Literature review

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"Mapping biodiversity changes across spatio-temporal scales"

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Contents

Outline

Literature review about the link between biodiversity facets trends and spatial/temporal scales.

The idea is to take every paper that talk about biodiversity trends (so far using just the species richness seems already a lot of paper) and to list **1)** which biodiversity metric they use **2)** which taxon/taxa they use, **3)** the spatial scale, **4)** the temporal scale and **5)** what is the dynamic (does the biodiversity metric increase/decrease/doesn't change over time/unclear).

Make a table of all these papers and `group_by(taxa) %>% order_by(spatial_scale | temporal_scale)`. Then see if for each taxa we can find a trend (a bit like in Chase *et al.* 2019 Oikos paper | Jarzyna *et al.* 2015 but here I am not making the analysis, just taking the analysis from papers). Best example found so far: Hill & Hamer 2004

Meeting with Petr

1) How is the trend of biodiversity metrics linked to spatial grain/spatial extent and temporal grain/temporal extent.

- Talk about papers which does compare (Jarzyna Jetz)
- The inconsistency of reporting scales (especially for models as in Jiguet et al.or Chiron et al., and for MSI metrics)

2) Data heterogeneity

- Lack of spatial replication. That's why this review is important
- The inconsistency of reporting scales (especially for models, and for MSI metrics)
- Lack in other than western countries
- Metric heterogeneity (Freixedas 2001 but they don't mention the macroecological ones as McGill, my struggle because of the time for space substitution as Hill & Hammer). Some metrics takes into account temporal dynamic but some papers don't look at the trend of these metrics (Jarzyna et al. 2015)

- Can we use space for time substitution as an actual substitution (Hill & Hammer)
- Pop trends are usually stronger (cf. all the abundance metrics)

3) Future directions

- Lack of data for other thsn western cvountries: important to harvest data in other countries

Dashboard

Reference paper

- 05/07/2021: research wos made with the literature review filter for the first query (stopped at #13) and created the second query (stopped at #2)
- 07/07/2021: questions to Petr: **1)** can the geometric mean of relative abundance + the weighted goodness of fit be used as biodiversity trend index, **2)** can the Farmland Bird Indicator (FBI) be used as biodiversity trend (for me it is more biodiversity health, Chiron et al 2013) **3)** what about the Red List Index trend? **4)** what about Multispecies population indexes?
- 08/07/2021: stopped at the article 41 for research #2.
- 12/08/2021: stopped at article 4 for research #4
- 13/08/2021: stopped at article 8 for research #4
- 17/08/2021: stopped at article 15 for research #4
- 18/08/2021: stopped at article 30 for research #4
- 19/08/2021: stopped at article 46 for research #4
- 20/08/2021: stopped at article 64 for research #4
- 01/09/2021: verifying spatial scales --> stopped at Dittrich 2019
- 02/09/2021: **Question 1:** for the FBI/WBI…*BI indexes, usually they use a GLM/GAM to predict the abundance over the entire spatial extent and then compute the metric. Basically, those metrics are geometric means of predicted species abundances. Which spatial scale to use: the spatial unit of the prediction (i.e. the plot), or the entire area predicted? (Imo, the second option is correct). **Question 2:** same question for the Geometric mean but I am realizing while writing this question that *BI are kind of similar to geometric means so answering the first question will answer this one.

Papers that are driving me mad: Doxa et al. (2010), Jiguet et al. (2012), and Chiron et al. (2013), Eglington and Pearce-Higgins (2012)

1. Introduction

Human life quality is intrinsically linked to ecosystems state that he is living in. Indeed, ecosystems services extend in a large spectrum of mechanisms including nutrient cycle, food production, or climate and water cycle regulation (Pereira et al., 2012). Some of those ecosystem functions are managed by bird biodiversity such as seed dispersal, controls pests or pollinate plant. Unfortunately, anthropogenic stressors like habitat loss, over exploitation, pollution or introduction of invasive species could lead biodiversity to its sixth mass extinction (Barnosky et al., 2011).

Biodiversity erosion is now known from everyone and political decisions has been stated in order to limit it (*e.g.* The Convention on Biological Diversity, 2021, 2010, 2002). However, these objectives have been so far not reached due mainly to our confusion and misunderstanding about biodiversity dynamic and how to determine it.

As a matter of fact, studying biodiversity can be confusing, especially because several choices must be done. Firstly, the level at which you are looking at the biodiversity must be chosen (*e.g.* species, functional, phylogenetic diversity). Secondly, one must decide which metric is the most appropriate for his study. There are many facets of biodiversity that can be measured by different metrics depending on the objective of your study. Measures of static biodiversity are commonly used such as species richness or α diversity (*i.e.* number of species, Whittaker, 1960), the Shannon index (Shannon, 1948) ,the Simpson index (Simpson, 1949) or the Hill number (Hill, 1973). The later three biodiversity indexes take into account the relative abundances of the species and can be considered as the *quality* of the biodiversity. On an other hand, the spatial and temporal β diversity will measure the species turnover and can be measured thanks to Whittaker's (Whittaker, 1972), Sørensen's (Sørensen, 1948) or Jaccard's (Jaccard, 1912) dissimilarity indexes (*e.g.* Keil et al., 2012).

However, overall biodiversity (*i.e.* taking into account species of every taxa) may not be relevant for one's case study. Thus, several multi-species indicators have also been created, taking into account the abundances of indicator species giving information on the ecosystem health. The most known ones are the Red List Index (Butchart et al., 2007, 2005, 2004) or the Biodiversity Change Index (Normander et al., 2012).

Using all the metrics cited above, we now know that the loss of global biodiversity is unprecedented.

However, current scientific literature has also shown that temporal trends in local changes of biodiversity can be opposite to trends at larger scales (*e.g.* Chase et al., 2019). Thus, current changes in biodiversity is far more complex than a simple global decrease: most of the ecosystems undergo alterations of their communities with changes in species composition (Blowes et al., 2019; Dornelas et al., 2013). Wonders persist about how the trend of these different metrics of biodiversity are link to the spatial and temporal scales used when measured.

In order to investigate this link between spatial scales and biodiversity metrics, birds is a relevant taxon. Thanks to the many ornithological monitoring and surveys, we now have a large number of long, high-quality time series on bird populations (Bejček and Stastný, 2016). Birds are easy to observe, easy to identify and thus many volunteers are motivated to conduct standardized sampling. Given their ability to change quickly of locations, their presence is also a good indicator for ecosystem health and thus several standardized metrics have been created to assess their populations. For instance, the geometric mean of relative abundances or the goodness-of-fit statistic (Studeny et al., 2011) are some of the baseline. Other multi-species indicators have also been created specifically for birds, such as the Farmland Bird Indicator (Gregory et al., 2005), the Forest Bird Indicator (Gregory et al., 2007) or the Wild Bird Indicator (Gregory and Strien, 2010).

Here, I propose to review articles assessing the temporal trends of different avian biodiversity metrics and to look at which spatial scales these studies have been done. Summarizing the trends of these qualitative and/or quantitative avian biodiversity indexes along with their spatial and temporal scales will help to see more clearly how the trends of biodiversity are linked to spatio-temporal scales. It is also important to demonstrate that the information about the sampling plan (*i.e.* spatial scale, time span, temporal scales etc) is not systematically indicated in the scientific literature and can bring confusion to the analysis and comparisons of their trends. I believe that this review can help to have a better overview of the current knowledge on the trend of biodiversity metrics of bird populations.

specify that it is mainly for continental/coastal birds but no look at islandic communities

2. Materials and Methods

For this review, articles of interest were the ones assessing temporal trends of the most common indicators (*i.e.* metrics) of avian biodiversity and specifying spatial and temporal scales. For this, I used the *''advanced search''* tool of the ISI Web of Science Core collection database with these four following queries:

1. `AB = ((biodiversity OR species richness OR diversity) AND (temporal trend* OR dynamic*) AND (bird* OR avia*))` which resulted in 1346 references.

2. `AB = ((biodiversity change index) AND (bird* OR avia*) AND trend*)` which resulted in 60 references.

3. `AB = ((species richness) AND (bird* OR avia*) AND trend*)` which resulted in 313 references.

4. `ALL=(birds AND species richness AND temporal trend)` which resulted in 88 references.

Alternatively, the articles which were often referred to in the relevant articles were also explored.

I decided to take into account only the articles for which there was spatial replicates, *i.e.* where the trend of the metric was assessed at several locations with the same spatial grain. With this replications, the trend reported is more reliable. For each query, the title and abstract of the articles were reviewed. When the temporal trend was explicitly specified (either visually or literally), the material and method part was read in order to collect the *spatial grain* of the trend (*i.e.* the area at which the trend is assessed), its *temporal grain* (*i.e.* the time span at which data have been gathered on the field), the *spatial extent* (*i.e.* the entire area at which the study applies), the *temporal extent* and the *beginning and ending years* of the study as well as the *general trend* of the metric (Tab. 3.5).

Concerning the trend assessment, different papers contain the *p-value* or directly specify the significant trend of the metric. However, a portion of papers gives only visual representations of the trend. For those, the standard error was used when displayed. For the very few only giving the trend, the rule of thumb was applied. Information can be found in the column *Note* of the Tab. 3.6 of the supplementary material. Moreover, the final trend retained (*i.e.* either *Increase*, *Stable* or *Decrease*) doesn't reflect all the fluctuations of the metric through time but rather the difference between the starting and ending points.

3. Results

Articles using spatial replicates to compute the trend of a metric were limited, either due to a lack of data or from an analysis focusing on the global trend of the data. For instance, the Breeding Bird Surveys (*e.g.* Sauer et al., 2013; Kamp et al., 2021) follow standardized sampling plan with spatial replications (*i.e.* census plots) but not all the trend of the metrics reported are averaged or summarized at specific grain sizes. As a matter of fact, the common method encountered in the scientific literature is to learn a predictive model from the data, predict the target feature (*i.e.* the variable of interest such as abundance or species richness) and then compute the metric and its trend from the output of the model and at the dataset spatial extent, giving no spatial replicates of the trend (*e.g.* Jiguet et al., 2005, 2012; Eglington and Pearce-Higgins, 2012; Doxa et al., 2010; Sauer et al., 2017).

- First of all: there was 9 *Decrease*, 31 *Increase* and 14 *Stable* computed trends across the literature.

- For each metric, the proportion of trend directions are:

rownames	Decrease	Increase	Stable	n
Abundance	0.33	0.27	0.40	15
Diversity	0.00	1.00	0.00	2
Evenness	0.33	0.67	0.00	3
Functional diversity	1.00	0.00	0.00	1
Functional evenness	0.00	1.00	0.00	1
Functional richness	0.00	1.00	0.00	1
Simpson	0.00	1.00	0.00	2
Spatial beta-diversity	0.00	0.00	1.00	1
SR	0.09	0.68	0.23	22
Temporal beta-diversity	0.00	0.67	0.33	6

- Reducing the spatial scales to fewer levels: so far, Local <= 25 Km^2, Regional > 25 Km^2 National for EUropean size countries and Continental for the sizes of USA and worldwide.

Table 3.1: Local

Metric	Decrease	Increase	Stable	n
Abundance	0.10	0.40	0.50	10
Diversity	NA	1.00	NA	2
Evenness	0.33	0.67	NA	3
Functional diversity	1.00	NA	NA	1
Functional evenness	NA	1.00	NA	1
Functional richness	NA	1.00	NA	1
Simpson	NA	1.00	NA	2
Spatial beta-diversity	NA	NA	1.00	1
SR	0.09	0.73	0.18	11
Temporal beta-diversity	NA	NA	1.00	1

Table 3.2: Regional

Metric	Decrease	Increase	Stable	n
Abundance	1	NA	NA	4
SR	NA	0.71	0.29	7
Temporal beta-diversity	NA	1.00	NA	3

Spatial grain (Km^2)	Decrease	Stable	Increase	n
Global	0.50	0.50	NA	2
Local	0.12	0.27	0.61	33
National	NA	0.40	0.60	5
Regional	0.29	0.14	0.57	14

Table 3.3: National

Metric	Decrease	Increase	Stable	n
Abundance	NA	NA	1.00	1
SR	NA	0.67	0.33	3
Temporal beta-diversity	NA	1.00	NA	1

Table 3.4: Global

Metric	Decrease	Increase	Stable	n
SR	1	NA	NA	1
Temporal beta-diversity	NA	NA	1	1

Table 3.5: Trends of different metrics of biodiversity at various spatial and temporal scales

Reference	Metric	Spatial grain (Km^2)	Temporal grain (year)	Spatial extent (Km^2)	Temporal extent (year)	Years	Country	Trend
Harrison et al. (2014)	Abundance	10000	1.0	200000	18	1994-2011	Great Britain, UK	Increase
	Abundance	10000	1.0	200000	18	1994-2011	Great Britain, UK	Stable
	Abundance	10000	1.0	200000	18	1994-2011	Great Britain, UK	Stable
Pilotto et al. (2020)	SR	Local	NA	10180000	NA	NA	Europe	Increase
	Simpson	Local	NA	10180000	NA	NA	Europe	Increase
	Abundance	Local	NA	10180000	NA	NA	Europe	Stable
	Temporal beta-diversity	Local	NA	10180000	NA	NA	Europe	Stable
Barnagaud et al. (2017)	SR	25	1.0	9834000	41	1970-2011	USA	Increase
	Evenness	25	1.0	9834000	41	1970-2011	USA	Increase
Reif et al. (2013)	SR	1619913600	1.0	79000	23	1982-2004	Czech Rep.	Stable
	SR	National	1.0	79000	23	1982-2004	Czech Rep.	Stable
	Spatial beta-diversity	1619913600	1.0	79000	23	1982-2004	Czech Rep.	Stable
Schipper et al. (2016)	Abundance	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Increase
	SR	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Increase

Table 3.5: Trends of different metrics of biodiversity at various spatial and temporal scales *(continued)*

Reference	Metric	Spatial grain (Km²)	Temporal grain (year)	Spatial extent (Km²)	Temporal extent (year)	Years	Country	Trend
	Diversity	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Increase
	Diversity	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Increase
	Functional richness	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Increase
	Functional evenness	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Increase
	Functional diversity	25	5.0	24710000	40	1971-2010	Canada, USA, Mexico	Decrease
Sorte and Boecklen (2005)	SR	25	1.0	9834000	36	1968-2003	USA	Increase
	Abundance	25	1.0	9834000	36	1968-2003	USA	Decrease
	Evenness	25	1.0	9834000	36	-	USA	Decrease
Wretenberg et al. (2010)	SR	0.03	1.0	1800	11	1994-2004	Sweden	Decrease
Ram et al. (2017)	SR	3.2	1.0	350000	18	1998-2015	Sweden	Increase
	Abundance	1.6	1.0	350000	18	1998-2015	Sweden	Increase
Harrison et al. (2016)	Abundance	10000	0.5	NA	20	1994-2013	UK	Increase
	Abundance	10000	0.5	NA	20	1994-2013	UK	Stable
	Abundance	10000	0.5	NA	20	1994-2013	UK	Stable

Table 3.5: Trends of different metrics of biodiversity at various spatial and temporal scales *(continued)*

Reference	Metric	Spatial grain (Km²)	Temporal grain (year)	Spatial extent (Km²)	Temporal extent (year)	Years	Country	Trend
Jarzyna and Jetz (2018)	SR	2500	1.0	9834000	45	1969-2013	USA	Increase
	SR	40000	1.0	9834000	45	1969-2013	USA	Increase
	SR	640000	1.0	9834000	45	1969-2013	USA	Increase
	SR	National	1.0	9834000	45	1969-2013	USA	Increase
	SR	World	1.0	148940000	45	1969-2013	World	Decrease
	Temporal beta-diversity	2500	1.0	9834000	45	1969-2013	USA	Increase
	Temporal beta-diversity	40000	1.0	9834000	45	1969-2013	USA	Increase
	Temporal beta-diversity	640000	1.0	9834000	45	1969-2013	USA	Increase
	Temporal beta-diversity	National	1.0	9834000	45	1969-2013	USA	Increase
	Temporal beta-diversity	World	1.0	148940000	45	1969-2013	World	Stable
Davey et al. (2012)	Simpson	1	1.0	242495	13	1994-2006	UK	Increase
	SR	1	1.0	242495	13	1994-2006	UK	Increase
	Evenness	1	1.0	242495	13	1994-2006	UK	Increase
Chiron et al. (2013)	Abundance	Admin. unit	1.0	643801	14	2007-2020	France	Decrease
	Abundance	Admin. unit	1.0	643801	14	2007-2020	France	Decrease

Table 3.5: Trends of different metrics of biodiversity at various spatial and temporal scales *(continued)*

Reference	Metric	Spatial grain (Km²)	Temporal grain (year)	Spatial extent (Km²)	Temporal extent (year)	Years	Country	Trend
	Abundance	Admin. unit	1.0	643801	14	2007-2020	France	Decrease
	Abundance	Admin. unit	1.0	643801	14	2007-2020	France	Decrease
Van Turnhout et al. (2007)	SR	Admin. unit	4.0	41543	28	1973-2000	Netherlands	Increase
	SR	25	4.0	41543	28	1973-2000	Netherlands	Increase
	SR	National	4.0	41543	28	1973-2000	Netherlands	Increase
Chase et al. (2019)	SR	150	5.0	2800000	30	1982–2011	USA, Canada	Stable
	SR	400	5.0	2800000	30	1982–2011	USA, Canada	Stable
	SR	800	5.0	2800000	30	1982–2011	USA, Canada	Stable
	SR	1350	5.0	2800000	30	1982–2011	USA, Canada	Increase
	SR	11000	5.0	2800000	30	1982–2011	USA, Canada	Increase
Bowler et al. (2021)	Abundance	National unit	1.0	520475	27	1990-2016	Czech Rep., Switzerland, Denmark, Germany	Stable

Supplementary materials

Table 3.6: Supplementary informations about each article

Reference	Spatial grain (Km^2)	Trend	Note
Harrison et al. (2014)	10000	Increase	To assess the metric, they use a GAM to predict the abundance over the entire area of interest (spatial resolution = 1 Km^2) and then compute the geometric mean of species abundance = Multi Species Index (as in Studeny et al. (2013)) from the prediction. Data used to learn the GAM are sampled from plots of 1 Km^2. Farmland communities
	10000	Stable	Farmland communities, GoF (λ = -1) = weighted towards the rare species
	10000	Stable	Farmland communities, GoF (λ = -2) weighted towards the common species
Pilotto et al. (2020)	Local	Increase	”Analyses of the trends in local biodiversity over large spatial scales”
	Local	Increase	”Analyses of the trends in local biodiversity over large spatial scales”
	Local	Stable	”Analyses of the trends in local biodiversity over large spatial scales”
	Local	Stable	”Analyses of the trends in local biodiversity over large spatial scales”
Barnagaud et al. (2017)	25	Increase	Mean change of SR at the road scales Area of the road = (40/0.8)*(pi*4002) with a road of 40 Km with point counts spaced by 0.8 Km and a census radius of 400m
	25	Increase	Not sure that it is at the road scale: ”Taxonomic evenness showed a marginal, yet significant, non-linear increase from close to 0.54 in the first decade to 0.56 in the last decade (Table 1), suggesting a light trend towards a more even distribution of species' abundances among species within local assemblages ”
Reif et al. (2013)	1619913600	Stable	JPSP data, transect scale
	National	Stable	JPSP data, national scale
	1619913600	Stable	Jaccard index, pairwise comparisions between transects
Schipper et al. (2016)	25	Increase	The metric (i.e. geometric mean) is meaned over each road. Area of the road = 50*(pi*4002) with 50 census point per road and a census radius of 400m
	25	Increase	NA

Table 3.6: Supplementary informations about each article *(continued)*

Reference	Spatial grain (Km²)	Trend	Note
	25	Increase	Metric = Shannon
	25	Increase	Metric = Simpson
	25	Increase	NA
	25	Increase	NA
	25	Decrease	NA
Sorte and Boecklen (2005)	25	Increase	The metric is meaned over each road. Area of the road = 50*(pi*4002) with 50 census point per road and a census radius of 400m
	25	Decrease	NA
	25	Decrease	Metric = evenness
Wretenberg et al. (2010)	0.03	Decrease	looking at the trend through different environmental policies, " local species richness (i.e. at the scale of sites = 3 hectares) decreased significantly probably as a result of an overall reduced abundance of several species. "
Ram et al. (2017)	3.2	Increase	SR for forest species meaned over roads, spatial grain = 8* .4 with road of 8 Km and census radius no limitations so assumed 200m
	1.6	Increase	MSI for forest species, road of 8 Km with no limitations so assumed 200m
Harrison et al. (2016)	10000	Increase	Geomteric mean of species abundance, they predict the abundance with resolution of 1 Km² and then computed the metric for each 10000 Km² cell across Great Britain, Visited twice a year
	10000	Stable	GoF (λ = -1) = toward rare species" The goodness-of-fit-based measure of biodiversity suggests that both rare and common species made gains through much of Britain in the first half of the time period, and losses in the second half.", Visited twice a year / Increase first half and second second halfGoF (λ = -1)

Table 3.6: Supplementary informations about each article *(continued)*

Reference	Spatial grain (Km²)	Trend	Note
	10000	Stable	GoF (λ = -2) = toward common species " The goodness-of-fit-based measure of biodiversity suggests that both rare and common species made gains through much of Britain in the first half of the time period, and losses in the second half.", Visited twice a year / Increase first half and second second half
Jarzyna and Jetz (2018)	2500	Increase	NA
	40000	Increase	NA
	640000	Increase	NA
	National	Increase	NA
	World	Decrease	NA
	2500	Increase	NA
	40000	Increase	NA
	640000	Increase	NA
	National	Increase	NA
	World	Stable	NA
Davey et al. (2012)	1	Increase	They predict the metric using a GAM with spatial resolution of 1 Km². Then they show the trend for the mean value of the metric per year
	1	Increase	NA
	1	Increase	NA
Chiron et al. (2013)	Admin. unit	Decrease	Concerning the spatial scale, predictions are made using the spatial unit of 4 Km² and the FBI is computed for each region of France, then meanned. Prediction with baseline scenario
	Admin. unit	Decrease	FBI prediction with CAP greening cenario
	Admin. unit	Decrease	FBI prediction with No Pillar I scenario
	Admin. unit	Decrease	FBI prediction with biofuel scenario

Table 3.6: Supplementary informations about each article *(continued)*

Reference	Spatial grain (Km^2)	Trend	Note
Van Turnhout et al. (2007)	Admin. unit	Increase	For each region, the trend is computed
	25	Increase	Mainly increase of SR but the proportion of negative trend were higher than for the regional scale
	National	Increase	National scale
Chase et al. (2019)	150	Stable	NA
	400	Stable	NA
	800	Stable	NA
	1350	Increase	NA
	11000	Increase	NA
Bowler et al. (2021)	National unit	Stable	Metric = MSI, as many and as intense increase (i.e. Czech Rep. and Switzerland) than decrease (i.e. Germany and Denmarl)

References

Barnagaud, J.-Y., Gaüzère, P., Zuckerberg, B., Princé, K., and Svenning, J.-C. (2017). Temporal changes in bird functional diversity across the United States. *Oecologia*, 185(4):737--748.

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O. U., Swartz, B., Quental, T. B., Marshall, C., McGuire, J. L., Lindsey, E. L., Maguire, K. C., Mersey, B., and Ferrer, E. A. (2011). Has the Earth's sixth mass extinction already arrived? *Nature*, 471(7336):51--57. Number: 7336 Publisher: Nature Publishing Group.

Bejček, V. and Stastný (2016). Velké ptačí mapování. *Vesmír*.

Blowes, S. A., Supp, S. R., Antão, L. H., Bates, A., Bruelheide, H., Chase, J. M., Moyes, F., Magurran, A., McGill, B., Myers-Smith, I. H., Winter, M., Bjorkman, A. D., Bowler, D. E., Byrnes, J. E. K., Gonzalez, A., Hines, J., Isbell, F., Jones, H. P., Navarro, L. M., Thompson, P. L., Vellend, M., Waldock, C., and Dornelas, M. (2019). The geography of biodiversity change in marine and terrestrial assemblages. *Science*, 366(6463):339--345. Publisher: American Association for the Advancement of Science Section: Research Article.

Bowler, D., Richter, R. L., Eskildsen, D., Kamp, J., Moshøj, C. M., Reif, J., Strebel, N., Trautmann, S., and Voříšek, P. (2021). Geographic variation in the population trends of common breeding birds across central Europe. *Basic and Applied Ecology*, 56:72--84.

Butchart, S., Stattersfield, A., Baillie, J., Bennun, L., Stuart, S., Akçakaya, H., Hilton-Taylor, C., and Mace, G. (2005). Using Red List Indices to measure progress towards the 2010 target and beyond. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1454):255--268. Publisher: Royal Society.

Butchart, S. H. M., Akçakaya, H. R., Chanson, J., Baillie, J. E. M., Collen, B., Quader, S., Turner, W. R., Amin, R., Stuart, S. N., and Hilton-Taylor, C. (2007). Improvements to the Red List Index. *PLOS ONE*, 2(1):e140. Publisher: Public Library of Science.

Butchart, S. H. M., Stattersfield, A. J., Bennun, L. A., Shutes, S. M., Akçakaya, H. R., Baillie, J. E. M., Stuart, S. N., Hilton-Taylor, C., and Mace, G. M. (2004). Measuring Global Trends in the Status of Biodiversity: Red List Indices for Birds. *PLoS Biology*, 2(12):e383.

Chase, J. M., McGill, B. J., Thompson, P. L., Antão, L. H., Bates, A. E., Blowes, S. A., Dornelas, M., Gonzalez, A., Magurran, A. E., Supp, S. R., Winter, M., Bjorkman, A. D., Bruelheide, H., Byrnes, J. E. K., Cabral, J. S., Elahi, R., Gomez, C., Guzman, H. M., Isbell, F., Myers-Smith, I. H., Jones, H. P., Hines, J., Vellend, M., Waldock, C., and O'Connor, M. (2019). Species richness change across spatial scales. *Oikos*, 128(8):1079--1091.

Chiron, F., Princé, K., Paracchini, M. L., Bulgheroni, C., and Jiguet, F. (2013). Forecasting the potential impacts of CAP-associated land use changes on farmland birds at the national level. *Agriculture, Ecosystems & Environment*, 176:17--23.

Davey, C. M., Chamberlain, D. E., Newson, S. E., Noble, D. G., and Johnston, A. (2012). Rise of the generalists: evidence for climate driven homogenization in avian communities. *Global Ecology and Biogeography*, 21(5):568--578. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1466-8238.2011.00693.x.

Dornelas, M., Magurran, A. E., Buckland, S. T., Chao, A., Chazdon, R. L., Colwell, R. K., Curtis, T., Gaston, K. J., Gotelli, N. J., Kosnik, M. A., McGill, B., McCune, J. L., Morlon, H., Mumby, P. J., Øvreås, L., Studeny, A., and Vellend, M. (2013). Quantifying temporal change in biodiversity: challenges and opportunities. *Proceedings of the Royal Society B: Biological Sciences*, 280(1750):20121931.

Doxa, A., Bas, Y., Paracchini, M. L., Pointereau, P., Terres, J.-M., and Jiguet, F. (2010). Low-intensity agriculture increases farmland bird abundances in France. *Journal of Applied Ecology*, 47(6):1348--1356. _eprint: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2664.2010.01869.x.

Eglington, S. M. and Pearce-Higgins, J. W. (2012). Disentangling the Relative Importance of Changes in Climate and Land-Use Intensity in Driving Recent Bird Population Trends. *PLoS ONE*, 7(3):e30407.

Gregory, R. D. and Strien, A. v. (2010). Wild bird indicators: using composite population trends of birds as measures of environmental health. *Ornithological Science*, 9(1):3--22.

Gregory, R. D., van Strien, A., Vorisek, P., Gmelig Meyling, A. W., Noble, D. G., Foppen, R. P., and Gibbons, D. W. (2005). Developing indicators for European birds. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1454):269--288. Publisher: Royal Society.

Gregory, R. D., Vorisek, P., Strien, A. V., Meyling, A. W. G., Jiguet, F., Fornasari, L., Reif, J., Chylarecki, P., and Burfield, I. J. (2007). Population trends of widespread woodland birds in Europe. *Ibis*, 149(s2):78--97. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1474-919X.2007.00698.x.

Harrison, P. J., Buckland, S. T., Yuan, Y., Elston, D. A., Brewer, M. J., Johnston, A., and Pearce-Higgins, J. W. (2014). Assessing trends in biodiversity over space and time using the example of British breeding birds. *Journal of Applied Ecology*, 51(6):1650--1660. _eprint: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12316.

Harrison, P. J., Yuan, Y., Buckland, S. T., Oedekoven, C. S., Elston, D. A., Brewer, M. J., Johnston, A., and Pearce-Higgins, J. W. (2016). Quantifying turnover in biodiversity of British breeding birds. *Journal of Applied Ecology*, 53(2):469--478. _eprint: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12539.

Hill, M. O. (1973). Diversity and Evenness: A Unifying Notation and Its Consequences. *Ecology*, 54(2):427--432. _eprint: https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.2307/1934352.

Jaccard, P. (1912). The Distribution of the Flora in the Alpine Zone.1. *New Phytologist*, 11(2):37--50. _eprint: https://nph.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1469-8137.1912.tb05611.x.

Jarzyna, M. A. and Jetz, W. (2018). Taxonomic and functional diversity change is scale dependent. *Nature Communications*, 9(1):2565.

Jiguet, F., Devictor, V., Julliard, R., and Couvet, D. (2012). French citizens monitoring ordinary birds provide tools for conservation and ecological sciences. *Acta Oecologica*, 44:58--66.

Jiguet, F., Julliard, R., Couvet, D., and Petiau, A. (2005). Modeling Spatial Trends in Estimated Species Richness using Breeding Bird Survey Data: A Valuable Tool in Biodiversity Assessment. *Biodiversity and Conservation*, 14(13):3305--3324.

Kamp, J., Frank, C., Trautmann, S., Busch, M., Dröschmeister, R., Flade, M., Gerlach, B., Karthäuser, J., Kunz, F., Mitschke, A., Schwarz, J., and Sudfeldt, C. (2021). Population trends of common breeding birds in Germany 1990–2018. *Journal of Ornithology*, 162(1):1--15.

Keil, P., Schweiger, O., Kühn, I., Kunin, W. E., Kuussaari, M., Settele, J., Henle, K., Brotons, L., Pe'er, G., Lengyel, S., Moustakas, A., Steinicke, H., and Storch, D. (2012). Patterns of beta diversity in Europe: the role of climate, land cover and distance across scales. *Journal of Biogeography*, 39(8):1473--1486. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2699.2012.02701.x.

Normander, B., Levin, G., Auvinen, A.-P., Bratli, H., Stabbetorp, O., Hedblom, M., Glimskär, A., and Gudmundsson, G. A. (2012). Indicator framework for measuring quantity and quality of biodiversity—Exemplified in the Nordic countries. *Ecological Indicators*, 13(1):104--116.

Pereira, H. M., Navarro, L. M., and Martins, I. S. (2012). Global Biodiversity Change: The Bad, the Good, and the Unknown. *Annual Review of Environment and Resources*, 37(1):25--50.

Pilotto, F., Kühn, I., Adrian, R., Alber, R., Alignier, A., Andrews, C., Bäck, J., Barbaro, L., Beaumont, D., Beenaerts, N., Benham, S., Boukal, D. S., Bretagnolle, V., Camatti, E., Canullo, R., Cardoso, P. G., Ens, B. J., Everaert, G., Evtimova, V., Feuchtmayr, H., García-González, R., Gómez García, D., Grandin, U., Gutowski, J. M., Hadar, L., Halada, L., Halassy, M., Hummel, H., Huttunen, K.-L., Jaroszewicz, B., Jensen, T. C., Kalivoda, H., Schmidt, I. K., Kröncke, I., Leinonen, R., Martinho, F., Meesenburg, H., Meyer, J., Minerbi, S., Monteith, D., Nikolov, B. P., Oro, D., Ozoliņš, D., Padedda, B. M., Pallett, D., Pansera, M., Pardal, M. n., Petriccione, B., Pipan, T., Pöyry, J., Schäfer, S. M., Schaub, M., Schneider, S. C., Skuja, A., Soetaert, K., Spriņģe, G., Stanchev, R., Stockan, J. A., Stoll, S., Sundqvist, L., Thimonier, A., Van Hoey, G., Van Ryckegem, G., Visser, M. E., Vorhauser, S., and Haase, P. (2020). Meta-analysis of multidecadal biodiversity trends in Europe. *Nature Communications*, 11(1):3486. Bandiera_abtest: a Cc_license_type: cc_by Cg_type: Nature Research Journals Number: 1 Primary_atype: Research Publisher: Nature Publishing Group Subject_term: Biodiversity;Climate-change ecology;Macroecology Subject_term_id: biodiversity;climate-change-ecology;macroecology.

Ram, D., Axelsson, A.-L., Green, M., Smith, H. G., and Lindström, k. (2017). What drives current population trends in forest birds – forest quantity, quality or climate? A large-scale analysis from northern Europe. *Forest Ecology and Management*, 385:177--188.

Reif, J., Prylová, K., Šizling, A. L., Vermouzek, Z., Šťastný, K., and Bejček, V. (2013). Changes in bird community composition in the Czech Republic from 1982 to 2004: increasing biotic homogenization, impacts of warming climate, but no trend in species richness. *Journal of Ornithology*, 154(2):359--370.

Sauer, J. R., Link, W. A., Fallon, J. E., Pardieck, K. L., and Ziolkowski, Jr., D. J. (2013). The North American Breeding Bird Survey 1966–2011: Summary Analysis and Species Accounts. *North American Fauna*, (79 (79)):1--32.

Sauer, J. R., Pardieck, K. L., Ziolkowski, Jr., D. J., Smith, A. C., Hudson, M.-A. R., Rodriguez, V., Berlanga, H., Niven, D. K., and Link, W. A. (2017). The first 50 years of the North American Breeding Bird Survey. *The Condor*, 119(3):576--593.

Schipper, A. M., Belmaker, J., Miranda, M. D. d., Navarro, L. M., Böhning-Gaese, K., Costello, M. J., Dornelas, M., Foppen, R., Hortal, J., Huijbregts, M. A. J., Martín-López, B., Pettorelli, N., Queiroz, C., Rossberg, A. G., Santini, L., Schiffers, K., Steinmann, Z. J. N., Visconti, P., Rondinini, C., and Pereira, H. M. (2016). Contrasting changes in the abundance and diversity of North American bird assemblages from 1971 to 2010. *Global Change Biology*, 22(12):3948--3959. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/gcb.13292.

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, 27(3):379--423. Conference Name: The Bell System Technical Journal.

Simpson, E. H. (1949). Measurement of Diversity. *Nature*, 163(4148):688--688. Bandiera_abtest: a Cg_type: Nature Research Journals Number: 4148 Primary_atype: Research Publisher: Nature Publishing Group.

Sorte, F. A. L. and Boecklen, W. J. (2005). Changes in the diversity structure of avian assemblages in North America. *Global Ecology and Biogeography*, 14(4):367--378. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1466-822X.2005.00160.x.

Sørensen, T. J. (1948). *A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons.* I kommission hos E. Munksgaard, København. OCLC: 4713331.

Studeny, A. C., Buckland, S. T., Harrison, P. J., Illian, J. B., Magurran, A. E., and Newson, S. E. (2013). Fine-tuning the assessment of large-scale temporal trends in biodiversity using the example of British breeding birds. *Journal of Applied Ecology*, 50(1):190--198. _eprint: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12026.

Studeny, A. C., Buckland, S. T., Illian, J. B., Johnston, A., and Magurran, A. E. (2011). Goodness of fit measures of evenness: a new tool for exploring changes in community structure. *Ecosphere*, 2(2):art15. _eprint: https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.1890/ES10-00074.1.

The Convention on Biological Diversity, B. (2021). The Convention on Biological Diversity. Publisher: Secretariat of the Convention on Biological Diversity.

Van Turnhout, C. A. M., Foppen, R. P. B., Leuven, R. S. E. W., Siepel, H., and Esselink, H. (2007). Scale-dependent homogenization: Changes in breeding bird diversity in the Netherlands over a 25-year period. *Biological Conservation*, 134(4):505--516.

Whittaker, R. H. (1960). Vegetation of the Siskiyou Mountains, Oregon and California. *Ecological Monographs*, 30(3):279--338. _eprint: https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.2307/1943563.

Whittaker, R. H. (1972). Evolution and Measurement of Species Diversity. *TAXON*, 21(2-3):213--251. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.2307/1218190.

Wretenberg, J., Pärt, T., and Berg, k. (2010). Changes in local species richness of farmland birds in relation to land-use changes and landscape structure. *Biological Conservation*, 143(2):375--381.