decline	0.9616 (0.0074) Moderate decline	farmland	short-distance/residents	15.3
European Goldfinch *Carduelis carduelis*	1.0165 (0.0029) Moderate increase	1.0052 (0.0042) Stable	other	short-distance/residents	15.6
European Greenfinch *Carduelis chloris*	1.0049 (0.0019) Moderate increase	1.0121 (0.0052) Moderate increase	other	short-distance/residents	27.8

Table 2. (cont)

Common Redpoll *Carduelis flammea*	0.9681 (0.0073) Moderate decline	0.9759 (0.0074) Moderate decline	other	short-distance/residents	13.0
Eurasian Siskin *Carduelis spinus*	0.9934 (0.0029) Moderate decline	0.9774 (0.0038) Moderate decline	forest	short-distance/residents	14.5
Common Rosefinch *Carpodacus erythrinus*	1.0006 (0.0027) Stable	0.9659 (0.0053) Moderate decline	other	long-distance	24.1
Short-toed Treecreeper [1, 5] *Certhia brachydactyla*	0.9927 (0.0071) Stable	1.0274 (0.0120) Moderate increase	forest	short-distance/residents	8.5
Eurasian Treecreeper *Certhia familiaris*	1.0004 (0.0024) Stable	0.9942 (0.0043) Stable	forest	short-distance/residents	9.0
Cetti's Warbler *Cettia cetti*		0.9909 (0.0160) Stable	other	short-distance/residents	12.6
White Stork [1] *Ciconia ciconia*	1.0275 (0.0132) Moderate increase	1.0176 (0.0061) Moderate increase	farmland	long-distance	3473.0
Western Marsh Harrier *Circus aeruginosus*	1.0421 (0.0085) Moderate increase	0.9993 (0.0092) Stable	other	long-distance	584.5
Zitting Cisticola [2] *Cisticola juncidis*		0.9903 (0.0128) Stable	other	short-distance/residents	10.0
Hawfinch [5] *Coccothraustes coccothraustes*	1.0167 (0.0060) Moderate increase	0.9707 (0.0070) Moderate decline	forest	short-distance/residents	54.0
Western Jackdaw *Coloeus monedula*	0.9950 (0.0038) Stable	0.9972 (0.0053) Stable	other	short-distance/residents	246.0
Stock Dove *Columba oenas*	1.0074 (0.0045) Stable	1.0055 (0.0117) Stable	forest	short-distance/residents	280.0
Common Wood Pigeon *Columba palumbus*	1.0194 (0.0022) Moderate increase	1.0244 (0.0016) Moderate increase	other	short-distance/residents	490.0
Northern Raven *Corvus corax*	1.0315 (0.0057) Moderate increase	1.0096 (0.0062) Stable	other	short-distance/residents	1158.0
Carrion & Hooded Crow *Corvus corone* & *cornix*	1.0051 (0.0021) Moderate increase	1.0130 (0.0032) Moderate increase	other	short-distance/residents	570.0
Rook *Corvus frugilegus*	1.0141 (0.004) Moderate increase	0.9884 (0.0070) Stable	farmland	short-distance/residents	488.0
Common Cuckoo *Cuculus canorus*	0.9883 (0.0016) Moderate decline	0.9897 (0.0049) Moderate decline	other	long-distance	113.0
Eurasian Blue Tit *Cyanistes caeruleus*	1.0094 (0.0013) Moderate increase	1.0281 (0.0047) Moderate increase	other	short-distance/residents	13.3
Azure-winged Magpie [2] *Cyanopica cyanus*		1.1101 (0.0466) Moderate increase	other	short-distance/residents	74.6
Common House Martin *Delichon urbicum*	0.9828 (0.0057) Moderate decline	1.0249 (0.0148) Uncertain	other	long-distance	14.5
Great Spotted Woodpecker *Dendrocopos major*	1.0122 (0.0017) Moderate increase	1.0240 (0.0070) Moderate increase	other	short-distance/residents	81.6
Lesser Spotted Woodpecker *Dendrocopos minor*	0.9307 (0.0233) Moderate decline	0.9378 (0.0657) Uncertain	forest	short-distance/residents	19.8
Syrian Woodpecker [3] *Dendrocopos syriacus*		1.0052 (0.0786) Uncertain	other	short-distance/residents	76.8
Black Woodpecker *Dryocopus martius*	1.0205 (0.0051) Moderate increase	1.0159 (0.0211) Uncertain	forest	short-distance/residents	321.0
Corn Bunting *Emberiza calandra*	0.9680 (0.0050) Moderate decline	0.9892 (0.0120) Stable	farmland	short-distance/residents	57.2
Rock Bunting [2, 5] *Emberiza cia*		1.0362 (0.0182) Moderate increase	other	short-distance/residents	25.0
Cirl Bunting *Emberiza cirlus*		1.0305 (0.0217) Uncertain	farmland	short-distance/residents	23.1
Yellowhammer *Emberiza citrinella*	0.9794 (0.0010) Moderate decline	0.9868 (0.0024) Moderate decline	farmland	short-distance/residents	26.5
Ortolan Bunting [5] *Emberiza hortulana*	0.9368 (0.0059) Steep decline	1.0176 (0.0129) Stable	farmland	long-distance	23.8
Black-headed Bunting [4] *Emberiza melanocephala*		1.0 (0.0945) Uncertain	farmland	long-distance	28.4
Rustic Bunting *Emberiza rustica*	0.9596 (0.0090) Moderate decline	0.9038 (0.0266) Moderate decline	forest	long-distance	17.9
Common Reed Bunting *Emberiza schoeniclus*	0.9934 (0.0019) Moderate decline	0.9951 (0.0055) Stable	other	short-distance/residents	18.3
European Robin *Erithacus rubecula*	1.0116 (0.0008) Moderate increase	1.0076 (0.0026) Moderate increase	other	short-distance/residents	18.2

Table 2. (cont)

Common Kestrel *Falco tinnunculus*	0.9919 (0.0037) Moderate decline	0.9748 (0.0103) Moderate decline	farmland	short-distance/residents	217.0
Collared Flycatcher [1, 5] *Ficedula albicollis*	1.0329 (0.0067) Moderate increase	0.9981 (0.0087) Stable	forest	long-distance	10.3
European Pied Flycatcher *Ficedula hypoleuca*	0.9910 (0.0014) Moderate decline	0.9948 (0.0031) Stable	forest	long-distance	11.6
Common Chaffinch *Fringilla coelebs*	0.9990 (0.0005) Moderate decline	1.0017 (0.0013) Stable	other	short-distance/residents	20.9
Brambling *Fringilla montifringilla*	0.9725 (0.0042) Moderate decline	0.9774 (0.0056) Moderate decline	other	short-distance/residents	24.0
Crested Lark [1, 5] *Galerida cristata*	0.8355 (0.0505) Steep decline	0.9987 (0.0104) Stable	farmland	short-distance/residents	41.9
Thekla Lark [2] *Galerida theklae*		1.0119 (0.0153) Stable	farmland	short-distance/residents	36.5
Common Snipe *Gallinago gallinago*	0.9775 (0.0027) Moderate decline	1.0054 (0.0058) Stable	other	short-distance/residents	116.0
Eurasian Jay *Garrulus glandarius*	1.0041 (0.0024) Stable	1.0367 (0.0092) Moderate increase	forest	short-distance/residents	161.0
Icterine Warbler *Hippolais icterina*	0.9824 (0.0021) Moderate decline	0.9848 (0.0044) Moderate decline	other	long-distance	14.6
Melodious Warbler *Hippolais polyglotta*		0.9873 (0.0130) Stable	other	long-distance	11.0
Barn Swallow *Hirundo rustica*	0.9971 (0.0024) Stable	0.9940 (0.0060) Stable	farmland	long-distance	15.8
Eurasian Wryneck [5] *Jynx torquilla*	0.9565 (0.0068) Moderate decline	0.9531 (0.0127) Moderate decline	other	long-distance	33.5
Red-backed Shrike *Lanius collurio*	1.0019 (0.0057) Stable	0.9949 (0.0101) Stable	farmland	long-distance	29.9
Lesser Grey Shrike [3] *Lanius minor*		1.0049 (0.0355) Uncertain	farmland	long-distance	46.6
Woodchat Shrike [2, 5] *Lanius senator*		0.9716 (0.010) Moderate decline	farmland	long-distance	35.0
Black-tailed Godwit *Limosa limosa*		0.9661 (0.0034) Moderate decline	farmland	long-distance	307.5
River Warbler [1, 5] *Locustella fluviatilis*	0.9908 (0.0064) Stable	0.9582 (0.0110) Moderate decline	other	long-distance	18.1
Common Grasshopper Warbler *Locustella naevia*	0.9897 (0.0082) Stable	0.9833 (0.0085) Moderate decline	other	long-distance	13.3
European Crested Tit *Lophophanes cristatus*	0.9858 (0.0069) Moderate decline	1.0086 (0.0212) Uncertain	forest	short-distance/residents	10.2
Woodlark [5] *Lullula arborea*	0.9778 (0.0340) Uncertain	1.0092 (0.0163) Stable	other	short-distance/residents	26.9
Thrush Nightingale *Luscinia luscinia*	1.0101 (0.0030) Moderate increase	1.0347 (0.0041) Moderate increase	other	long-distance	23.8
Common Nightingale *Luscinia megarhynchos*	0.9639 (0.0052) Moderate decline	1.0084 (0.0061) Stable	other	long-distance	18.3
Calandra Lark [2] *Melanocorypha calandra*		1.0072 (0.0105) Stable	farmland	short-distance/residents	59.2
European Bee-eater *Merops apiaster*		0.9868 (0.0384) Uncertain	other	long-distance	56.6
White Wagtail *Motacilla alba*	0.9965 (0.0016) Moderate decline	0.9887 (0.0045) Moderate decline	other	short-distance/residents	21.0
Grey Wagtail [5] *Motacilla cinerea*	1.0023 (0.0138) Stable	1.0024 (0.0107) Stable	other	short-distance/residents	17.2
Western Yellow Wagtail *Motacilla flava*	0.9673 (0.0115) Moderate decline	0.9673 (0.0056) Moderate decline	farmland	long-distance	13.9
Spotted Flycatcher *Muscicapa striata*	0.973 (0.0053) Moderate decline	0.9976 (0.0111) Stable	other	long-distance	14.6
Spotted Nutcracker *Nucifraga caryocatactes*	0.9873 (0.0140) Stable	0.9432 (0.0221) Moderate decline	forest	short-distance/residents	169.0
Black-eared Wheatear [2] *Oenanthe hispanica*		0.9690 (0.0149) Moderate decline	farmland	long-distance	17.2
Northern Wheatear [5] *Oenanthe oenanthe*	0.9647 (0.0085) Moderate decline	0.9887 (0.0055) Moderate decline	other	long-distance	22.3

Table 2. (cont)

Eurasian Golden-oriole [1] *Oriolus oriolus*	1.0164 (0.0044) Moderate increase	1.0371 (0.0112) Moderate increase	other	long-distance	79.0
Great Tit *Parus major*	1.0002 (0.0009) Stable	1.0163 (0.0026) Moderate increase	other	short-distance/residents	19.0
House Sparrow *Passer domesticus*	0.9712 (0.0032) Moderate decline	1.0078 (0.0039) Moderate increase	other	short-distance/residents	27.4
Eurasian Tree Sparrow *Passer montanus*	0.9799 (0.0042) Moderate decline	0.9919 (0.0088) Stable	farmland	short-distance/residents	22.0
Grey Partridge *Perdix perdix*	0.9334 (0.0099) Moderate decline	0.9768 (0.0159) Uncertain	farmland	short-distance/residents	381.0
Coal Tit *Periparus ater*	1.0002 (0.0021) Stable	0.9994 (0.0089) Stable	forest	short-distance/residents	9.1
Rock Sparrow [2, 5] *Petronia petronia*		1.0311 (0.0129) Moderate increase	farmland	short-distance/residents	30.5
Black Redstart [1, 5] *Phoenicurus ochruros*	1.0046 (0.0041) Stable	1.0157 (0.0087) Stable	other	short-distance/residents	16.5
Common Redstart *Phoenicurus phoenicurus*	1.0064 (0.0025) Moderate increase	1.0110 (0.0068) Stable	forest	long-distance	14.5
Western Bonelli's Warbler *Phylloscopus bonelli*		1.0390 (0.0271) Uncertain	forest	long-distance	8.9
Common Chiffchaff *Phylloscopus collybita*	1.0248 (0.0012) Moderate increase	0.9828 (0.0028) Moderate decline	forest	long-distance	7.5
Wood Warbler *Phylloscopus sibilatrix*	0.9753 (0.0026) Moderate decline	0.9710 (0.0059) Moderate decline	forest	long-distance	8.2
Willow Warbler *Phylloscopus trochilus*	0.9837 (0.0008) Moderate decline	0.9843 (0.0019) Moderate decline	other	long-distance	8.7
Eurasian Magpie *Pica pica*	0.9947 (0.0020) Moderate decline	0.9816 (0.0059) Moderate decline	other	short-distance/residents	166.0
Grey-headed Woodpecker [1, 5] *Picus canus*	1.0138 (0.0222) Uncertain	1.0181 (0.0178) Uncertain	forest	short-distance/residents	137.0
European Green Woodpecker *Picus viridis*	1.0205 (0.0062) Moderate increase	1.0509 (0.0154) Moderate increase	other	short-distance/residents	176.0
Willow Tit *Poecile montanus*	0.9647 (0.0035) Moderate decline	1.0154 (0.0149) Stable	forest	short-distance/residents	10.2
Marsh Tit *Poecile palustris*	0.9767 (0.0040) Moderate decline	1.0179 (0.0173) Uncertain	forest	short-distance/residents	10.6
Dunnock *Prunella modularis*	0.9879 (0.0011) Moderate decline	0.9994 (0.0039) Stable	other	short-distance/residents	19.7
Eurasian Crag Martin [2] *Ptyonoprogne rupestris*		1.0406 (0.0247) Uncertain	other	short-distance/residents	23.5
Red-billed Chough [2] *Pyrrhocorax pyrrhocorax*		1.0500 (0.0293) Uncertain	other	short-distance/residents	305.0
Eurasian Bullfinch *Pyrrhula pyrrhula*	0.9885 (0.0025) Moderate decline	0.9729 (0.0072) Moderate decline	forest	short-distance/residents	21.8
Firecrest [1, 5] *Regulus ignicapilla*	1.0022 (0.0091) Stable	1.0012 (0.0206) Stable	forest	short-distance/residents	5.6
Goldcrest *Regulus regulus*	0.9922 (0.0015) Moderate decline	0.9748 (0.0040) Moderate decline	forest	short-distance/residents	5.7
Whinchat *Saxicola rubetra*	0.9823 (0.0059) Moderate decline	1.0149 (0.0039) Moderate increase	farmland	long-distance	16.6
European Stonechat [1, 5] *Saxicola rubicola*	0.9852 (0.0535) Uncertain	0.9801 (0.0188) Uncertain	farmland	short-distance/residents	15.3
European Serin [1, 5] *Serinus serinus*	0.9645 (0.0051) Moderate decline	0.9895 (0.0166) Stable	farmland	short-distance/residents	11.2
Eurasian Nuthatch *Sitta europaea*	1.0120 (0.0034) Moderate increase	1.0191 (0.0107) Stable	forest	short-distance/residents	22.0
Eurasian Collared-dove *Streptopelia decaocto*	1.0256 (0.0025) Moderate increase	1.0639 (0.0059) Strong increase	other	short-distance/residents	146.0
European Turtle Dove *Streptopelia turtur*	0.9629 (0.0031) Moderate decline	0.9898 (0.0070) Stable	farmland	long-distance	132.0
Spotless Starling [2] *Sturnus unicolor*		1.0425 (0.0066) Moderate increase	farmland	short-distance/residents	90.8
Common Starling *Sturnus vulgaris*	0.9758 (0.0036) Moderate decline	0.9957 (0.0044) Stable	farmland	short-distance/residents	79.9

Table 2. (cont)

Eurasian Blackcap *Sylvia atricapilla*	1.0267 (0.0010) Moderate increase	1.0286 (0.0028) Moderate increase	other	short-distance/residents	15.5
Garden Warbler *Sylvia borin*	0.9932 (0.0011) Moderate decline	0.9902 (0.0034) Moderate decline	other	long-distance	13.9
Subalpine Warbler *Sylvia cantillans*		1.0143 (0.0246) Uncertain	other	long-distance	10.8
Common Whitethroat *Sylvia communis*	1.0110 (0.0014) Moderate increase	1.0131 (0.0024) Moderate increase	farmland	long-distance	14.5
Lesser Whitethroat *Sylvia curruca*	1.0006 (0.0018) Stable	1.0157 (0.0039) Moderate increase	other	long-distance	10.1
Sardinian Warbler *Sylvia melanocephala*		1.0048 (0.0212) Stable	other	short-distance/residents	11.3
Barred Warbler [1, 5] *Sylvia nisoria*	1.0005 (0.0380) Uncertain	0.9716 (0.0221) Uncertain	other	long-distance	24.4
Dartford Warbler [2] *Sylvia undata*		0.9452 (0.0131) Moderate decline	other	short-distance/residents	9.5
Hazel Grouse *Tetrastes bonasia*	0.9900 (0.0087) Stable	1.0086 (0.0147) Stable	forest	short-distance/residents	429.0
Common Redshank *Tringa totanus*	0.9737 (0.0057) Moderate decline	0.9776 (0.0104) Moderate decline	other	short-distance/residents	121.5
Winter Wren *Troglodytes troglodytes*	1.0182 (0.0009) Moderate increase	1.0222 (0.0020) Moderate increase	other	short-distance/residents	8.9
Redwing *Turdus iliacus*	0.9976 (0.0017) Stable	1.0132 (0.0030) Moderate increase	other	short-distance/residents	61.2
Common Blackbird *Turdus merula*	1.0072 (0.0007) Moderate increase	1.0138 (0.0015) Moderate increase	other	short-distance/residents	113.0
Song Thrush *Turdus philomelos*	0.9972 (0.0009) Moderate decline	1.0277 (0.0020) Moderate increase	other	short-distance/residents	66.6
Fieldfare *Turdus pilaris*	1.0083 (0.0018) Moderate increase	0.9964 (0.0029) Stable	other	short-distance/residents	104.0
Mistle Thrush *Turdus viscivorus*	0.9873 (0.0028) Moderate decline	1.0047 (0.0067) Stable	forest	short-distance/residents	115.0
Eurasian Hoopoe [1, 5] *Upupa epops*	1.0485 (0.0527) Uncertain	1.0161 (0.0265) Uncertain	farmland	long-distance	61.4
Northern Lapwing *Vanellus vanellus*	0.9674 (0.0031) Moderate decline	1.0027 (0.0036) Stable	farmland	short-distance/residents	226.0

[1] Long-term trend is for the period 1982–2006.
[2] Short-term trend is for the period 1996–2006.
[3] Short-term trend is for the period 1999–2006.
[4] Short-term trend is for the period 2004–2006.
[5] Index in early years might be less reliable.
[6] Index might be influenced by releases by hunters.

Confidence limits and the extent of fluctuations in a species index were also used to assess whether a species should be included in an indicator. Indices with low precision and large fluctuations were examined in detail and when changes in the indices were considered doubtful, they were excluded from the calculation of the multi-species indicators. For more details on data quality control see http://www.ebcc.info/index.php?ID=362.

Defining species traits

Species were classified as 'common farmland' or 'common forest species' using assessments of bird habitat relationships within four bio-geographical regions (Atlantic, Boreal, Continental and Mediterranean), which were then combined into a single European classification. Biogeographical regions were used solely for species habitat classification, not for the computation of supranational population indices, where geographical regions were used instead (see Producing supranational indices and trends). Selection was based on species being: (1) abundant and widespread – species with ≥ 50 000 breeding pairs in Europe; (2) characteristic of farmland/forest using an assessment of predominant regional habitat use – characteristic species are those where ≥ 50% of the regional population uses farmland/forest for breeding or feeding. The group 'all common species' includes species characteristic of farmland and forest and other common species (species characteristic for other habitats or habitat generalists). For details see http://www.ebcc.info/index.php?ID=301. As species differ in their geographical distributions, the regional multi-species population indices are based on slightly different species. This, however, should not pose a problem for assessing differences between regional indices as the species have been selected to be characteristic for a given habitat type in a region.

Species were classified according to their migratory behaviour as long-distance migrant or short-distance migrant/resident in Europe following Cramp *et al.* (1977–1994). The first group was defined as a species migrating from Europe to sub-Saharan Africa or Asia. The second group was defined as migrant birds that chiefly winter within Europe and North Africa, including resident, sedentary and eruptive species. We did not make a distinction between sedentary species or short-distance migrants here because for many European species, northern populations are short-distance migrants while southern populations are sedentary.

Estimating changes in biomass

Changes in the absolute biomass of each species were calculated as changes in species body mass. Body mass (W) was estimated as the mean of reported male or female body mass in grams or, where this was not available, from unsexed birds, taken from Cramp *et al.* (1977–1994) (see Table 2). The biomass of each species per country in a given year (B_t) was calculated as follows:

$$B_t = (W*2)*\sum N_x*I/I_t$$

where W is species body mass, N_x is population size of species in a country x in 2000, I is species population index in 2000 and I_t is species population index in a year t.

Changes in the absolute biomass of all farmland species together and other habitats were then calculated as the sum of biomass for each species in each year.

Changes in absolute biomass were then converted into an index of relative change (%) where the first year of the time series was set as 100% for each version of the time series. The total index of biomass change was then calculated using a chaining index (Marchant *et al.* 1990, Ter Braak *et al.* 1994).

Changes in absolute biomass for individual species were calculated as the difference between the absolute biomass of a species in 2006 and 1980. For species with incomplete time series the absolute biomass in years where data on population changes are missing was estimated using the total index of biomass change as follows:

$$B_x = B_y * (I_x/I_y)$$

where B_x is the estimate of biomass in a year x, B_y is the biomass of a species in the first year for which data on population change is available, I_x is the index of population change in a year x and I_y is the index of population change in a year y.

The values we used for the assessment of changes in biomass are approximations because, for instance, body mass of a species might vary among populations, especially according to latitude. However, this should not pose a problem for comparing trends in biomass rather then biomass per se.

As the index of biomass is affected by species body size, population size and rate of change of population size, it does not give all the species equal weight as in the population index. Therefore, the index of biomass should be understood as complementary to the population index. Data on some large-bodied species characteristic of European farmland are missing also in the PECBMS dataset. This might pose a bias in biomass trends calculated from these data. However, such large-bodied species are usually species with less abundant populations, such as Great Bustard *Otis tarda* or some raptors (Falconiformes), and their biomass is unlikely to exceed that of the species in the PECBMS dataset. Therefore, we believe the risk of potential bias is low.

Testing changes in indicators

Trends in the composite species indicators have been tested using linear mixed models in the lme4 package of the R statistical software (see http://lme4.r-forge.r-project.org). The raw data used in the models are the abundance index values for each species in each year. In all models, species identity was considered a random effect to account for differences between the average species index values, as these values were not available for all species in all years. We then tested for a common pattern in temporal trend in the species index values by considering a fixed linear effect of year. To test for potential different trends between regions or migration strategies, we further considered the tested variable (region or migration strategy) and its interaction with year. We also used the program TrendSpotter, which is based on structural time series analysis and the Kalman filter (Visser 2004), and was suggested to be used both to smooth the trends in the indicators and to assess the statistical significance of changes in the smoothed trends (Soldaat *et al.* 2007). TrendSpotter provides a test of index change with 95% confidence limits from the last time point in the time series to the first point. We treated as statistically significant smoothed trends where the confidence limits of change from the start to the end of the period did not overlap zero. TrendSpotter ignores the uncertainties of species indices and may thereby underestimate standard errors. For long time series, however, we believe that the underestimation is limited because uncertainties will also be expressed in the year-to-year fluctuations of the species indices.

RESULTS

Data from bird monitoring schemes from 21 European countries show that common birds that are characteristic for farmland (36 species) have declined dramatically, nearly halving in average number over the last 27 years and to a much great degree than common forest species or all common birds taken together (Fig. 1). The decline of farmland birds was steepest from 1980 to around 1995, but has stabilized subsequently (Fig. 2a). The index of farmland birds declined significantly between 1980 and 2006 at the European level (result of the linear mixed model, $t = -4.056$, $P < 0.0001$, Fig. 2a). The same survey data demonstrate an overall significant decline among common forest birds too, though of smaller amplitude, and a similar significant decline in the set of species covered by the PECBMS as a whole (Fig. 2b,c). In both cases, population levels have been relatively stable since around 1995 (Fig. 2).

The five species contributing most to the pattern of decline in the abundance of farmland birds are Grey Partridge, European Turtle Dove *Streptopelia turtur*, Western Yellow Wagtail *Motacilla flava*, Northern Lapwing *Vanellus vanellus* and Corn Bunting *Emberiza calandra* (Fig. 3a). Although the predominant pattern among farmland birds is for numbers to be falling, several birds have shown increases too (Table 2, Fig. 3b). The three species increasing most, although those increases are relatively small, are: Rook, Common Whitethroat *Sylvia communis*, and Red-backed Shrike *Lanius collurio* in our dataset (Fig. 3b). Several other birds are now increasing in number, but those trends are quite recent and some are less certain (Table 2).

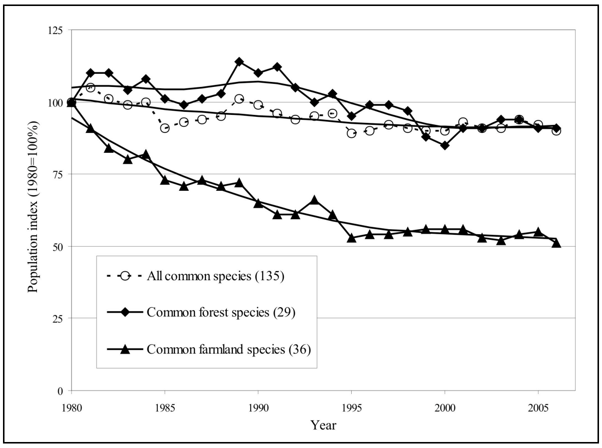
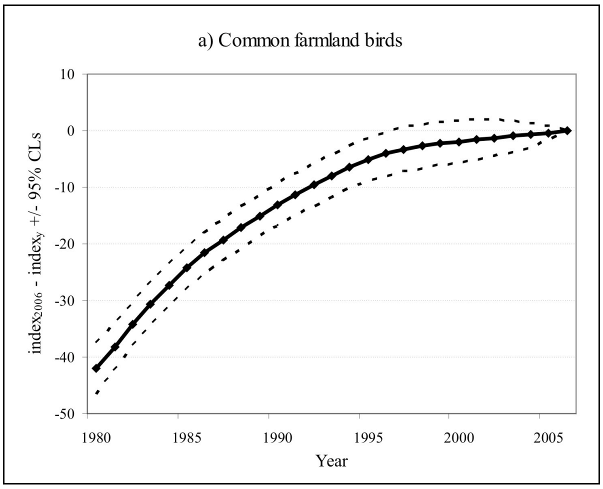
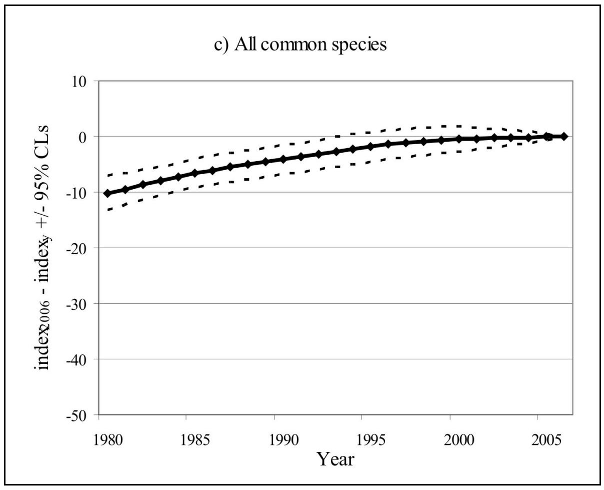


Figure 1. Population trends of common European birds from 1980 to 2006. The indices are the geometric means of European species indices within three groups of species: common farmland birds, common forest birds and all common species. The solid lines in each case are the statistically smoothed indices for each of these three groups. Numbers in parentheses are the numbers of species in each index. Changes between the index value in the first and last year for the index, and the smoothed index, are: farmland birds, –49% and -44%; common forest birds, –9% and –13%, and all common species; and –10% and –10%, respectively.





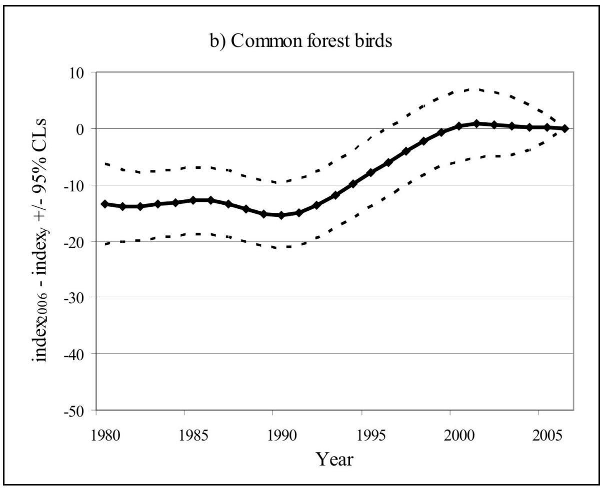
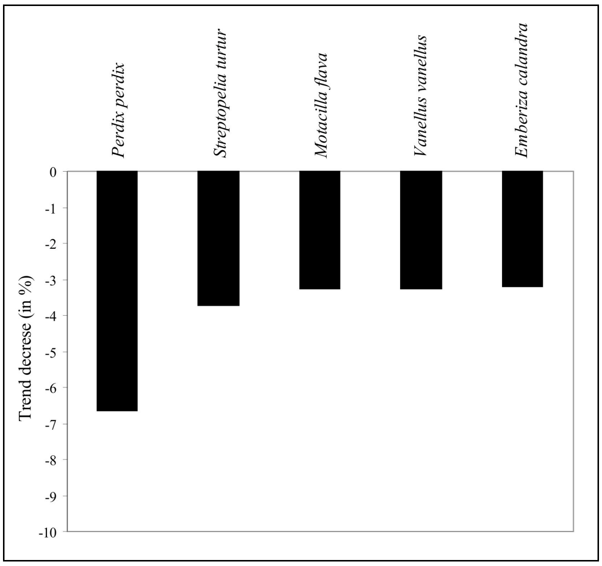
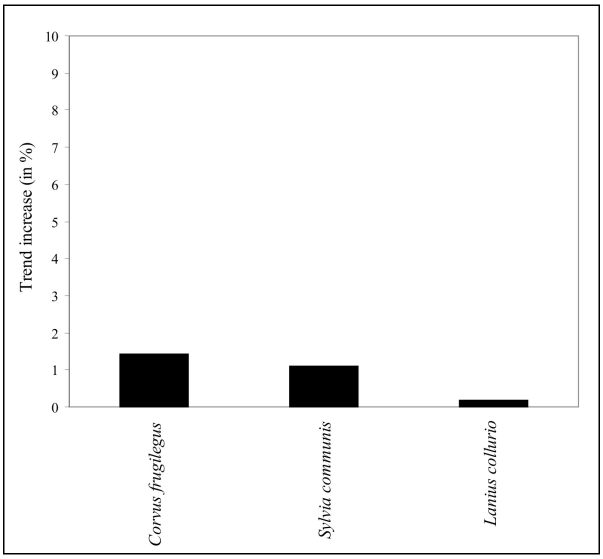


Figure 2. Differences between the smoothed population index in 2006 and the indices in all preceding years, with 95% confidence limits for (a) common farmland birds (*n* = 36), (b) common forest birds (*n* = 29) and (c) all common species (*n* = 135).

The decline of farmland birds appears to be steepest in West and North Europe and less steep in South Europe (Fig. 4). Farmland birds in Central & East Europe show an intermediate trend (Fig. 4). There is, however, no significant difference in species trends between the four geographical regions (trend difference between control group – Eastern Europe – and Northern Europe, $t = 1.96$, $P = 0.051$; Southern Europe, $t = -1.35$, $P = 0.18$; Western Europe, $t = -1.33$, $P = 0.18$). The lack of significance illustrates the variability of species trends within these groups, but also highlights obvious differences in trend precision between the regions. Data from South Europe in particular come from a smaller set of countries over a shorter time period and should be treated with caution.



a) Five farmland species showing the largest population declines



b) Three farmland species showing the largest increases

Figure 3. Average per annum percentage change in species population indices from 1980 to 2006 for (a) the five farmland species showing the largest declines, and (b) the three farmland species showing the largest increases. Species with less reliable indices in the early years are excluded (see Methods).

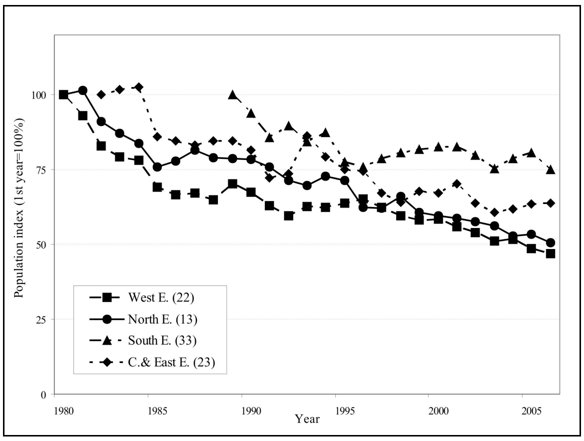


Figure 4. Farmland bird indicators in four European regions: West Europe (Austria, Belgium, Denmark, former West Germany, Ireland, Netherlands, Switzerland, United Kingdom), North Europe (Finland, Norway, Sweden), South Europe (France, Italy, Portugal, Spain), Central & East Europe (Czech Republic, Estonia, former East Germany, Hungary, Latvia, Poland). Numbers in parentheses are numbers of species in each indicator. Change between index value in first and last year: West Europe, –53%; North Europe, –50%; South Europe, –25%; Central & East Europe, –36%.

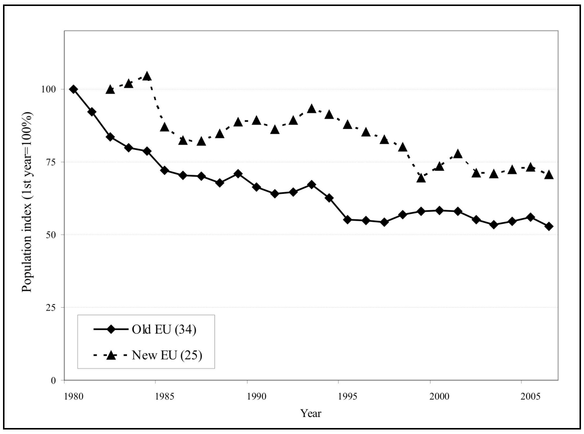


Figure 5. The farmland bird indicator for the Old EU Member States (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, UK) and New EU Member States, which joined the EU in 2004 or 2007 (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Poland). Numbers in parentheses are numbers of species in each indicator. Change between index value in first and last year: New EU, –29%; Old EU, –47%.

The information on species trends can be subdivided by other geopolitical boundaries too (Fig. 5), and by the migratory behaviour of the birds (Fig. 6). For example, there is a contrast between the composite trends of farmland birds in countries that entered the EU in 2004 or 2007 in comparison with those countries that were members of the EU prior to 2004 (Fig. 5). There appears to be a positive trend in new EU Member States from 1986 to 1993, which almost compensated for losses in the early 1980s. However, thereafter a further decline is apparent in the new EU countries and at a rate that equals or may exceed that in the old Member States. Overall, however, trends of farmland birds in New EU Member States are more positive than those in Old EU Member States (results of the linear mixed model, $t = -2.62$, $P = 0.009$).

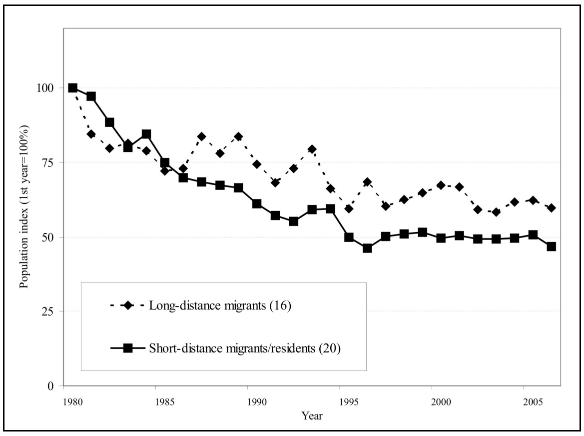


Figure 6. Multi-species index for long-distance migratory and short-distance migratory/resident farmland birds in Europe. Numbers in parentheses are numbers of species in each indicator. Change between index value in first and last year: long-distance migrants, –40%; short-distance migrants/residents, –53%.

The farmland birds in our dataset include species with various migratory strategies from species that regularly migrate to their wintering grounds outside the area covered by PECBMS data (long-distance migrants), to species that are either residents or migrate within the area covered by the scheme (short-distance migrants and residents). Population trends of both groups of these farmland birds are downwards, but counter to our prediction, species that are residents or short-distance migrants in Europe are declining at a faster rate than long-distance migrants (Fig. 6; $t = -3.11$, $P = 0.002$).

In summary, almost three-quarters of farmland species with available long-term trend data (23) have declined in number between 1980 and 2006 in Europe; only three species increased, while five others have been stable (Table 3). Several typical farmland bird species, such as Grey Partridge, Northern Lapwing, European Turtle Dove, Eurasian Skylark *Alauda arvensis* and Corn Bunting, have declined across Europe, while a few farmland species, such as Rook, White Stork *Ciconia ciconia*, Common Whitethroat or Red-backed Shrike, have increased in the same period (Table 2). The short-term trends (1995–2006), however, show a different pattern in a species set including 34 species, several of them with predominantly Mediterranean distributions. The proportion of species with stable or increasing trends in the short-term period is higher (56%), as is the number of species with trends classified as uncertain (15%, Table 3).

Table 3. Summary of species trends of European common farmland, common forest and all common species. Trends are classified according to trend (slope) value and its standard error (see Methods for details).

Trend category	Number of species	
	Long-term (1980/2–2006)	Short-term (1995/6–2006)
(a) Common farmland species		
Decline (steep or moderate)	16	10
Stable	2	13
Increase (steep or moderate)	3	6
Uncertain	2	5
(b) Common forest species		
Decline (steep or moderate)	12	9
Stable	9	11
Increase (steep or moderate)	6	2
Uncertain	1	7
(c) All common species		
Decline (steep or moderate)	50	36
Stable	24	46
Increase (steep or moderate)	30	31
Uncertain	5	19

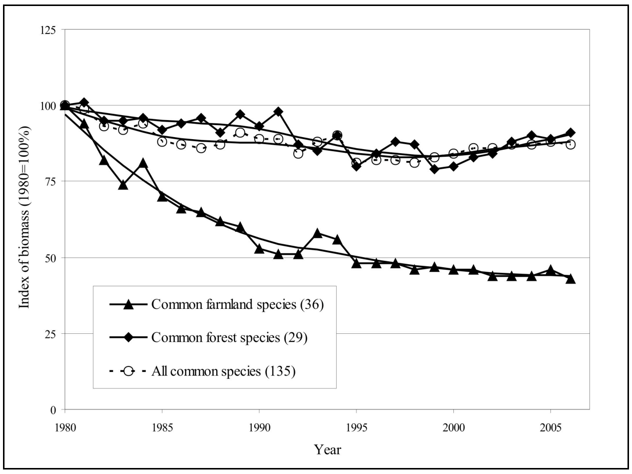
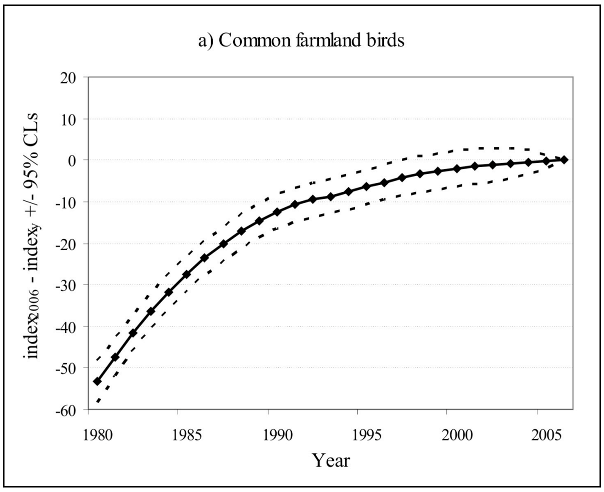
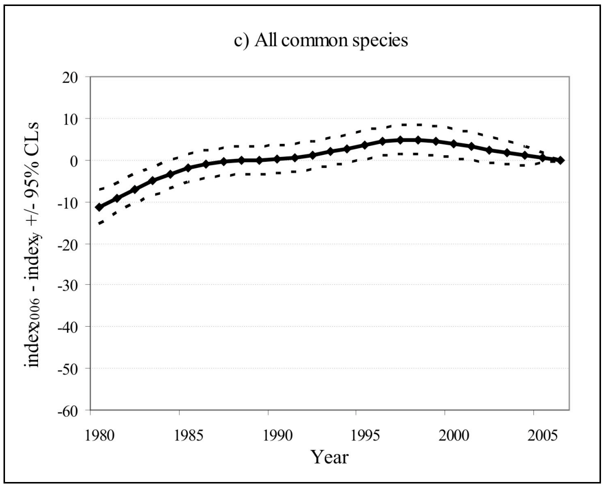


Figure 7. Index of change in biomass of common European birds from 1980 to 2006. Indices of European biomass are presented for three groups of species: common farmland birds, common forest birds and all common species. The solid lines in each case are the statistically smoothed indices for each of these three groups. Numbers in parentheses are the numbers of species in each index. Change between the index value in the first and last year for the index, and the smoothed index, are: farmland birds, –57 and -55%; common forest birds, –9 and –9%; and all common species, –13 and –10%, respectively.





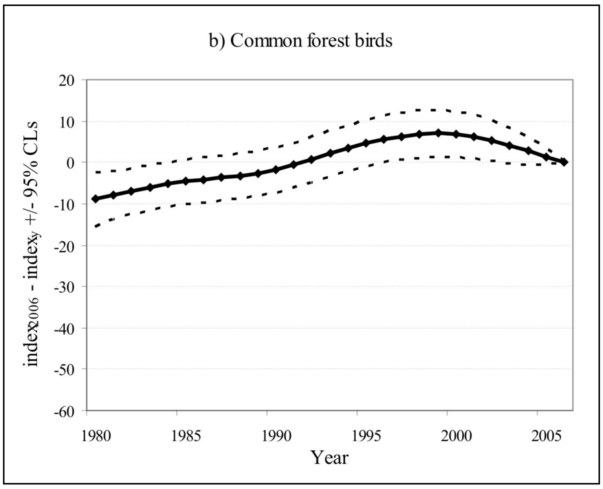


Figure 8. Differences between the smoothed biomass index in 2006 and the indices in all preceding years, with 95% confidence limits for (a) common farmland birds (*n* = 36), (b) common forest birds (*n* = 29) and (c) all common species (*n* = 135).

If we convert indices of abundance into indices of biomass for breeding birds, this shows that the biomass of common farmland birds has fallen very steeply; the index value has fallen significantly by well over 50% over the 27-year period (Figs 7 and 8a). The biomass of common forest birds in Europe has declined significantly too, by about 9% over this period (Figs 7 and 8b), as has the index of biomass for all common species by about 13% (Fig. 7). Although the biomass index for farmland birds shows a gradual decline, mimicking the index of abundance (Figs 1 and 2a), the indices for forest birds, and all species taken together, show an increasing trend in biomass from around 2000 (Fig. 8b,c). Interestingly, the increasing trend in biomass contrasts with the flat trend in abundance for these birds at this time (cf. Figs 2 and 8). The five species contributing most to the pattern of decline in the biomass index for farmland birds are Grey Partridge, Common Starling, Eurasian Skylark, European Turtle Dove and Corn Bunting (Fig. 9).

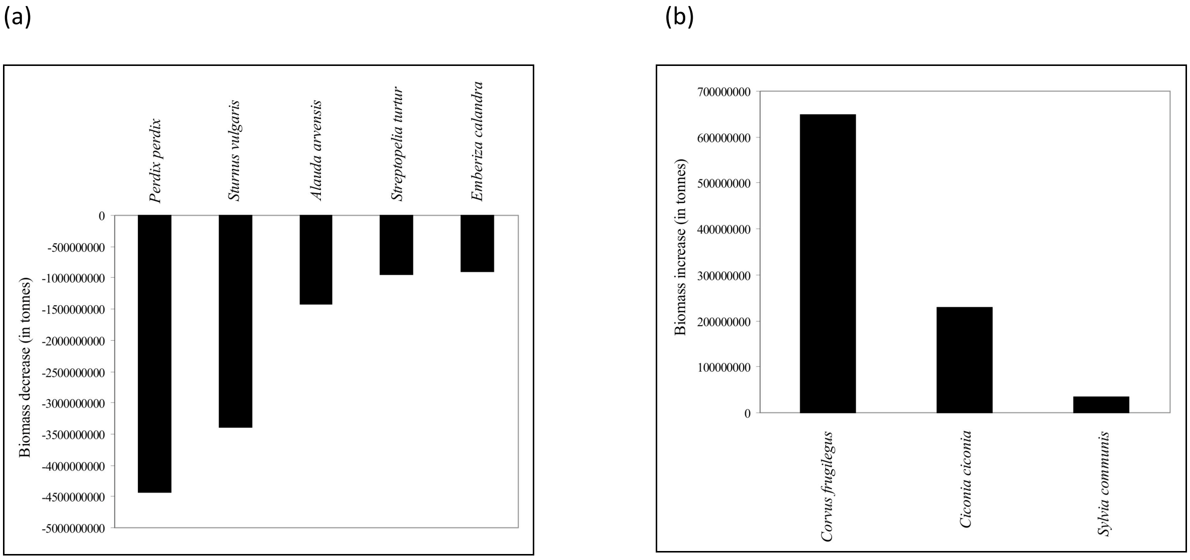


Figure 9. Change in species biomass from 1980 to 2006 for (a) the five farmland species showing the largest declines, and (b) the three farmland species showing the largest increases. Species with index which might be less reliable in early years are not included (see Methods).

DISCUSSION

Our results confirm previous findings, either based on estimates of population trends (Donald *et al.* 2001) or from systematic monitoring data (Gregory *et al.* 2005, PECBMS 2008), that farmland birds in Europe have declined substantially in the last two or three decades. Equivalent information from earlier periods, although much less complete, suggests that the decline of farmland birds had begun even earlier and it appears that our indicator, starting in 1980, misses a key period of population decline, which happened in the 1960s and 1970s (Fuller *et al.* 1995, Wretenberg *et al.* 2006, Báldi & Faragó 2007).

Interestingly, if we convert population indices into indices of biomass for farmland birds, this shows a very similar pattern of decline to that shown by the multi-species population indicator. In fact, the biomass of the farmland bird species has more than halved during the last 27 years, slightly more than the farmland bird indicator itself.

As we might expect, the five species contributing most to the pattern of decline in the biomass index for farmland birds are some of the larger-bodied farmland birds and interestingly two of these, Common Starling and Eurasian Skylark, do not feature in the top five species driving changes in populations of farmland birds (Fig. 3). In contrast, Western Yellow Wagtail and Northern Lapwing do not feature in the top five species driving changes in biomass. At first sight, this is surprising for the latter species because it is a relatively large-bodied bird, yet the European populations of Common Starling and Eurasian Skylark dwarf its numbers, and this explains the difference. In the only similar study of which we are aware, Dolton and Brooke (1999) found that the biomass of the farmland birds contributed the most to the decline of bird biomass in the UK. Two of the species contributing most to biomass loss in the UK, Grey Partridge and Common Starling, feature at a European level, as does the Skylark (Fig. 9), which is mentioned by Dolton and Brooke. We have confirmed a similar pattern for common birds at a European scale. The trends we detect provide a strong signal of decline in European farmland biodiversity, although our dataset does not include other bird species using farmland in other parts of the year. Further investigations into changes in biomass of birds in agricultural habitats would be desirable and in particular any potential linkages to ecosystem function and services (see Şekercioğlu *et al.* 2004).

It is interesting to note that trends in biomass roughly parallel trends in numbers and although this is not unexpected because the two are not independent, this need not always be the case. In recent years, for example, trends in bird numbers among all common species and common forest birds have been roughly stable, while biomass has been increasing (Figs 2, 3, 7 and 8). It appears that in common forest birds (and also in all common species) some species affect the overall biomass index disproportionately. This suggests that diverse drivers may be in play for these two groups of species.

Sanderson *et al.* (2006) have shown that species migrating transcontinental distances, usually wintering in sub-Saharan regions, have declined more than European resident or short-distance migrant birds. They analysed good-quality trend information for all species from 42 European territories taken from *Birds in Europe* (Tucker & Heath 1994, BirdLife International 2004). They showed that the trends of intercontinental migrants were significantly more negative than those of short-distance migrants or residents. It should be noted that they found significant declines among migrants for the period 1970–90 but not for 1990–2000, suggesting a changing pattern. There are species in our dataset (e.g. European Turtle Dove, Western Yellow Wagtail), for which we might speculate that their negative trends are at least partly caused by deteriorating habitats in wintering areas or by adverse conditions on migration routes; but there is counter evidence too (Browne *et al.* 2004, 2005, Bradbury & Bradter 2004, Newton 2004, Gilroy *et al.* 2008, 2009). At this point, however, it is important to recognize that our knowledge of these birds is highly biased towards Europe, and we know surprisingly little about the ecology of these birds and the pressures on their populations in Africa. On average, among our set of European farmland birds, long-distance migrants appear to be doing better than short-distance migrants and residents as their population trends are slightly more positive, but still downwards (Fig. 6). A similar pattern, i.e. no effect of migratory strategy on trends of farmland birds, was found in the Czech Republic (Reif *et al.* 2008b). This might suggest that forces driving population declines of farmland birds are stronger on the breeding grounds than those occurring on the wintering areas and migration routes, and/or the driving forces differ between regions in Europe. The data in our dataset may be considered of higher quality because they come from standardized annual monitoring schemes. However, comparison with the results of Sanderson *et al.* (2006) is not straightforward because data from *Birds in Europe* (Tucker & Heath 1994, BirdLife International 2004) come from a much wider geographical area than the PECBMS dataset. We cannot rule out a potential bias in our species selection as our sample of species is small.

The relative stability of the European farmland bird indicator since 1995 could be seen as a positive signal for conservation and even as indicating a halt to the loss of biodiversity in European agricultural landscapes. In particular, when a year within this stable period is selected as a first year (e.g. 2000), one can get a positive message of change. However, the long-term trend should be considered and the index should be assessed for longer time periods (e.g. 10 years). Studying the farmland indicator at regional levels strongly suggests that population declines are continuing in West and North Europe (Fig. 4). The trends appear to be slightly less negative in Central & East Europe and South Europe, although there is no statistical difference between the regions (Fig. 4). Data from South Europe started to contribute to the European indices rather recently, because most monitoring schemes there were initiated from the late 1990s onwards. It is therefore likely that recent stability in the farmland bird indicator in the last decade in Europe is partly due to the inclusion of trend data from regions with more recent and less negative time series. On the other hand, the lack of monitoring data in the early 1980s from South Europe and partly also from Central & East Europe might suggest that the negative picture in the 1980s is overly influenced by the situation in West and North Europe. However, at least in some countries the decline of farmland birds began prior to the1980s (e.g. Fuller *et al.* 1995, Kujawa 2002, Wretenberg *et al.* 2006, Báldi & Faragó 2007), and a negative picture of population trends of farmland birds in Europe is also supported by negative trends in their biomass too.

The causes of the decline of farmland birds in Europe reflect a whole suite of factors linked to the management of farmed land (Newton 2004). Generally, loss of spatial and temporal heterogeneity in

European farmland is behind an observed decline of many farmland birds and other taxa too (Benton *et al.* 2003, Devictor & Jiguet 2007).

Most causes of decline of farmland birds in Europe can be grouped into factors linked to intensification of agriculture (Newton 2004). It has been shown that agricultural intensification, as supported by the Common Agricultural Policy (CAP) in the EU, is linked to the decline of European farmland birds and other biodiversity (Donald *et al.* 2002, 2006). Indeed, this was supported by species trends produced by the PECBMS (Fig. 5). A temporary reverse of the declines occurred in Central & East Europe in the early 1990s, coinciding with a period when intensity of agriculture in those countries fell after the collapse of communism (Gregory *et al.* 2005). The last update of European farmland bird indicators, however, shows that farmland birds continue to decline further in Central & East Europe (PECBMS 2008), which suggests the trends in this region will mimic those seen in western Europe if current trends in land use continue.

Most research into the causes of population declines of farmland birds in Europe, as published in international journals, comes from western and northern European countries, particularly from the UK. Much less has been published from southern Europe and from central and eastern European countries. Although individual studies from the former Eastern Bloc suggest that EU-driven intensification may have a detrimental effect on the relatively healthy and rich populations there (Donald *et al.* 2002, Herzon & O'Hara 2007, Herzon *et al.* 2008), information on species trends and their causes in these parts of Europe remains patchy. Some case studies from central Europe (Reif *et al.* 2008b) or from southern Europe (Sirami *et al.* 2008) suggest that land abandonment, succession of vegetation and the decreasing area of arable land may play an important role. We might speculate about other differences between western and eastern parts of Europe, such as the different migration routes and wintering areas of birds, which may also play a role. A need for further research, especially in eastern and southern parts of Europe, is therefore clear.

European farmland birds have undergone a drastic decline in their breeding populations in the last three decades. Much of this decline has been linked to the intensification of agriculture. Consequently, there have been efforts to mitigate the negative impacts of agricultural practices on birds and other taxa. In the EU, agri-environmental schemes (e.g. Vickery *et al.* 2004a, Wilson *et al.* 2007) are intended to play such a positive role. Similar schemes have also been developed in other non-EU countries, e.g. in Switzerland (Birrer *et al.* 2007), and organic farming or set-aside land might also have a positive effect on birds and other biodiversity, although often they were not designed with that intention. Many studies have shown that agri-environmental schemes and other measures, including set-aside, can indeed have a positive effect on birds (Berg & Kvarnback 2005, Bracken & Bolger 2006, Birrer *et al.* 2007). However, such evidence usually exists at field or farm scale only. On the other hand, other studies have shown that such schemes do not help as much as expected (Kleijn *et al.* 2001, Stevens & Bradbury 2006). The positive effects of mitigation measures might contribute to the rather flat curve of the European farmland bird indicator in the last decade (Fig. 1), but good evidence is lacking.

As suggested by Butler *et al.* (2010), further intensification of agriculture in Central & East Europe might pose the greatest threat to common farmland birds in Europe by 2020. Kleijn *et al.* (2009) suggest that conservation measures should be focused on issues and areas where they will be most cost-effective. In addition, the design of agri-environmental schemes should also consider landscape structure (Tscharntke *et al.* 2009). The potential positive impacts of such measures directly intended to mitigate against the harmful impacts of intensive agriculture (e.g. agri-environmental schemes), or other production measures (e.g. set-aside) on bird populations, remain to be investigated at a continental scale. The farmland bird indicator for West Europe, i.e. part of Europe with the most intensive agriculture and similar national indicators (e.g. UK, Netherlands, France, Sweden), demonstrates that farmland birds are still in serious decline year on year in many places.

Our results confirm the previously reported decline of common farmland birds in Europe. The decline in relative population index has been accommpanied by a steep decline in the biomass of farmland birds too. Information on other taxa, although much less detailed, suggests that loss of biodiversity in European farmland has been considerable. Although patterns in numbers and biomass may differ among regions, the direct and indirect evidence suggests that changes in land use, and especially agricultural intensification, have been the most important drivers of these patterns. More has to be done to reverse the negative trends where they exist and more research and monitoring is needed, especially in eastern and southern parts of Europe.

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