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Author(s): Richard D. Gregory and Arco van Strien
Source: Ornithological Science, 9(1):3-22.
Published By: The Ornithological Society of Japan
DOI: http://dx.doi.org/10.2326/osj.9.3
URL: http://www.bioone.org/doi/full/10.2326/osj.9.3

Ornithol Sci 9: 3–22 (2010)

SPECIAL FEATURE Monitoring bird populations

Wild bird indicators: using composite population trends of birds as measures of environmental health

Richard D. GREGORY[1,#] and Arco van STRIEN[2]

[1] *European Bird Census Council and The Royal Society for Protection of Birds, The Lodge, Sandy, Bedfordshire, SG19 2DL, UK*
[2] *Statistics Netherlands, P.O. Box 24500, 2490 HA The Hague, The Netherlands*

ORNITHOLOGICAL SCIENCE

Abstract World leaders have set global and regional targets to reduce the rate of biodiversity loss by 2010, and their relative success, or failure, in meeting these aims will be measured against a set of indicators. For such indicators to be effective, they need to meet a range of practical and scientific criteria. Their development is often driven pragmatically by the information available. One such biodiversity indicator that has proven highly effective and influential in Europe is the wild bird indicator. This is based on the composite population trends of birds combined using a geometric mean and derived from national breeding bird surveys. Recent work has emphasized the importance of common species to ecosystem functioning and suggested that the depletion of their populations might significantly affect ecosystem services. National governments and the European Union are increasingly using these measures to assess sustainable development strategies, environmental and ecosystem health, as well as in the fulfillment of biodiversity targets. Equivalent indicators have been published in North America. There are a number of reasons to believe that birds might be useful indicators of biodiversity. They are sensitive to anthropogenic changes, they are well known, excellent time-series exist, and they have a resonance and connection with people and their lives. Yet, there are counter arguments and some risks in using birds in this way. Our work provides a blueprint for others to follow using similar data on birds or other taxa, and in other countries and regions. In the discussion, we review the strengths and weaknesses of using bird population trends as biodiversity indicators, and look forward to how this work might be developed. Wild bird indicators only measure a component of biodiversity change and need to be used carefully to assist policy makers and land managers in managing the natural resources and conserving nature.

Key words Biodiversity targets, Birds, Environmental health, Population trends, Wild bird indicators

Why monitoring matters

There is a rich tradition of biological monitoring across the globe. As a group, birds are probably better known and better studied than any other taxa. This seems to reflect both an innate interest in birds across many human cultures and also the practical ease of identifying, studying, surveying and monitoring wild birds compared to other groups. Interest in the status of birds and other wildlife has arguably never been so great, both for their intrinsic value and worth, and increasingly for their extrinsic value and worth. This is fueled to a considerable degree by the stark realization that further decline in the state of nature might have profound consequences for the lives of people and their economies through the loss of the natural resources and the ecological services they provide (Carpenter et al. 2006). This was in part the motivation for world leaders to pledge in 2002 "*to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth*". At a European and European Union (EU) scale, political leaders have gone further in aiming "*to halt biodiversity loss by 2010*". As we write this paper in 2010, it is timely to

(Received 12 February 2010; Accepted 12 April 2010)
Corresponding author, E-mail: richard.gregory@rspb.org.uk

see what progress has been made at least in respect of the birds we monitor in Europe.

Our paper is biased towards birds and data derived from large-scale surveys of breeding populations that tend to cover the more abundant and widespread species, but many of the same principles could be applied to other bird data and equivalent trend data for other taxonomic groups. Our focus on the more widespread, abundant and even common species in the environment differs from the traditional pillars of conservation involving a focus on rare and localized species, and the protection of the richest sites. 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 that might significantly disrupt ecosystem structure, function and services.

We explain later why birds might be useful indicators of nature more broadly, but birds have no special indicator status over and above other taxa. We will show that birds have proven to be highly effective indicators of the impacts of environmental change in Europe in both crystallising how biodiversity is changing and influencing policy responses to address perceived problems. Our work is driven by pragmatism because when it comes biological monitoring of birds, or other groups, what is desirable is always compromised by what is practically possible (Buckland et al. 2005). In this paper, we wish to convince you that birds can act as excellent barometers, or bellwethers, or indicators of environmental health and of the sustainability of human resource use.

By monitoring here, we mean repeated bird surveys or counts across a set of sites using standardized methods and protocols, and following a predefined survey design that measures change through time as an aid to species and site protection and management (Gregory et al. 2004a). We see no great distinction between monitoring and surveillance in practice, although some authors have suggested one (Furness & Greenwood 1993). When monitoring data is collected according to a formal framework (and sometimes when it is not), considering survey objectives, sampling strategy and fieldwork methods, then these data and derived information can have a variety of useful applications. These range from identifying emerging environmental and conservation issues, understanding the impacts of land use and environmental changes on species, measuring the efficacy of conservation actions for sites and species, and providing summary information on the state of nature and how it is changing. These data have critical value in setting priorities for species research and conservation to ensure that the most threatened species and most important sites become the focus of attention. Monitoring data play an essential part in setting species and site conservation priorities in Europe and North America (Carter et al. 2000; BirdLife International 2004; Eaton et al. 2009) and at global scales too (Stattersfield & Capper 2000). Monitoring data have been widely used to advance understanding in theory and practice in conservation biology and mainstream ecology over many years.

We view monitoring as an essential component of any evidence-based approach to nature conservation at a time when monitoring in general is often held in low esteem by academics and funding bodies (Yoccoz et al. 2001; Nichols & Williams 2006; Wiens 2009). This is unfortunate and some of the criticisms seem outdated and poorly informed, at least, in respect of the bird monitoring work with which we are familiar in Europe and North America. We share the view of Wiens (2009) and echoed by others, that investment in monitoring needs to be strengthened, rather than diminished, in a world that is changing rapidly and facing ever new threats. Unfortunately, there is a tendency for some academics and funding bodies to exploit the data provided by enthusiasts and conservationists, rather than placing the funding of its collection and collation on a sounder footing, and engaging in its design and implementation. This situation needs to change and there is some excellent bird and other monitoring work that leads the way.

What are we trying to measure?

At the outset, it is important to define what we are trying to capture in our metrics of biodiversity change. Lamb et al. (2009) focus on the concept of the intactness of biodiversity, meaning the degree to which the observed community deviates from a natural, reference or desired condition. Others have focused on related ideas of ecosystem or environmental health, habitat condition or health, environmental services, and even measurement of specific management options and practices. Another way of describing the same process is termed ‘biotic homogenization’ (McKinney & Lockwood 1999). This describes a process of anthropogenic change where some generalist species that respond positively to human-induced change, progressively out compete the many specialist species that responded negatively to land use change and fragmentation. In this way, a few 'winners' replace the many 'losers' in wholesale change in the environment. The result is a more homogeneous environment with lower biodiversity at national, regional and global scales (McKinney & Lockwood 1999).

We tend to label the indices we have developed in Europe as measures of ecosystem health or habitat condition, but biologically they are closer to measures of 'biotic homogenization'.

Why birds might be good indicators

There are a number of reasons to think that birds as a group might act as reasonable biodiversity indicators. They occur high in food chains and are sensitive to environmental change (both anthropogenic and natural). They are widespread, diverse and mobile, living in most terrestrial and marine habitats across all continents. They are relatively easy to identify, survey and census, and their phylogenetic status is well defined. Count data are realistic and relatively inexpensive to collect (especially when counts are made by skilled and motivated volunteers). Methods of survey design (i.e. sampling strategy and fieldwork methods) and analysis are well developed. Long-term time series exist allowing contemporary patterns to be understood in a historical context and masses of supplementary knowledge and information exists to aid the evaluation of species trends and composite species trends. Birds have a resonance and connection with people and their lives from the public to decision makers alike. Birds deliver ecosystem services to humans, certainly in the form of cultural services, but also in terms of provisioning, regulating and supporting services (Whelan et al. 2008). Birds can act as an excellent communication tool to raise awareness of biodiversity issues in a way that many other taxa cannot.

However, one could easily argue against using birds as biological indicators too. The degree to which a single taxon can faithfully represent the status and trends in other taxa is a matter of debate. Birds are much less specialised in microhabitat use than other taxa and often operate at a much larger spatial scale. Their mobility compared to other taxa is also a problem as their movements and migratory behaviour mean that their population dynamics integrate effects across often very large and different areas. We also know that some species benefit from anthropogenic change when others do not and predicting such responses is not always easy. Birds are likely to respond to an integrated set of environmental factors rather than a single one so we must interpret their trends with care. Of course, many of the same and other limitations would equally apply to any other single taxon.

Indicator concepts

An indicator is a surrogate measure for a parameter that is too ephemeral or difficult technically or practically to measure and capture directly (Landres et al. 1988; Hilty & Merenlender 2000; Lindenmayer et al. 2000). A historic example is the Island Canary, *Serinus canaria* (Linnaeus), in the coalmine. Miners kept caged Canaries, a small finch, as an early warning to alert them to the presence of poisonous gases. Canaries are much more sensitive to deadly fumes than humans so their death signaled danger and saved many miner's lives. The Canary in the coalmine analogy is often applied to environmental damage. Other less dramatic examples include lichens indicating air quality, plant species indicating soil moisture or soil fertility, or bird of prey populations reflecting pesticide contamination (Furness & Greenwood 1993). Such indicators are often used in research and environmental management as diagnostic tools. The terms indicator, indicator species, signal species, bio-indicator, bio-monitor, keystone, umbrella, and focal species tend to have different and sometimes overlapping meanings (Landres et al. 1988; Lambeck 1997; Caro & O'Doherty 1998; Hilty & Merenlender 2000; Lindenmayer et al. 2000; Gregory et al. 2005, 2007). Many of these concepts, especially when a single species is chosen to represent and protect a wider community, have proven unworkable. The focal species concept, in which a group of species is used as a conservation tool for example in site selection has proven more effective, and this is consistent with the way we have developed multi-species indicators.

For indicators to be effective, they need to meet a range of sometimes competing practical and scientific criteria (Table 1). Note that indicators should not be seen as a short cut, or substitute for the detailed knowledge needed to explore and understand the causes of change in individual species or ecosystems, and then to formulate adaptive actions to remedy perceived problems (Bibby 1999). Indicators might, to a certain degree, inform each step in this process, but they cannot replace sound autecological research and

Table 1. Key attributes of an effective biodiversity indicator.

Attribute	Details
Representative	Includes all species in a taxon or a representative group
Immediate	Capable of regular update, ideally on an annual basis
Simplifying	Reduces complex information into an accessible form
Easily understood	Simple and transparent to a range of audiences
Quantitative	Accurate measurement with assessment of precision
Responsive to change	Sensitive to environmental change over short time scales
Timeliness	Allows rapid identification of patterns and early warning of issues
Susceptible to analysis	Data can be disaggregated to understand the underlying patterns
Realistic to collect	Quantitative data can be collected within the resources of manpower and finance over medium to long term
Indicative	Representing more general components of biodiversity than the constituent species trends, ideally reflecting ecosystem health
User driven	Developed in response to the need of policy and decision makers
Policy relevant	Allow policy makers to develop and adapt policy instruments
Stability	Relatively buffered from highly irregular natural fluctuations
Tractable	Susceptible to human influence and change

experimental and other research.

The choice of an appropriate biodiversity indicator is not straightforward because biodiversity is multifaceted and the information we have available to us is highly biased taxonomically as well as spatially and temporally. There is much discussion about a single measure of biodiversity, but little real prospect of delivering it and doubts as to whether a single metric would have meaning. We favour the idea of having a series of complementary indices that capture different facets of biodiversity and how it is changing. Faced with the complexity of biodiversity it is easy to be overwhelmed by the task of trying to monitor and conserve what we have. Yet, we have shown that a simple approach that makes best use of information available to us, and attempts to extend and improve that information base, can be highly effective.

What to measure

There are a number of options as to what to record in the field depending on the circumstances, your objectives, the terrain and habitat, and logistics from simple presence and absence to species counts or density estimates with distance sampling to overcome problems associated with species' detectability.

An obvious measure to focus on, when understanding the state of biodiversity and how it is changing, might seem to be the number of species at a site (species richness), yet there is consensus that richness is a poor measure of biological change (Buckland et al. 2005; Lamb et al. 2009). Diversity indices measure species richness and evenness in a community. Species richness is problematic because most biologists would see increased richness associated with the entry of a non-native species, or an increasing number of generalist species, as a sign of habitat degradation, rather than improvement. The classic indices of diversity, the Simpson's and Shannon indices, fail in this context because neither reflects changes in overall abundance. Furthermore, if all species are declining in a community at the same rate then both indices remain stable, which is unsatisfactory. Lamb et al. (2009) tested the effectiveness of several indices using simulation. They concluded, "that by the time that richness and diversity indices detect any changes in the state of biodiversity it is likely to be too late to do anything about it". We concur in suggesting that diversity indices are limited as indicators of biodiversity change because these indices do not adequately describe ecosystem health or the process of biological homogenization.

While Buckland et al. (2005) tested a modified version of the Shannon index, we favour the use of geometric means; tests of their effectiveness, along with our own experience, support this view (Buckland et al. 2005; Lamb et al. 2009). Both of these studies point to the potential problem of adding an arbitrary value to avoid taking the logarithm of zero, but since we take the geometric mean of species' indices at national or supranational scales (not at a site level) and few common species go extinct, this is not a practical issue.

If standardized bird counts are made at a series of sites through time, one can use standard methods of trends analysis (see below) to estimate time trends in the form of indices of year effects. Such measures are relative and so they are anchored to a base year when the index is set usually to a value of 1 or 100 for ease of communication. When indices of this kind are computed for a group of species, one is then able to average the trends by year to describe the average population behaviour of the constituent species. An arithmetic mean is inappropriate because of the way the indices are scaled; a doubling index from 1 to 2 needs to be equivalent but opposite to an index halving from 1 to 0.5. A geometric mean achieves this and is recommended for a number of other properties too. The geometric mean is the natural scale in this case since populations grow geometrically, not arithmetically. It also tends to dampen extreme fluctuations and acts to reduce bias. Multi-species population indicators tend to treat each species equally and this means that an increase is treated as desirable, while a decline is undesirable. However, an increasing number of opportunistic, generalist, non-native species is likely to be judged undesirable, and that is why we select habitat specialists within our indicators. The European wild bird indicators routinely exclude non-native species as an unnatural component of the avifauna.

The composite geometric mean captures the average behaviour of the constituent species. It balances both the number of species increasing and declining as well as the magnitude of their trends. Imagine a situation where birds either increase or decrease at a constant rate, if more species decline than increase, the index goes down, if more species increase than decline, it goes up. In reality, of course, indices are likely to describe complex species trends and it is important to understand the contribution of individual species and particular periods, to make sense of the resulting indicators. Bear in mind also that composite trends have the ability to mislead and be misused too, as is the case for any statistic.

Bird detectability

For many types of bird survey detectability is an issue because any comparison of the raw "unadjusted" counts between sites and through time must assume that the probability of detecting birds is the same. However, some birds present in a study area will always go undetected, regardless of the survey method, how well the survey is carried out, and the competence of the observers. Comparison of unadjusted counts will only be valid if the numbers represent a constant proportion of the actual population present across space and time. Detectability is an important concept in wildlife surveys and has been a matter of much debate (Buckland et al. 2001; Rosenstock et al. 2002; Thompson 2002) and recent statistical developments.

A solution is to "adjust" counts to take account of detectability and a number of different methods have been proposed (Thompson 2002). The "double-observer" approach uses counts from primary and secondary observers, who alternate roles, to model detection probabilities and adjust the counts (Nichols et al. 2000). The "double-sampling" approach uses the findings from an intensive census at a sub-sample of sites to correct the unadjusted counts from a larger sample of sites (Bart & Earnst 2002). The "removal model" assesses the detection probabilities of different species during the period of a point count and adjusts the counts accordingly (Farnsworth et al. 2002). "Distance sampling" models the decline in the detectability of species with increasing distance from an observer and corrects the counts appropriately (Buckland et al. 2001). The "binomial mixture model" uses counts from repeated visits within a period of closed population sizes (Royle & Dorazio 2008).

Distance sampling is a way of estimating bird densities from line or point count transect data and of assessing the degree to which our ability to detect birds differs in different habitats and at different times (Buckland et al. 2001; Rosenstock et al. 2002). The software to undertake these analyses is freely available at: www.ruwpa.st-and.ac.uk/distance. This method is often recommended because distance sampling in the field, e.g. recording a distance to each bird, or more often recording birds in distance bands (e.g. 0–25 m, 20–50 m, 100 m and over for line transects, 0–30 m and 30 m and over for point transects) is often practical when alternatives are not. While we flag the issue of bird detectability, most breeding bird surveys do not routinely adjust counts when assessing trends. Distance sampling and other methods are useful to provide improved estimates of population sizes, but so far, there is little evidence that detection probability adds significant bias to bird trends (Johnson 2008).

METHODS TO DEVELOP INDICATORS

1) The '*Quality of Life*' indicators in the United Kingdom

The idea of developing a wildlife indicator came from a review of indicators to underpin the 1999 United Kingdom (UK) Sustainable Development Strategy (Gregory et al. 2004b, 2008). It was recognized that existing information on traditional conservation issues, such as the number and condition of special sites, the number and status of priority species and habitats, did not reflect the general health of common and widespread wildlife in the countryside—and that the latter formed a key part of what is meant by sustainability. Birds were chosen because they are regarded as good indicators of the state of wildlife, good trend information was available for them, and they have great public resonance.

A range of data sources are available on bird trends in the UK and the indicators that were developed attempted to make maximum use of what was available (Gregory et al. 2003). The main data sources are annual surveys such as the BTO's Common Birds Census (CBC), the BTO/JNCC/RSPB Breeding Bird Survey (BBS), the BTO's Waterway Birds Survey, and Waterway Breeding Bird Survey, the JNCC Seabird Monitoring Programme, and a small number of special surveys. For each species, indices are computed using the best dataset available considering representativeness, the period covered by the survey and its periodicity. Indicator methods are described in Gregory et al. (2003). Data for constituent species were analysed usually using Generalized Linear (GLM) or Generalized Additive Models (GAM), to provide annual parameter estimates of abundance, statistically smoothed in the latter case. The annual indices for each species were then standardised to a common start year, and the annual indicator values calculated as the geometric mean of the constituent species values.

The '*Quality of Life indicator*', as it was called, was based on common native bird species (i.e. those having more than 500 breeding pairs in the UK around 1990). Species were classified to their specialized habitat using Gibbons et al. (1993), who assigned species to habitats according to where they predominately breed and forage. Once allocated to a habitat, the trend for that species is generated using all available data, which in some cases will include data collected in other habitats. It is often possible to create habitat-specific trends within habitat types, which might be preferable, but that was not possible in the early census data in the UK (Newson et al. 2009).

2) Wild bird indicators in Europe

There is a strong tradition of land bird monitoring in Europe going back many years. The European Bird Census Council (http://www.ebcc.info/), an association of ornithologists co-operating to improve bird monitoring and the management and conservation of birds in Europe, has promoted the development of a pan-European monitoring scheme for breeding birds (van Strien et al. 2001; Vorsek et al. 2008). The establishment of a project coordinator for a *Pan-European Common Bird Monitoring Scheme* (PECBMS: http://www.ebcc.info/pecbm.html) in 2002 has allowed such a programme to develop (Gregory et al. 2005, 2007, 2008). The PECBMS is an initiative to deliver policy-relevant biodiversity indicators in Europe using information on bird trends. It now involves over twenty countries with land bird monitoring schemes and the number of national count schemes is growing all the time. The European Bird Census Council has promoted and nurtured new national breeding bird surveys in Europe and The Royal Society for the Protection of Birds has funded the establishment of several breeding bird surveys.

All national coordinators of the PECBMS assess all-sites totals per species using the predominant statistical technique to impute missing values in count data, that is, Poisson regression (a GLM model; McCullagh & Nelder 1989), as implemented in the TRIM software (Trends and Indices for Monitoring data; Gregory et al. 2005; Pannekoek & Van Strien 2001). Poisson regression is also available in the generalized linear model modules of many other statistical packages, but TRIM is an efficient implementation to analyse time-series of count data collected in many sites and to produce indices and associated standard errors. It is a widely used freeware program (available via www.ebcc.info). The basic TRIM model contains both site effects and year effects and estimates missing values from the data of all surveyed sites:

$$\log \mu_{ij} = \alpha_i + \gamma_j,$$

with α_i the effect for site i and γ_j the effect for year j on the log of expected counts μ_{ij}. Missing counts for particular sites are estimated ('imputed') from changes in all other sites, or sites with the same characteristics, if the basic model is extended with covariates. The assumption is that changes observed in surveyed sites also apply to non-surveyed sites.

The usual approach to statistical inference for log-linear models is maximum likelihood estimation and associated calculations of standard errors and test statistics. These estimation and testing procedures are based on the assumption of independent Poisson distributions for the counts. Such an assumption is likely to be violated when animals are counted because the variance may be larger than expected for a Poisson distribution (over-dispersion), for instance, when the animals occur in colonies. Furthermore, counts are often not independently distributed because the counts at a particular point in time may depend on the counts at the previous time-point (serial correlation). TRIM uses procedures for estimation and testing that take into account these two phenomena (a Generalised Estimating Equations approach, McCullagh & Nelder 1989).

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. We combined the all-sites totals in five regional groupings (West: Ireland, UK, Netherlands, Denmark, Austria, Switzerland, former West Germany, Belgium; North: Sweden, Finland, Norway; East/Central: former East Germany, Estonia, Latvia, Poland, Czech Republic, Hungary, Slovakia; South: France, Spain, Portugal, Italy; South East: Bulgaria). 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. 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). 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 in order 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.

We used a slightly adapted version of TRIM tailored to combine all-sites totals per country and their standard errors instead of raw counts per site. Instead of deriving the standard errors in the usual statistical way from count data and model fit, we applied the standard errors (and the year-year covariances) that resulted from the calculation of the all-sites totals per country. Van Strien et al. (2001) assessed that the procedure to combine country all-sites totals yields similar indices and standard errors as when all underlying raw data from all countries were used.

The methods used by bird population monitoring schemes differ among countries. Methods included spot/territory mapping, line and point count transects. Schemes differ also in how the sample plots were selected, varying from free choice of sampling plots (i.e. fieldworkers select where they count birds) to systematic, stratified random, or random selection of survey plots. Although free choice poses a potential risk of bias, and there has been a move towards more formal sampling strategies through time, it is argued that such changes have not introduced systematic bias in national or European trends (Gregory et al. 2005).

At a European scale, wild bird indicators for particular species groups are calculated as the geometric mean of the supranational species' indices and species are weighted equally. We defined habitat specialists through consultation with bird experts across Europe against agreed criteria (http://www.ebcc.info/index.php?ID=301).

INDICATORS IN PRACTICE

1) Wild bird indicators in the UK

Around 250 bird species occur in the UK on a regular basis, as resident or summer breeders, or as wintering or passage migrants. Their numbers and geographical ranges are tracked by a variety of survey schemes. Around 85% of these species breed in the UK and 20% of these are rare breeding species (fewer than about 500 pairs). Population trends of the former are captured in multi-species indicators that are published annually by government. By way of illustration, Figure 1 shows how a geometric mean can be used to describe the average trends of birds that

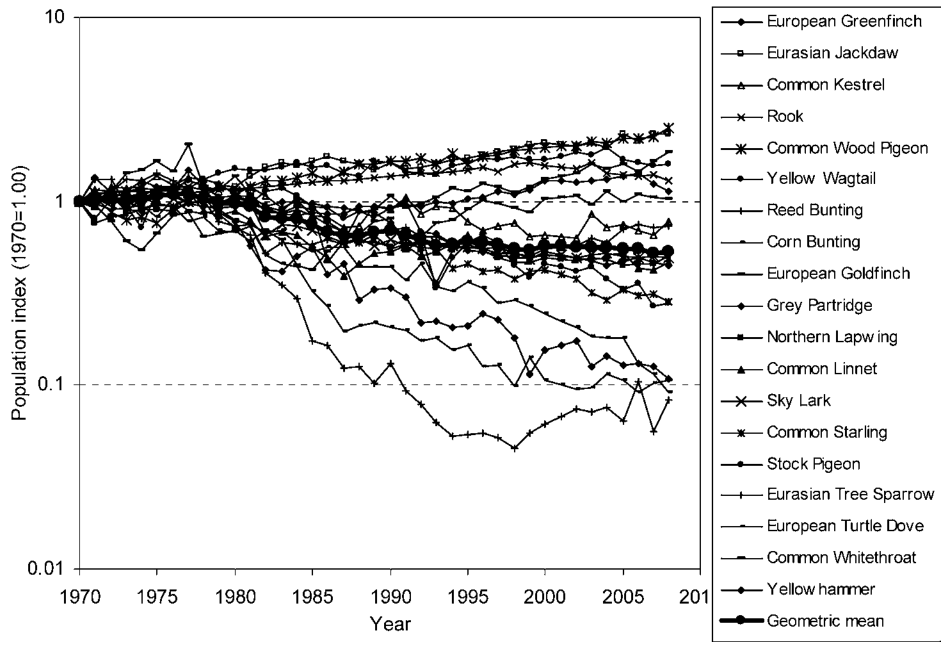

Fig. 1. An example of how a geometric mean can be used to describe the average trends among a group of related bird species. The figure shows individual population trajectories for 19 widespread farmland bird species included in the United Kingdom government's Farmland Bird Indicator from 1970 to 2008, plotted on a logarithmic scale. Population indices are fixed to a starting value of 1.00 in 1970. The bold line is the geometric mean of these species describing the average population trend for this group with each species weighted equally. The species are Common Kestrel, *Falco tinnunculus* (Linnaeus), Grey Partridge *Perdix perdix* (Linnaeus) Northern Lapwing *Vanellus vanellus* (Linnaeus), Stock Pigeon *Columba oenas* (Linnaeus), Common Wood Pigeon *Columba palumbus* (Linnaeus), European Turtle Dove *Streptopelia turtur* (Linnaeus), Sky Lark *Alauda arvensis* (Linnaeus), Yellow Wagtail *Motacilla flava* (Linnaeus), Common Whitethroat *Sylvia communis* (Latham), Eurasian Jackdaw *Corvus monedula* (Linnaeus), Rook *Corvus frugilegus* (Linnaeus), Common Starling *Sturnus vulgaris* (Linnaeus), Eurasian Tree Sparrow *Passer montanus* (Linnaeus), European Greenfinch *Carduelis chloris* (Linnaeus), European Goldfinch *Carduelis carduelis* (Linnaeus), Common Linnet *Carduelis cannabina* (Linnaeus), Yellowhammer *Emberiza citrinella* (Linnaeus), Reed Bunting *Emberiza schoeniclus* (Linnaeus) and Corn Bunting *Emberiza calandra* (Linnaeus).

are specialists of farmland. Overall, the farmland bird indicator has fallen by about half over the last forty years. Statistical uncertainty around such trends can be measured in a number of ways (Fig. 2). Confidence limits on the trends can be bootstrapped, re-sampling species site counts, or re-sampling individual species indices (Figs 2a, b: see Buckland et al. 2005), the latter being much more variable in this example, reflecting the variability between species' trends (Fig. 1). We can also use a jackknife approach to successively recalculate the indicator, missing one species out, to test for the influence of individual species (Fig. 2c). The idea is not to discern the identity of each species in the figure, but to test for robustness. Excluding Eurasian Tree Sparrow and Corn Bunting would make the indicator relatively more positive because their populations are declining fast. Excluding Common Wood Pigeon and Eurasian Jackdaw would make the indicator more negative because their populations are rising. Overall, however, the influence of individual species on the geometric mean is small in this example. Finally, we show how a statistically smoothed indicator derived from a GAM, can be used to remove year-to-year variation and reveal the underlying trend (Fig. 2d).

The UK wild bird indicator shows that the trend for all widespread species taken together is relatively stable over four decades, but average trends differ according to the main habitat of the bird species and their drivers (Fig. 3, Table 2). On average, seabird populations have increased, but they may now be in decline. Their population trends are intimately linked to fishery practices and oceanic change. Birds associated with wet breeding habitats show population vari-

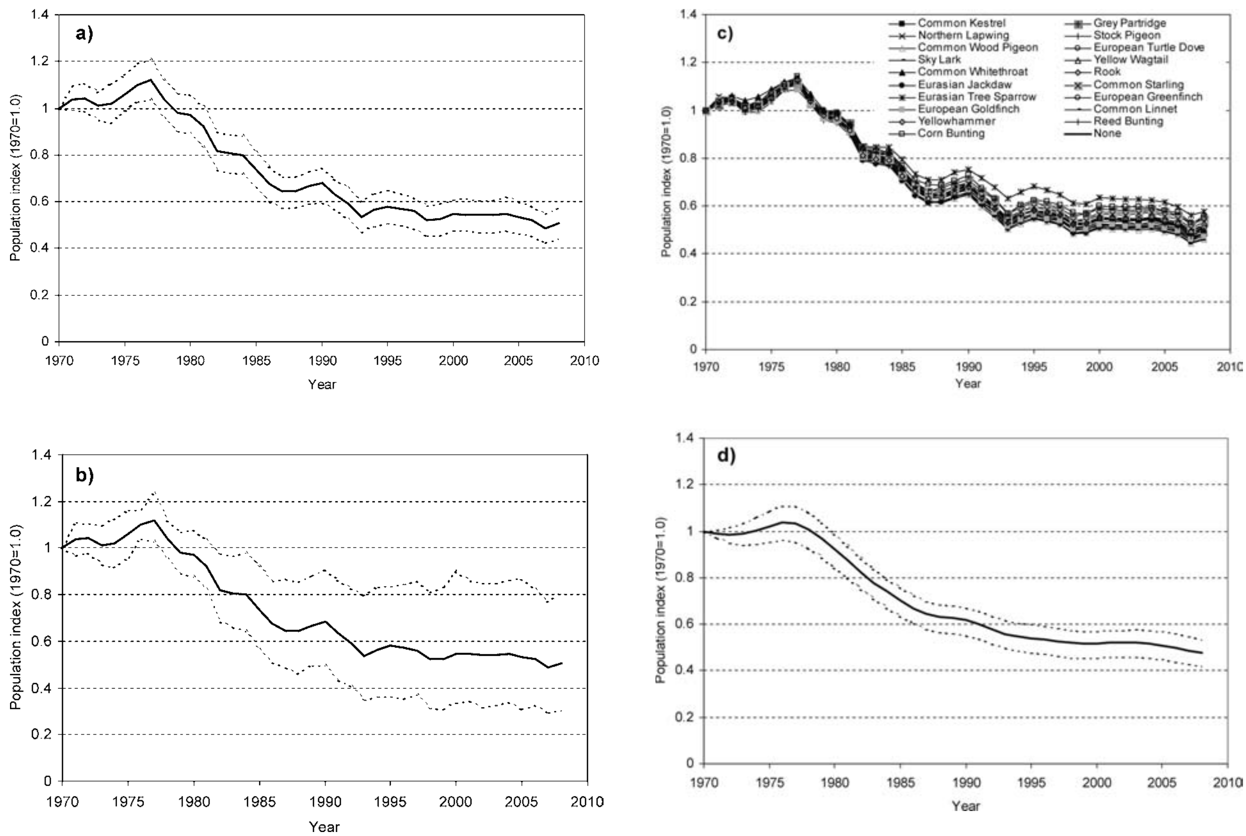

Fig. 2. Population trends of widespread farmland birds in England. Farmland Bird Indicator (the solid line) contains 19 species included in Fig. 1 indexed to a value of 1.0 in 1970 and shown on an arithmetic scale. The figure shows: a) a multi-species indicator with 95% confidence limits derived from re-sampling species/sites counts; b) the same indicator with 95% confidence limits derived from re-sampling species indices; c) successive versions of the indicator calculated missing one species out each time (the missing species is listed in the legend); and d) an indicator and 95% confidence limits based on statistically smoothed species' indices with re-sampling from species/sites counts.

ability, but no strong trend. Some of the declining species in this group, like breeding waders, have suffered as land has been drained and agriculture became more intensive. These changes might in turn increase predation pressure. Others birds in this group may have benefited from sympathetic management of watercourses. Forest and farmland birds however have declined markedly, and while the former show greater stability in the last decade, the latter do not. A change in farming methods towards more intensive and specialised agriculture, with an associated loss of hedgerows and marginal habitats, and changes in cropping patterns, have driven the decline of farmland birds in the UK, and elsewhere in Europe (Wilson et al. 2009). Change in forest structure due to the loss of active forest management, maturation of stock and increased deer browsing are thought to have driven forest bird declines. Urban birds appear to have increased over the last decade or so, perhaps benefiting from better habitat quality (Table 2). Similar information is not available for the UK uplands, but some wading birds and songbirds at least appear to be in decline. Within habitats, we find that generalist birds have tended to prosper, while the specialists have declined. As noted above, the rare and scarce species tend to be missed by standard monitoring schemes and in the UK and we have around 40 rare breeding species occupying a number of habitats. Around 60% of these species have increased in number in recent decades some spectacularly. They include charismatic birds such as Red Kite, *Milvus milvus* (Linnaeus), Eurasian Marsh Harrier, *Circus aeruginosus* (Linnaeus), Stone-curlew, *Burhinus oedicnemus* (Linnaeus), Woodlark, *Lullula arborea* (Linnaeus) and Dartford Warbler, *Sylvia undata* (Boddaert). Most are recovering from a historical low

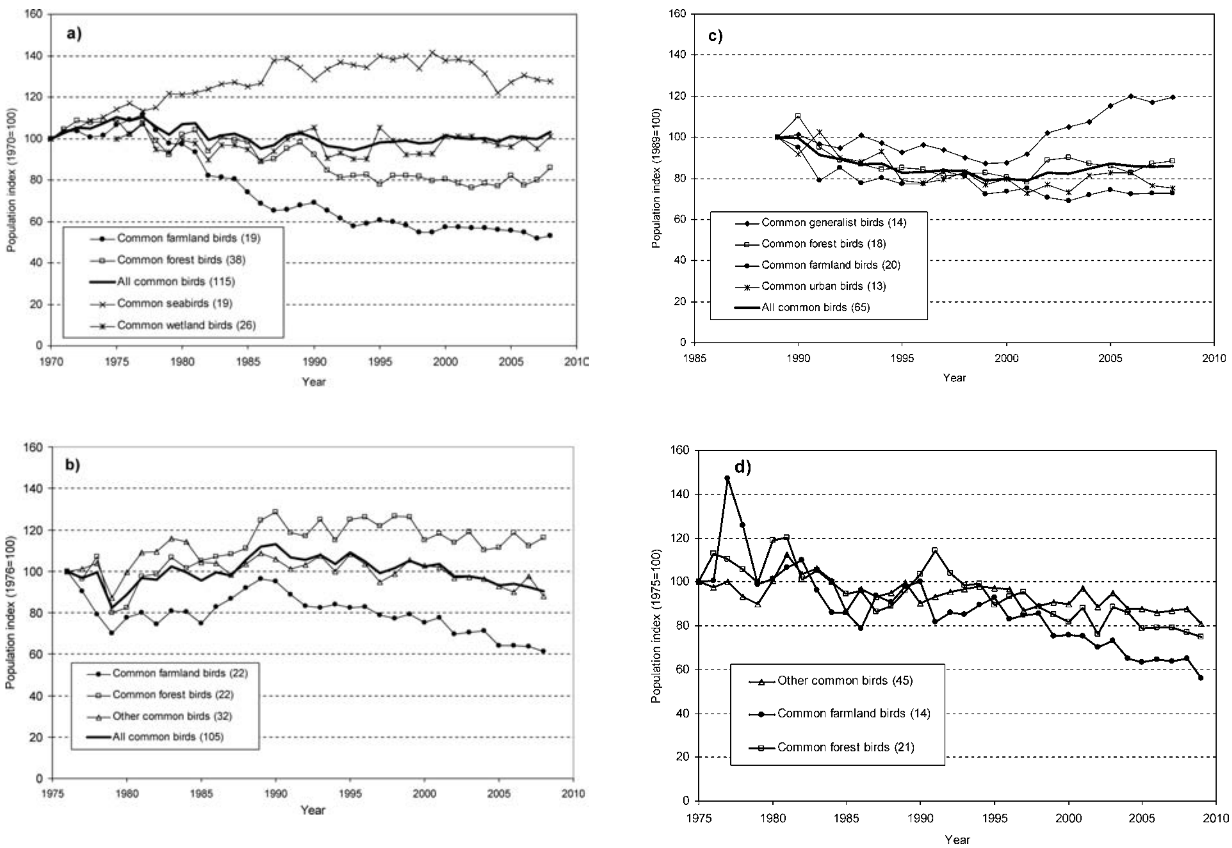

Fig. 3. Examples of national Wild Bird Indicators being used by governments in Europe to assess progress within strategies that assess the sustainability of human resource use and of environmental health: a) United Kingdom, b) Denmark, c) France, and d) Sweden. Numbers in parenthesis are the number of species in each grouping. Indices are fixed to a value of one hundred in their first year and plotted on an arithmetic axis. The length of time series differs between countries as to some degree does the underlying bird monitoring data and the way the species data are grouped.

Table 2. Wild Bird Indicators for the United Kingdom. The United Kingdom Sustainable Development and England Biodiversity Strategy Indicators describe the long- and short-term population trends of bird species grouped by their preferred habitats, with their main drivers. Trend figures are the percentage change in index values for the relevant period.

Species group (number of species)	Long-term trend	Short-term trend	Suggested key drivers
Breeding birds	**1970–2008**	**1998–2008**	
All species (114)	3%	6%	Multiple & diverse
Seabird species (19)	28%	−5%	Fishery practice & oceanic change
Water & wetland species (26)	1%	9%	Change in agricultural practices
Woodland species (38)	−14%	5%	Change in woodland structure
Farmland species (19)	−47%	−4%	Change in agricultural practices
Urban species (27)	NA	11%*	Sympathetic management & food provision
Wintering birds	**1975/1976–2006/2007**	**1996/19976–2006/2007**	
All waterbird species (46)	57%	−6%	Site & species protection & management
Wildfowl species (27)	62%	−9%	Site & species protection & management
Wader species (15)	44%	−5%	Site & species protection & management

* English trends 1994–2008

linked to habitat loss and persecution, and their improving fortunes reflect considerable investment in research and in ambitious and largely successful conservation initiatives. It would be misleading to assume that the population trends of these birds was in any way representative of the general state of the environment, as the wild bird indicators demonstrate. The trends among rare birds however offer another complementary perspective on how nature is changing.

Equivalent national wild bird indicators for Denmark (Heldbjerg & Eskilsen 2009), France (Julliard et al. 2003; Jiguet 2008) and Sweden (Lindström et al. 2010) show variation between habitats as in the UK and slight differences in how the species are grouped; but the decline of farmland specialists is a common theme (Fig. 3).

While in this paper we only discuss the development of indicators of breeding birds, it should be noted that similar indicators have been created for wintering bird populations in the UK and North America (U.S. NBCI 2009). Winter waterbirds (wildfowl and waders), of which the UK hosts internationally important numbers each winter, have increased substantially in recent decades, but now show short-term declines that are not well understood (Table 2).

2) Policy use in the UK

The wild bird indicator is one of 20 high-level UK Sustainable Development Framework Indicators, which are designed to monitor the priority areas for action identified by the sustainable development strategy. This has resulted in a high profile for the bird indicators, equivalent to that of other framework indicators that are more familiar to the public, such as employment, poverty and education.

The UK Government's response to the plight of farmland birds came in the form of a Public Service Agreement with a public pledge to "*care for our living heritage and preserve natural diversity by reversing the long-term decline in the number of farmland birds by 2020, as measured annually against the underlying trends*". With the target came a detailed delivery plan that identified milestones, the time scale, and actions necessary to meet this aim. Progress is measured annually against a statistically smoothed version of the English farmland bird indicator (Fig. 2d). The delivery mechanism was a new agri-environment scheme introduced in 2005. An entry-level option was open to all farmers and rewarded them financially for delivering wildlife habitats and for soil and water management. A higher-level option rewarded farmers financially for delivering more advanced management prescriptions designed to bring significant benefits for birds and the environment. It is too early to say if these actions will ultimately be successful, and some fine-tuning is needed in terms of the implementation of the schemes, but any failure would not be for a lack of ambition on the part of government agencies and NGOs. Similarly, the forest bird indicator has been adopted by the UK government's Forestry Commission as an indicator of sustainable forestry, with a target to reverse the long-term decline in bird populations by 2020. In this way, the wild bird indicators, along with parallel measures for other taxa and associated information, have served to focus conservation actions across many organisations towards agreed targets for species recovery and conservation actions (Gregory et al. 2004b, 2008).

3) Wild bird indicators in Europe

In the same way that wild bird indicators have been created in the UK, they have also been developed for Europe as a whole and for the countries within the European Union, where adequate national monitoring data exist. The wild bird indicator for Europe is based on combined bird trend data from 22 countries. Overall, it shows a small decline among all widespread species when grouped together (−8% from 1980–2007), no obvious trend among specialist forest birds (−2% from 1980-2007), but a very considerable decline among specialist farmland birds (−48% from 1980–2007), that is most pronounced from the 1980s and early 1990s (Fig. 4a). The statistically smoothed trends and confidence limits, derived from the program TrendSpotter (Visser 2004; Soldaat et al. 2007), confirm these patterns (Fig. 4b). If we convert this information into a percentage change (with confidence limits) relative to the latest time point in 2007, this helps us visualise the trend patterns and assess the significance of the trend (Fig. 4c). We can see that both the farmland and forest indices mostly lay below the zero line (Fig. 4c) and this shows their values were generally below that in 2007, and where the confidence limits of change do not overlap zero, then that indicates a significant difference. In 1980, the farmland bird index was 43% lower than in 2007 (significantly different from zero change) and by 1990, it was 10% below that value (again significantly different from zero change indicating significant decline). However, by 2000, it was just 3% below the 2007 value and that change was not significantly dif-

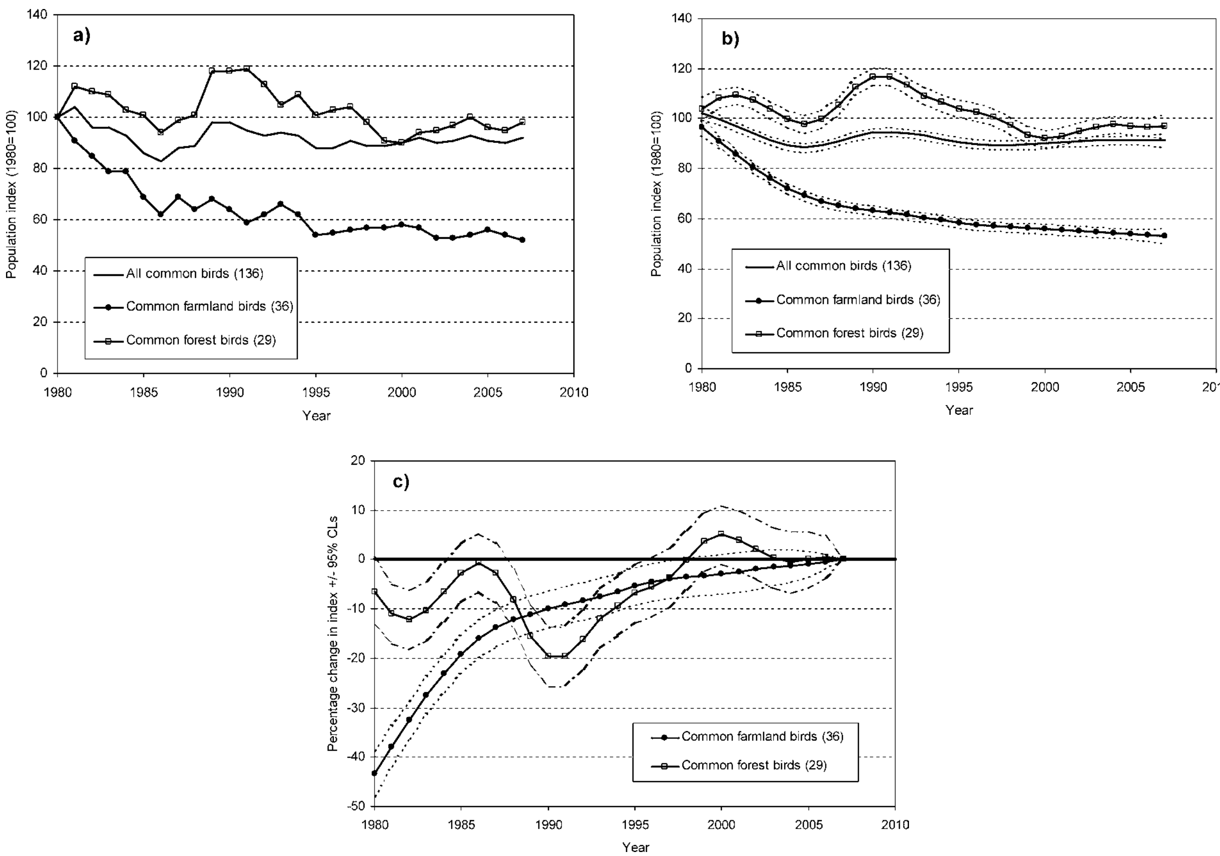

Fig. 4. Population trends of widespread birds in Europe. Numbers in parenthesis are the number of species in each grouping. Indicators are fixed to a value of 1.0 in 1980 and shown on an arithmetic scale. Composite species trends are shown for all common birds (solid line), common forest birds (open squares), and common farmland birds (filled circles). The figure shows a) trends in the annual index values, b) statistically smoothed trends with 95% confidence limits and c) percentage change in the smoothed trend backwards from the last year in the series 2007. In a) and b) the Y-axis is a population index, whereas in c) it is the percentage change in the smoothed index from 2007 to the year in question with confidence limits. The line at zero indicates no change from the value in 2007. Smoothed trends and confidence limits were calculated using the program TrendSpotter, which is based on structural time series analysis and the Kalman filter (Visser 2004).

ferent from zero (Fig. 4c). This illustrates that the decline of farmland birds was extremely steep from 1980 to about 1985 and has gradually lessened with no obvious decline in the last decade or so (Fig. 4c). Looking at the forest bird index in the same way, there have been periods of increase and decrease relative to 2007, with a gradually improving situation from around 1990 onwards (Fig. 4c).

4) Policy use in Europe

The farmland bird indicator has been adopted by the European Union (EU) as a baseline indicator under the Rural Development Regulations and as a Sustainable Development and Structural Indicator. Currently, it is the only biodiversity indicator to receive such recognition and achieve such a high profile. The Rural Development Regulations, for example, require EU member states to develop a plan for agriculture that is measured against a national farmland bird indicator. The wild bird indices also feature in the SEBI 2010 (Streamlining European 2010 Biodiversity Indicators) set of biodiversity indicators, led by the European Environment Agency.

Wild bird indicators have been developed and are being used by nearly twenty national governments in Europe within strategies to assess sustainable development and environmental health. They include Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Latvia, Netherlands, Norway, Portugal, Slovenia, Spain (Catalonia), Sweden, Switzerland, and United Kingdom. The indicators have been developed in various different ways and adapted to meet national policy requirements, but they mostly follow the model we describe.

The formal adoption of a biodiversity indicator in the EU is significant. It places information and concerns about the environment alongside much higher profile social and economic drivers, and identifies biodiversity as a cross cutting issue. It provides a clear indication to the EU as to whether they are meeting global and regional targets for biodiversity loss, at least in respect of these birds. However, so far the indicators have not led to immediate policy responses and conservation actions, as we have seen in the UK. We need a stronger commitment from the EU and national governments in Europe, to turn ambitions for halting biodiversity loss into practical targets, recovery plans and actions for nature conservation.

An obvious question for farmland birds is about the future and the degree to which we can predict how land use and other policy changes might impact their populations. The fate of farmland birds and other wildlife in Europe has been a matter of debate. There is mounting evidence that changes in agricultural practices have impacted severely on many animals and plants, as well as upon rural economies, water and soil conservation, and other ecosystem services. There is a related debate on how the Common Agriculture Policy, the EU's main agricultural policy tool, might be modified.

We have explored this issue using a trait-based framework that can be used to quantify the potential detrimental impact of land-use change on farmland bird species and thus on the farmland bird indicator across Europe (Butler et al. 2007, in press). By way of validation, we showed first that species' risk scores derived from the assessments of the environmental effects of agricultural intensification and land abandonment across Europe were significantly correlated with the annual population growth rates of the farmland birds. Higher risk scores were associated with species with negative population growth rates and therefore experiencing population declines, as we would expect.

We then used this framework to predict the value of the farmland bird indicator in 2020 under a number of different, but plausible, land-use change scenarios for Europe (Butler et al. in press). We did this using two models that related species' risk scores to population growth rates, and used parameter estimates from the derived models to make predictions about how farmland birds might respond to specific changes. The 'basic' model uses this simple relationship to make predictions, but it cannot be used to describe changes in intensity or extent of land use, and so the 'scale' model introduces a scaling mechanism to increase risk with the level of change. Each model did a reasonable job in predicting the observed value of the farmland bird indicator in 2005 (Fig. 5). Our predictions for 2020 are uncertain, but they strongly suggest that continued agricultural management at current levels, the loss of compulsory set-aside land, and continued land abandonment, would all see the indicator fall in value, but that accelerated agricultural intensification in eastern Europe posed the greatest threat to farmland bird populations (Fig. 5). It is easy to imagine such impacts from what we know already about farmland birds in Europe, but the great value of a trait-based risk assessment is that we are able to quantify potential effects and uncertainty.

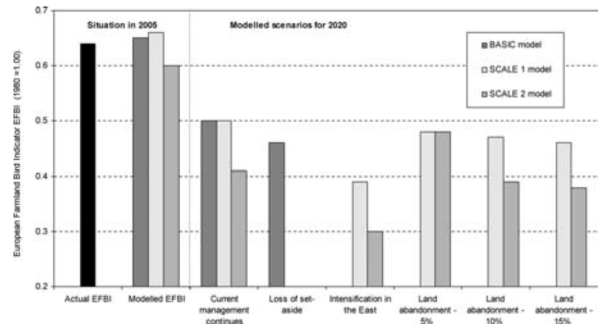

Fig. 5. Predictions for the European Farmland Bird Indicator (EFBI) for 2020 derived from models based on a trait-based risk assessment (Butler et al. in press). The figure shows the observed indicator value in 2005 and the modelled predictions for that year from two models, 'basic' and 'scale' (see Butler et al. in press). 'Scale 1' considers total risk to species, whereas 'Scale 2' considers only diet- and nest-related risk. The figure shows modelled scenarios for 2020 associated with continued current management, the loss of compulsory set-aside, accelerated agricultural intensification in eastern Europe, and continued land abandonment at different levels, using various models.

DISCUSSION

1) Species selection

One of the difficulties using the methods we describe is how to robustly select species for inclusion in species groups for individual habitats. Given a stated desire to measure changes in homogenization, we need to select species that have a particular connection and reliability on resources (feeding or nesting) in a specific habitat. We want to select habitat "specialists" rather than "generalists", but while these terms are commonly used, they are hard to pin down ecologically, and hard to measure. A specialist might be defined as having a narrow 'niche breadth', but measuring multi-dimensional niche space is a challenge (Gregory & Gaston 2000). Discussions among species experts and the use of key species literature can be used to form a reasonable consensus on habitat requirements (as used in Europe and North America); but they are likely to be subjective to a degree.

It would be better to have an accurate quantitative measure of specialization per species. Julliard et al. (2006) and Devictor et al. (2008) have used the coefficient of variation (SD/mean) of species densities across habitats types in France as a practical measure of specialization. They assume a species is more specialized to certain habitat if its density there is higher than elsewhere. If a species density varies little across habitats, then it is viewed as a generalist. In practice, this measure may be confounded by sample size, detectability and how the habitat classification is applied. If you split the categories into subcategories, some species might suddenly appear to become stronger or weaker specialists. A greater conceptual problem is the potential circularity in the definition of specialist species: if a species declines it may well narrow its habitat preferences because it cannot survive in marginal habitat types anymore, and vice versa as a species increases. We know little about how niche breadth might change through time and co-vary with species abundance; is a specialist always a specialist, and a generalist always a generalist? Of course, this depends on how you view a specialist. If a species specializes on resources that are widespread and abundant at a point time, we might label it a generalist. If one specializes on resources that are rare and atypical, we say it is a specialist. The latter concept of 'niche position', rather than 'niche breadth' (Gregory & Gaston 2000), may well help to clarify what a specialist means. The choice of species is bound up with the question of what we are attempting to capture in our indicator, so it is important to define our objective. Work in Europe and North America has defined species habitat requirements robustly at the outset using the best available published information and knowledge to avoid any suggestion of bias in species selection.

2) To weight or not to weight

The indicators we have developed weight species equally and at first sight that might seem to be too simple an approach. One might, for example, weight species indices by the specialization of that species, the desirability of the species, species abundance, species body mass, precision of the species trend, degree of endemism, conservation value, phylogenetic uniqueness or diversity, cultural preference, or sensitivity to a particular driver (see Buckland et al 2005). In each case, the resulting index would have a particular meaning, interpretation and use. It is important to understand how weighting might affect the indicator (Table 3). We would certainly like to explore and develop such ideas using our data to understand the behaviour of alternative indices, but adding complexity of this kind might also have a cost in reducing comprehension. Our focus has been to develop biodiversity indices that convey information on bird trends and the simple geometric mean of grouped species trends has proven effective in that respect, but we would welcome further development.

In that respect, we mention the idea that biodiversity indices might be weighted by species biomass and we have explored this idea for European birds (Vorisek et al. in press). One can imagine a number of reasons why indices of biomass might deviate from indices of abundance because, for example, we would predict that different drivers would affect large- and small-bodied species differentially—although we should point out that these two measures are closely linked. Somewhat to our surprise, we found that the European indices for biomass and abundance were highly similar (Fig. 6). The indicator of biomass for farmland birds has declined marginally more for biomass than for abundance (by 55% compared to 48%), but overall the trends were very similar. The pattern of changes in bird abundance and biomass detected in European farmland birds suggests a considerable loss of biodiversity and we can only speculate as to whether such changes and loss have impacted upon ecosystem function and services.

Indicators can also be constructed using a weight related to the sensitivity of a species to a particular driver, where the form of that relationship is well established. A good example is the Climatic Impact Indicator (CII) that demonstrates how climatic change is impacting upon bird populations in Europe (Fig. 7: Gregory et al. 2009), but the method could be applied more generally. The indicator is based on a combination of observed population trends monitored from 122 common bird species in 20 European countries over 26 years, and projected potential shrinkage, or

Table 3. How species weighting might influence a multi-species indicator.

Proposed indicator weight	Advantages?	Disadvantages?
None	Simple method. Simplicity in communication and interpretation. Not value driven.	Difficulty in defining specialist species, but quantitative methods could be used.
Degree of specialization	A better measure of biodiversity change reflecting loss of intactness and ecosystem . health	Difficulty in defining and measuring specialization, but quantitative methods could be used.
Desirability of species, including cultural preference	Places a value on each species, either positive or negative (for undesirables). Makes our ambition plain.	Subjective and value driven.
Species abundance	Abundant species dominate reflecting their ecological importance in communities.	Abundant species dominate and mask other important changes. Difficult to understand because of non-independence (abundant species may become rare, rare ones common).
Species body mass (biomass)	Integrates abundance and biomass in the environment.	The heaviest and most abundant species dominate.
Precision of species' trend	Better reflects the underlying species trends.	Abundant species dominate because their precision measures are smallest. Bias if species for which protection measures are taken are monitored better. Bias in time series if data quality changes over time.
Degree of endemism	Recognises the special status of endemics, which corresponds with the idea of measuring biotic homogenization.	Downplays other species.
Conservation status	Recognises a difference in species priorities. The most endangered and threatened species drive the indicator.	Status reflects a number of criteria and can be subjective. Downplays other species. Potential circularity if trend drives the status. Bias if species for which protection measures are taken are monitored better.
Phylogenetic uniqueness	Recognises the individual genetic value of species and phylogenetic history	Might mask other important changes and downplays diverse taxa
Phylogenetic diversity	Recognises the genetic value of species and phylogenetic history	Might mask other important changes
Species sensitivity to a defined driver	Links species trends to a defined driver. Not necessarily a replacement of the current indicator approach, but useful in addition	Requires well-established causal link between species and drivers.

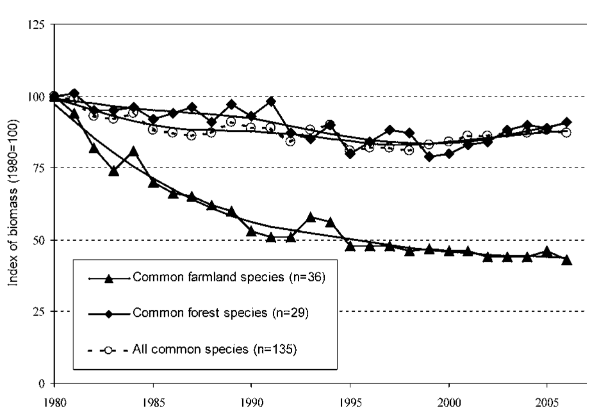

Fig. 6. An indicator of biomass trends among widespread European birds from 1980 to 2006. Indices of biomass are fixed to a value of 100 in 1980 and shown on an arithmetic scale. The solid lines in each case are the statistically smoothed indices for each of these three groups derived from TrendSpotter. Numbers in parentheses are the numbers of species in each index. Changes between the smoothed index value in the first and last year are: −55% for common farmland birds, −9%, common forest birds, and −10% for all common species.

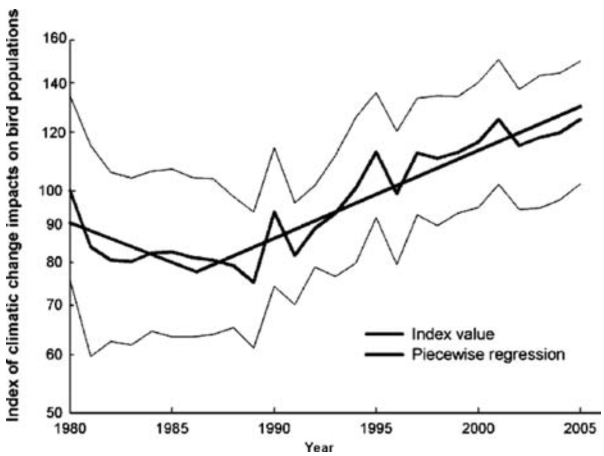

Fig. 7. An indicator of the impact of climatic change on European breeding bird populations. The Climatic Impact Indicator is the weighted ratio of the index of species whose potential geographical ranges are expected to expand to that for those species expected to contract, due to climatic change according to ensemble climatic envelope models (Gregory et al. 2009). The indicator is set to 100 in 1980. Thin lines show 90% bootstrap confidence intervals for annual values from 10,000 bootstrap replicates. The black line shows a piecewise least squares regression model fitted to the annual values.

expansion, of range size for each of these species at the end of this century (~2070–2099), derived from ensemble climatic envelope models.

The CII is calculated in two steps. First, we divided bird species into those for which ensemble models indicated an increase in potential geographical range and those with projected decreases in geographical range. For each of the two groups of species, we then calculated a multi-species index from population indices for individual species (using a geometric mean), with the weight of the contribution of each species to the index being based on the modelled projected change in potential range extent. In simple terms, population trends of birds that are predicted to be strongly affected by climatic change in our models (either negatively or positively), have greater influence on the indicator. Second, the CII is calculated in a given year as the ratio of the index for those species projected to increase in potential range to that of those species projected to decrease in geographical range. The two groups of species have equal weighting in the indicator.

The indicator demonstrates that climatic change is having a detectable effect on bird populations at a European scale, including evidence of negative as well as positive effects on their populations. The number of bird species observed to be negatively impacted is three times larger than those observed to be positively affected. The CII has increased strongly in the past twenty years, coinciding with a period of rapid climatic warming in Europe (Fig. 7). Potential links between changes in bird populations and ecosystem functioning and resilience are not well understood. It is suggested that increasing climatic effects might alter ecosystem functioning and resilience.

3) A Global Wild Bird Index?

There is a large amount of ongoing and historic bird monitoring information (bird surveys and atlases) available across the globe, but little synthesis of the trend information, except, and notably, as it is used in the Red List Index (RLI: Butchart et al. 2004, 2007), and the Living Planet Index (LPI: Collen et al. 2009). The RLI measures trends in the extinction risk of species. The LPI measures composite population trends taken from diverse time-series data for more than 6,400 populations of over 2,000 species of mammal, bird, reptile, amphibian and fish from all around the globe (Collen et al. 2009).

The challenge for us is to collate relevant long-term bird monitoring data and to assess the degree to which it might contribute to a global wild bird indicator. The 'Wild Bird Index' (WBI) project aims in time to measure population trends of a large suite of birds to act as a barometer of ecosystem health (http://www.twentyten.net/wbi). The methodology for producing such indices is well developed as we have shown here. Such an index would measure biodiversity change in a similar fashion to the LPI, the main difference being that the WBI would incorporate trend data from formally designed breeding bird surveys to deliver robust and representative indicators. The requirement for robust data, however, means that data coverage is currently very patchy.

The WBI project aims to promote and encourage the development of national bird population monitoring schemes. Where such schemes already exist, it will coordinate and facilitate the collation of bird species' data and the generation of trend indices and indicators. Where there are none, it aims to provide tools and support to implement similar data collation and synthesis in a set of countries across regions. A key tool will be the web-based facility Worldbirds, (http://www.worldbirds.org/mapportal/worldmap.php), which will support the entry and collation of bird survey data.

CONCLUSION

The indicators we have developed in Europe have many of the characteristics of effective biodiversity indicators (Table 1) and have proven highly influential. They have contributed to recent global assessments of biodiversity trends (Butchart et al. 2010, Secretariat of the Convention on Biological Diversity 2010). National governments and the EU are increasingly using these measures to assess sustainable development strategies, environmental and ecosystem health. Overall, the indicators demonstrate considerable biodiversity loss in Europe sustained over several decades, but with variation between habitats and countries; future predictions for farmland birds at least are somewhat bleak. There have been distinct phases in the trend patterns. Our work provides a blueprint for others to follow using similar data on birds or other taxa, and in other countries and regions. Indeed, in North America, an equivalent approach has used data from the North America Breeding Bird Survey, the Christmas Bird Count, and the Waterfowl Breeding Population and Habitat Survey to create indicators reflecting the health of major habitats and the environmental services they provide (U.S. NABCI Committee 2009). Trends were analysed using a hierarchical model using Bayesian methods and multi-species indicators for habitats created following equivalent methods to those used in this paper. A similar approach is being trialed in Australia using presence/absence data from their national bird atlas project (Cunningham & Olsen 2009). Plans are underway to extend land bird monitoring in different regions and to mobilise relevant trend information in the WBI project (above).

Yet, the indicators we have developed for birds are imperfect in many ways and in this discussion, we have examined some of the practical and theoretical issues. One arguable weakness is that we tend to under-represent rare and scarce species. It would be possible to build indices for rare species (Gregory et al. 2003) and incorporate additional trend data from other sources into the wild bird indicators, but in doing so, we would alter the nature of the indicator. Naturally, we wish to improve the quality of the wild bird indicators at national and supranational scales. This means expanding and improving the national monitoring schemes, their sampling strategies, field methods, automation and data checking, and trend analyses. It will also involve improved quality control at a supranational level and testing for species sensitivity, as we have done here for the English farmland bird indicator (Fig. 2). We would also like to explore some of the alternative indicators we have described. Wild bird indicators only measure a component of biodiversity change and need to be used carefully to inform policy makers and land managers, but they have proven a powerful tool in raising awareness of growing threats to nature.

In Asia, and in Japan specifically, knowledge of birds and bird populations is extremely good and monitoring data of different kinds exists, although we suspect there may be gaps in countries, species, site and habitat coverage. We recommend a review of the existing medium- to long-term breeding and non-breeding season datasets in Asia with a view to further developing species trend analysis and wild bird indicators. This should cover both the common and widespread species in the countryside, as well as the rare. We would also recommend the establishment (or reinstatement/relaunch) of formally designed breeding bird surveys, and wintering waterbird surveys in Asian countries, informed by a gap-analysis as part of the review. Finally, we would encourage collaboration so that expertise, interest and enthusiasm are shared across countries, and datasets are pooled and combined so that they provide greater understanding and can have greater effect.

ACKNOWLEDGMENTS

Thanks go to the many individuals and organisations responsible for national data collation in Europe, from the many skilled volunteers to the professional staff responsible for analysis and reporting. The wild bird indicators in the UK are compiled by the RSPB, BTO and JNCC on behalf of the Department of the Environment, Food and Rural Affairs. We thank David Noble, Anna Renwick, Andrew Joys, Stephen Baillie and Mark Eaton for access to these data. We thank Henning Heldbjerg, Fréderic Jiguet and Åke Lindström for supplying their respective national data. Great thanks to the European network who make this work possible: Norbert Teufelbauer, Christian Vansteenwegen, Anne Weiserbs, Jean-Paul Jacob, Anny Anselin, Thierry Kinet, Anotoine Derouaux, Svetoslav Spasov, Zdeněk Vermouzek, Josef Chytil, Jiří Reif, Henning Heldbjerg, Michael Grell, Anne Eskildsen, Andres Kuresoo, Jaanus Elts, Risto A. Väisänen, Fréderic Jiguet, Johannes Schwarz, Martin Flade, Tibor Szep, Olivia Crowe, Dick Coombes, Lorenzo Fornasari, Elisabetta de Carli, Ainars Aunins, Ruud P. B. Foppen, Magne Husby, Przemek Chylarecki, Barbara Archita, Ricardo Martins, Ana Meirinho, Geoff Hilton, Juan Carlos del Moral, Virginia Escandell, Åke Lindström, Sören Svensson, Hans Schmid, David G. Noble, Kate Risely, and Andrew Joys. Thanks also to Petr Vorisek, Jana Škorpilová, Adriaan Gmelig Meyling, Leo Soldaat, Tom van der Meij, Tomáš; Telenský, Ian Burfield, Anne Teller, Norbert Schaffer, and David W. Gibbons. The Royal Society for Protection of Birds and the European Commission support the Pan European Common Bird Monitoring Scheme financially. Special thanks to Tatsuya Amano and Mark Brazil for assistance with the manuscript.

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