



Literature review

PhD candidate: François Leroy

Programme: Environmental Earth Sciences

Department: Spatial Sciences

*"Mapping biodiversity changes across
spatio-temporal scales"*

Advisor: doc. Ing. Petra Šímová, Ph.D.

Consultant: Mgr. Petr Keil, PhD

Beginning of study: October 2020

Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 2 | Materials and Methods | 3 |
| 3 | On the link between spatial grain and trends of biodiversity | 9 |
| 4 | A lack of consistency | 13 |
| 4.1 | Spatial replicates are not a standard | 13 |
| 4.2 | Metric heterogeneity | 14 |
| 4.3 | On the temporal scale | 14 |
| 5 | Future directions | 15 |
| 6 | Conclusion | 17 |
| | References | 18 |
| | Supplementary materials | 23 |

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).

We now know that the loss of global biodiversity is unprecedented and political decisions has been stated in order to limit it (*e.g.* of the Convention on Biological Diversity & Centre, 2006, pp. 2010, 2002). 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 spatio-temporal 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 & Stastný, 2016; Kamp et al., 2021; Sauer et al., 2013). 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.

However, 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.* taxonomic, 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 (M. O. 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). All these metrics assess the taxonomic diversity, *i.e.* they use the species as unit. However, it has also been shown that functional and phylogenetic diversity can provide supplementary information on the community structure and its dynamic (*e.g.* McGill et al., 2006; Mouquet et al., 2012; Webb et al., 2002).

An other measure of biodiversity of great interest is the abundance of the populations. As a matter of fact, as individuals react to disturbances of ecosystems by disappearing, the population trends are considered as resulting of the ecosystems health. Overall populations are impossible to assess, but determining the abundance of few indicator species can give a relevant summary on how is going the entire ecosystem (Gregory et al., 2005). These family of metrics are called the multi-species indicators (MSI) and we have seen the emergence of several of them according to the ecosystem considered. We can cite here the farmland bird indicator, woodland bird indicator or one of the most informative, which summarizes these two previous metrics: the Wildland Bird Indicator (Gregory et al., 1999; Gregory & Strien, 2010). The main idea of these metrics is to compute the geometric mean of abundance of few key species over time.

Finally a last class of indicators, not considered here, take into account both species and ecosystems feature into a summarizing index. The most known ones are the Red List Index (S. Butchart et al., 2005; S. H. M. Butchart et al., 2007; S. H. M. Butchart et al., 2004) or the Biodiversity Change Index (Normander et al., 2012).

Here, I propose to review articles assessing the temporal trends of different macroecological avian biodiversity metrics and to look at which spatial and temporal scales these studies have been done. I decided to consider the most common indicators used to assess biodiversity at the community level and higher, such as the diversity indexes (*e.g.* species richness, functional diversity...) or the abundance indexes (McGill et al., 2015). 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 link between trends of biodiversity metrics of bird populations and the spatio-temporal scales.

specify that it is mainly for continental/coastal birds but no look at islandic communities and change
Stable to *No trend*

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.

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 at one census session), 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 (Table 2.1). 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 these replications, the trend reported at one spatial grain is more reliable. However, at larger spatial grains (*i.e.* national, continental or global scales), spatial replicates are rarer. Thus, I decided to take note of these unreplicated

trends only when they were found in a article were spatial replicates were used at smaller scales.

Spatial grain sizes are discretized into four levels: *local* $\leq 25 \text{ Km}^2$, *regional* $> 25 \text{ Km}^2$, *national* when an entire country is considered and *global* at the worldwide scale.

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 Table 6.1 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.

I have found 31 references in which authors were both determining the temporal trend of a metric of interest and explicitly defining the grain size. However, only 17 of them are using spatial replicates and are thus relevant for this study (Table 2.1). The classes of metric are: *Species richness*, *Evenness*, *Abundance*, *Diversity*, *Temporal beta-diversity*, *Spatial beta-diversity*, *Functional diversity*, *Functional evenness*, *Functional richness*. Some of this classes contain several different indexes. This is the case for instance for the class *Diversity*, which can be defined by either the Shannon or the Simpson index, or for the class *Abundance* which contains various multi-species indicators (for more information, see Table 6.1).

Table 2.1: Trends of different metrics of biodiversity at various spatial and temporal scales

| Reference | Metric | Spatial grain (Km²) | Temporal grain (year) | Spatial extent (Km²) | Temporal extent (year) | Years | Country | Trend |
|--|-----------|------------------------|--------------------------|-------------------------|---------------------------|-----------|--|----------|
| Barnagaud et al., 2017 | Evenness | Local | 1.0 | 9834000 | 41 | 1970-2011 | USA | Increase |
| D. Bowler et al., 2021 | SR | Local | 1.0 | 9834000 | 41 | 1970-2011 | USA | Increase |
| | Abundance | National | 1.0 | 520475 | 27 | 1990-2016 | Czech Rep., Switzerland, Denmark, Germany | Stable |
| | | | | | | | | |
| Chase et al., 2019 | SR | Local | 5.0 | 2800000 | 30 | 1982–2011 | USA, Canada | Stable |
| | SR | Regional | 5.0 | 2800000 | 30 | 1982–2011 | USA, Canada | Stable |
| | SR | Regional | 5.0 | 2800000 | 30 | 1982–2011 | USA, Canada | Stable |
| | SR | Local | 5.0 | 2800000 | 30 | 1982–2011 | USA, Canada | Increase |
| Chiron et al., 2013 | SR | Local | 5.0 | 2800000 | 30 | 1982–2011 | USA, Canada | Increase |
| | Abundance | Regional | 1.0 | 643801 | 14 | 2007-2020 | France | Decrease |
| | Abundance | Regional | 1.0 | 643801 | 14 | 2007-2020 | France | Decrease |
| | Abundance | Regional | 1.0 | 643801 | 14 | 2007-2020 | France | Decrease |
| | Abundance | Regional | 1.0 | 643801 | 14 | 2007-2020 | France | Decrease |
| Davey et al., 2012 | Diversity | Local | 1.0 | 242495 | 13 | 1994-2006 | UK | Increase |
| | Evenness | Local | 1.0 | 242495 | 13 | 1994-2006 | UK | Increase |
| | SR | Local | 1.0 | 242495 | 13 | 1994-2006 | UK | Increase |

Table 2.1: Trends of different metrics of biodiversity at various spatial and temporal scales (*continued*)

| Reference | Metric | Spatial grain (Km ²) | Temporal grain (year) | Spatial extent (Km ²) | Temporal extent (year) | Years | Country | Trend |
|---------------------------|----------------------------|-------------------------------------|--------------------------|--------------------------------------|---------------------------|-----------|----------------------|----------|
| Harrison et al., 2014 | Abundance | Local | 1.0 | 200000 | 18 | 1994-2011 | Great Britain, UK | Increase |
| | Abundance | Local | 1.0 | 200000 | 18 | 1994-2011 | Great Britain, UK | Stable |
| | Abundance | Local | 1.0 | 200000 | 18 | 1994-2011 | Great Britain, UK | Stable |
| Harrison et al., 2016 | Abundance | Local | 0.5 | 242495 | 20 | 1994-2013 | UK | Increase |
| | Abundance | Local | 0.5 | 242495 | 20 | 1994-2013 | UK | Stable |
| Jarzyna and Jetz, 2018 | Abundance | Local | 0.5 | 242495 | 20 | 1994-2013 | UK | Stable |
| | SR | Regional | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | SR | Regional | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | SR | Regional | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | SR | National | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | SR | Global | 1.0 | 148940000 | 45 | 1969-2013 | World | Decrease |
| | Temporal beta-diversity | Regional | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | Temporal beta-diversity | Regional | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | Temporal beta-diversity | Regional | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |

Table 2.1: Trends of different metrics of biodiversity at various spatial and temporal scales (*continued*)

| Reference | Metric | Spatial grain (Km ²) | Temporal grain (year) | Spatial extent (Km ²) | Temporal extent (year) | Years | Country | Trend |
|--|----------------------------|-------------------------------------|--------------------------|--------------------------------------|---------------------------|-----------|------------------------|----------|
| | Temporal beta-diversity | National | 1.0 | 9834000 | 45 | 1969-2013 | USA | Increase |
| | Temporal beta-diversity | Global | 1.0 | 148940000 | 45 | 1969-2013 | World | Stable |
| Pilotto et al., 2020 | Abundance | Local | NA | 10180000 | NA | NA | Europe | Stable |
| | Diversity | Local | NA | 10180000 | NA | NA | Europe | Increase |
| | SR | Local | NA | 10180000 | NA | NA | Europe | Increase |
| | Temporal beta-diversity | Local | NA | 10180000 | NA | NA | Europe | Stable |
| Ram et al., 2017 | Abundance | Local | 1.0 | 350000 | 18 | 1998-2015 | Sweden | Increase |
| | SR | Regional | 1.0 | 350000 | 18 | 1998-2015 | Sweden | Increase |
| Reif et al., 2013 | Spatial beta-diversity | Local | 1.0 | 79000 | 23 | 1982-2004 | Czech Rep. | Stable |
| | SR | Local | 1.0 | 79000 | 23 | 1982-2004 | Czech Rep. | Stable |
| | SR | National | 1.0 | 79000 | 23 | 1982-2004 | Czech Rep. | Stable |
| Schipper et al., 2016 | Abundance | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
| | Diversity | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
| | Diversity | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |

Table 2.1: Trends of different metrics of biodiversity at various spatial and temporal scales (*continued*)

| Reference | Metric | Spatial grain (Km ²) | Temporal grain (year) | Spatial extent (Km ²) | Temporal extent (year) | Years | Country | Trend |
|-----------------------------|-------------------------|-------------------------------------|--------------------------|--------------------------------------|---------------------------|-----------|------------------------|----------|
| Sorte and Boecklen, 2005 | Functional diversity | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Decrease |
| | Functional evenness | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
| | Functional richness | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
| | SR | Local | 5.0 | 24710000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
| | Abundance | Local | 1.0 | 9834000 | 36 | 1968-2003 | USA | Decrease |
| | Evenness | Local | 1.0 | 9834000 | 36 | - | USA | Decrease |
| | SR | Local | 1.0 | 9834000 | 36 | 1968-2003 | USA | Increase |
| | SR | Regional | 4.0 | 41543 | 28 | 1973-2000 | Netherlands | Increase |
| | SR | Local | 4.0 | 41543 | 28 | 1973-2000 | Netherlands | Increase |
| | SR | National | 4.0 | 41543 | 28 | 1973-2000 | Netherlands | Increase |
| Wretenberg et al., 2010 | SR | Local | 1.0 | 1800 | 11 | 1994-2004 | Sweden | Decrease |
| Inger et al., 2015 | Abundance | National | 1.0 | 10180000 | 22 | 1980-2001 | Europe | Decrease |
| Donald et al., 2001 | Abundance | National | NA | 10180000 | 21 | 1970-1990 | Europe | Decrease |

3. On the link between spatial grain and trends of biodiversity

The median spatial extent of the 17 articles is $5.20475 \times 10^5 \text{ Km}^2$, with the smallest area of 1800 Km^2 and the greatest representing the global emerged surface (*i.e.* $1.4894 \times 10^8 \text{ Km}^2$). Overall, there were 11 *Decrease*, 31 *Increase* and 14 *Stable* reliable trends (*i.e.* spatially replicated) across the literature, without consideration of any metric or spatial scales.

One have to keep in mind that the proportions of the trends presented here is not representative of the overall the scientific literature. Taking only the articles with spatial replicates reduces the number of studies and thus doesn't reflect the overall dynamic of biodiversity, which is not the purpose of this review. As a matter of fact, meta-analysis by Fraixedas et al. (2020) indicates that around half of bird related indicators are declining and that only 20% of them are increasing.

In our case, local scales are more represented than the others and the number of papers decreases with the increasing spatial scale (Figure 3.1). This is expected, as the spatial replications get more demanding in organization and resources as the grain size enlarges. The *Increase* of the metrics seems to be dominating at smaller scales. On an other hand, the proportion of *Decrease* is more important at regional scales than at local scales. At the global scale, no *Increase* were found.

Replicated species richness and abundance metrics are very represented in the scientific literature (Figure 3.2). The less common trend of abundance is *Increase*, whilst *Decrease* and *Stability* are both as common. Diversity indexes (*i.e.* Sørensen and Jaccard) were always found increasing and temporal β -diversity was found most of the time increasing and never decreasing. The small frequency of the other metrics doesn't allow one to discuss the trend proportions.

At local scales, species richness experiences dominantly increase (Figure 3.3). Evenness indexes, *i.e.* taxonomic and functional evenness, are mainly found increasing. Concerning the abundance indexes, the stability dominates but the increase is also often witnessed. In contrast, **at regional scale**, abundance metrics always decrease, whilst temporal β -diversity always increase. Species richness experiments mainly increases, then stability but no decrease is reported. Concerning **national and global scales**, one have to keep in mind that spatial replicates are less frequent and that most of the trends reported here

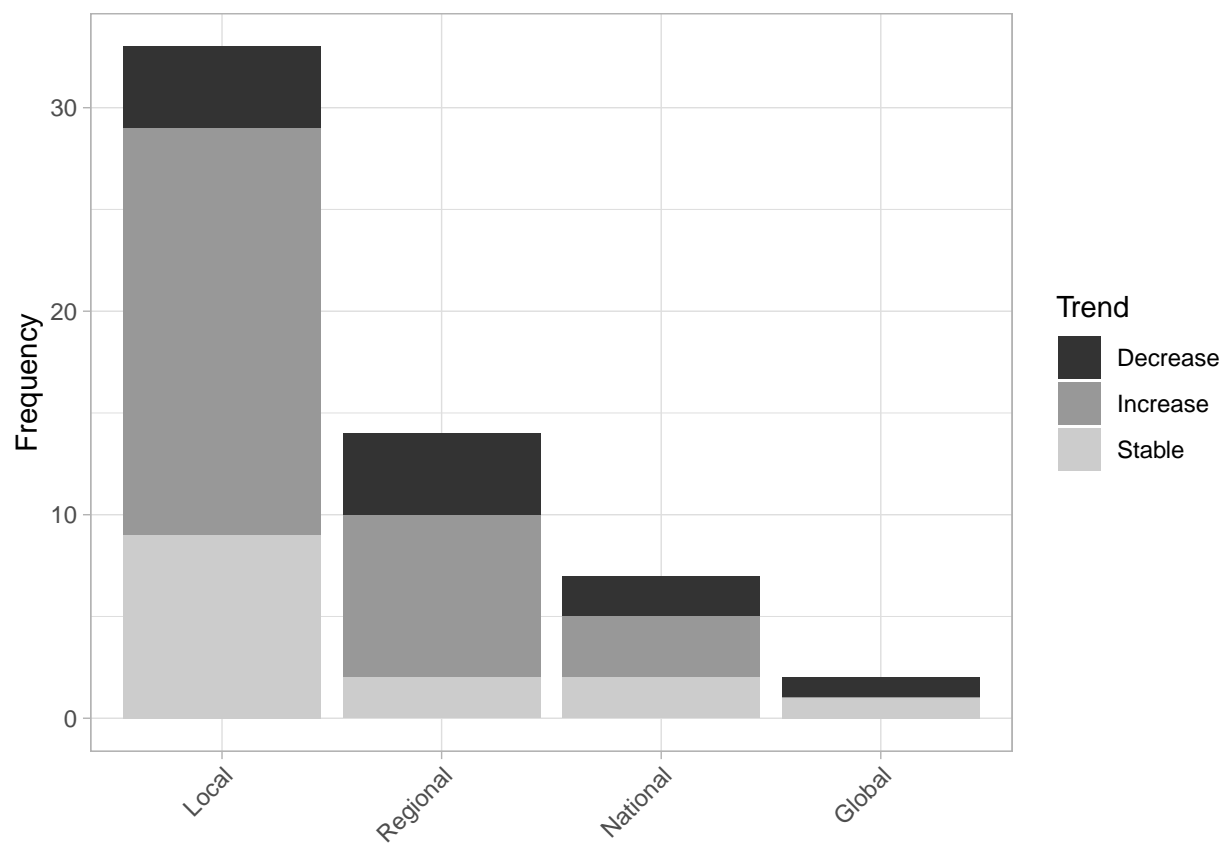


Figure 3.1: Proportion of *Increase*, *Decrease* or *Stable* trends for each spatial scale

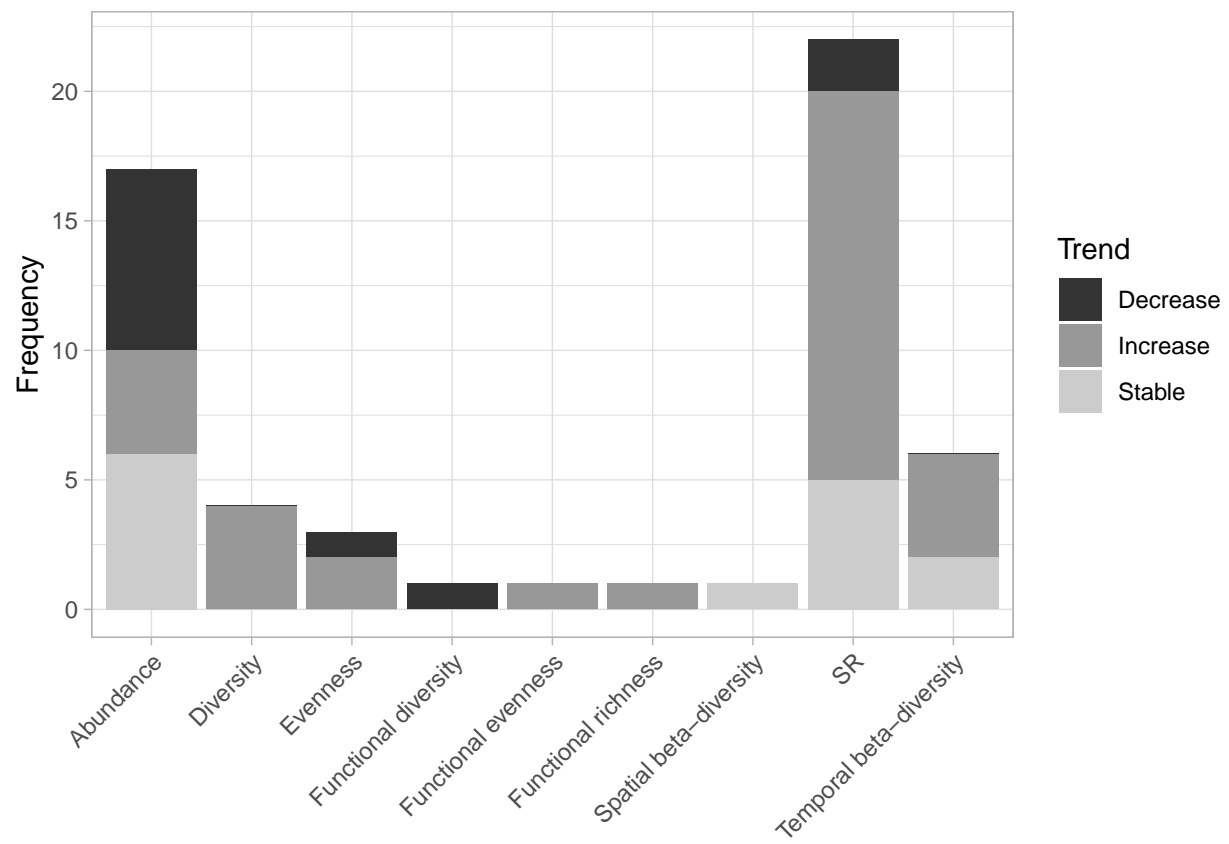


Figure 3.2: Proportion of *Increase*, *Decrease* or *Stable* trends for each of the metric

for these two spatial scales are not replicated. Exceptions are made by D. Bowler et al. (2021) and Donald et al. (2001). The former showed negative trends in abundance indexes for Denmark and Germany and positive trends for Switzerland and Czech Republic, indicating that one can not conclude about general trend at national scale (here referred as *Stable*). For Donald et al. (2001), trends of mean populations were computed for 30 european countries and most of them were negatives. No positive trend seem dominant at these spatial scales. Global trends only come from Jarzyna and Jetz (2018).

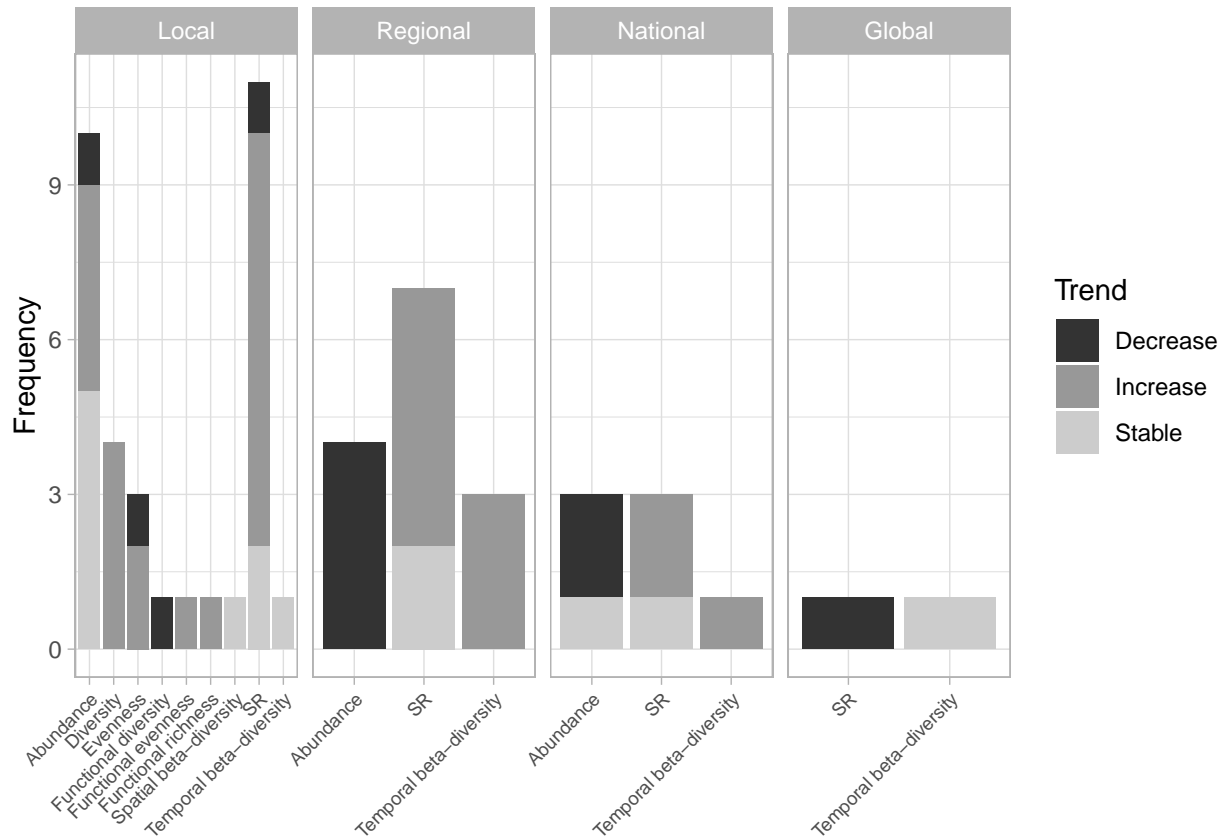


Figure 3.3: Proportion of *Increase*, *Decrease* or *Stable* trends for each metric. Each panel represent one spatial scale

Number of studies using spatial replicates is limited. Thus, observing general rules about spatial scaling of trends of macroecological metrics is not possible with the current state of the scientific literature. However, concerning species richness, we can see that the decrease is global, but that this decrease is rare at lower spatial scales. In fact, increases are more often observed, confirming the high perturbations that biodiversity is undergoing (Dornelas et al., 2014; Vaidyanathan, 2021). This analysis goes along with the temporal β -diversity which is always observed either stable or increasing, sign of instability of the ecosystems.

On an other hand, the decrease of abundances seem to appear mainly at regional or national scales. This may be due to the fact that local scale samplings are done usually outside of very anthropized ecosystems, such as cities. Increasing the scale to regional and national increases the proportion of cities and farmland area, which can have negative impact on bird populations (Reif, 2013).

4. A lack of consistency

4.1 Spatial replicates are not a standard

Articles computing the trend of a metric with spatial replicates were limited, either due to a lack of data or because the trend was assessed for the spatial extent of the data. For instance, the Breeding Bird Surveys (*e.g.* Kamp et al., 2021; Sauer et al., 2013) follow standardized sampling plan with spatial replications (*i.e.* census plots). However, not all the trend reported for the BBS are summarized at their specific grain sizes and were sometimes computed at their respective national scales, therefore without spatial replication. For instance, the common method encountered to assess population trends (*i.e.* abundance indexes) is to learn a predictive model from the data, predict the target feature (*i.e.* abundance) and then compute the metric and its trend from the output of the model at the national spatial extent (*e.g.* Doxa et al., 2010; Eglington & Pearce-Higgins, 2012; Jiguet et al., 2005; Jiguet et al., 2012; Sauer et al., 2017). These analysis are essential from a conservation point of view and are a majority (Fraixedas et al., 2020): they give valuable information about ecosystem health at large spatial extent and are thus used as arguments by decision-makers. However, they represent just one trend amongst all the possible trends that can be found at this spatial scales and thus doesn't give information about the link between spatial grain and temporal trend. An other common type of studies are the one using the space-for-time substitution (Walker et al., 2010) to assess the trend of a metric (one of the best example is J. K. Hill & Hamer, 2004). One could think that using this studies could increase significantly the spatial replicates. However, the space-for-time substitution is mainly used to assess the impact of a process (*e.g.* before/after logging, before/after urbanization etc) meaning that the trend computed is highly biased, which we try to avoid for our topic.

Even less articles were computing the trends of metrics with spatial replicates at various spatial grain. This was the case for only Chase et al. (2019) and Jarzyna and Jetz (2018). It is also important to cite here Jarzyna et al. (2015), who did iteration computing of temporal change community metrics (*i.e.*

temporal dissimilarity, temporal turnover, extinction and colonization) at several spatial scales. However, the temporal trend of these metrics weren't considered and are therefore not reported in Table 2.1.

4.2 Metric heterogeneity

Macroecology has seen its metrics blooming these last decades, in search of a multiparametric indexes taking into account all the components of an ecosystem, as do the composite indicators (*e.g.* the red list index, S. H. M. Butchart et al., 2007; biodiversity change indexes, Normander et al., 2012). The latter have proven very effective in order to assess conservation policies and are able to synthesize the ecosystem complexities. This has been especially the case for the birds, who are of great interest in assessing the dynamic of ecosystem health (Fraixedas et al., 2020). Thus, studies focusing only on macroecological metrics are less common than expected. Coupled with the need of spatial replicates, studying the link between the trend of macroecological metrics and spatio-temporal scales still needs to be explored.

4.3 On the temporal scale

The oldest study started in 1968 and the median duration is 23 years, with a minimum time span of 11 years and a maximum of 45.

Determination of the temporal grain was way more complicated, as there is no consensus on the subject. Usually, the temporal grain of the sampling is specified, but sometimes with inaccuracies (*e.g.* “in the early morning”). However, the temporal grain of the sampling plan doesn't represent the final temporal grain. For instance, some metrics are summed over a certain spatial extent (*e.g.* summing the species richness over an atlas square, like in Van Turnhout et al., 2007). In this case, the temporal grain should also be summed, but this was not specified. On an other hand, when the metric is averaged over a spatial grain, the sampling temporal grain can be considered.

Nevertheless, an other problem arises when the trend is computed. Usually, one compute the metric out of the data and considers the value to be representative of half a year or a year. In this case, there is no consensus on what should be the temporal grain: should one keep the grain of the sampling? Should one consider it to be the time-span covered by the sampling? In my analysis, the latter has been used (Table 2.1).

For the cases where the metric was determined out of model (e.g. Harrison et al., 2014), the final temporal grain was most of the time explicitly given, with an order of length of the year.

In short, temporal grain has no clear definition as it is different according to the metric computed, how it is computed and if the temporal trend is assessed. Even though it is now clear that the temporal grain of the sampling is important, there is no such consensus regarding the temporal grain of the trend.

Highest temporal grains are found with increasing spatial extent (Figure 4.1). Data used in the selected article are mainly structured data, *i.e.* data following a well established sampling plan. This type of survey need resources and organizations which makes them sparser. Increasing the total area to sample makes *de facto* the time needed to sample the area to increase and eventually the temporal grain. However, this entanglement between spatial and temporal grain scales is only related to the constraints of the sampling. This limitation can be overcome thanks to citizen science data, which are nowadays more and more used (e.g. D. E. Bowler et al., 2021; Isaac et al., 2014; Isaac et al., 2020). The opportunistic feature of these data make the number of observations more important, even over a large area. These data, with high temporal grain resolution for large spatial scales, are yet to be used to explore in more detail the temporal scaling of biodiversity trend.

5. Future directions

In order to find general patterns and reliable results about spatio-temporal scaling of biodiversity trends, replications are needed. That is, iteratively computing trends of biodiversity at certain scales across the globe. However, out of 17 papers, 5 were located in North America and 12 in Europe. This is a striking example of the well-known lack of studies outside Europe and, to a lesser degree, North America (Fraixedas et al., 2020). Yet, biodiversity dynamic across scales in Europe is not representative of global dynamic, especially due to the lesser ecosystem representations, the variations in anthropization, conservation policies etc. Thus, studies replicating the computation of trends at several spatio-temporal scales are needed outside of Europe if one wants to understand the scaling of biodiversity dynamic. These non-european studies are even more needed when working at spatial grains the size or greater than Europe. In this case, spatial replication means having data about other continents.

Even if a consensus exists about the importance of spatial grains, the final spatial grain of the metric computed is not always specified. One should consider the way the metric is computed, *e.g.* if it was

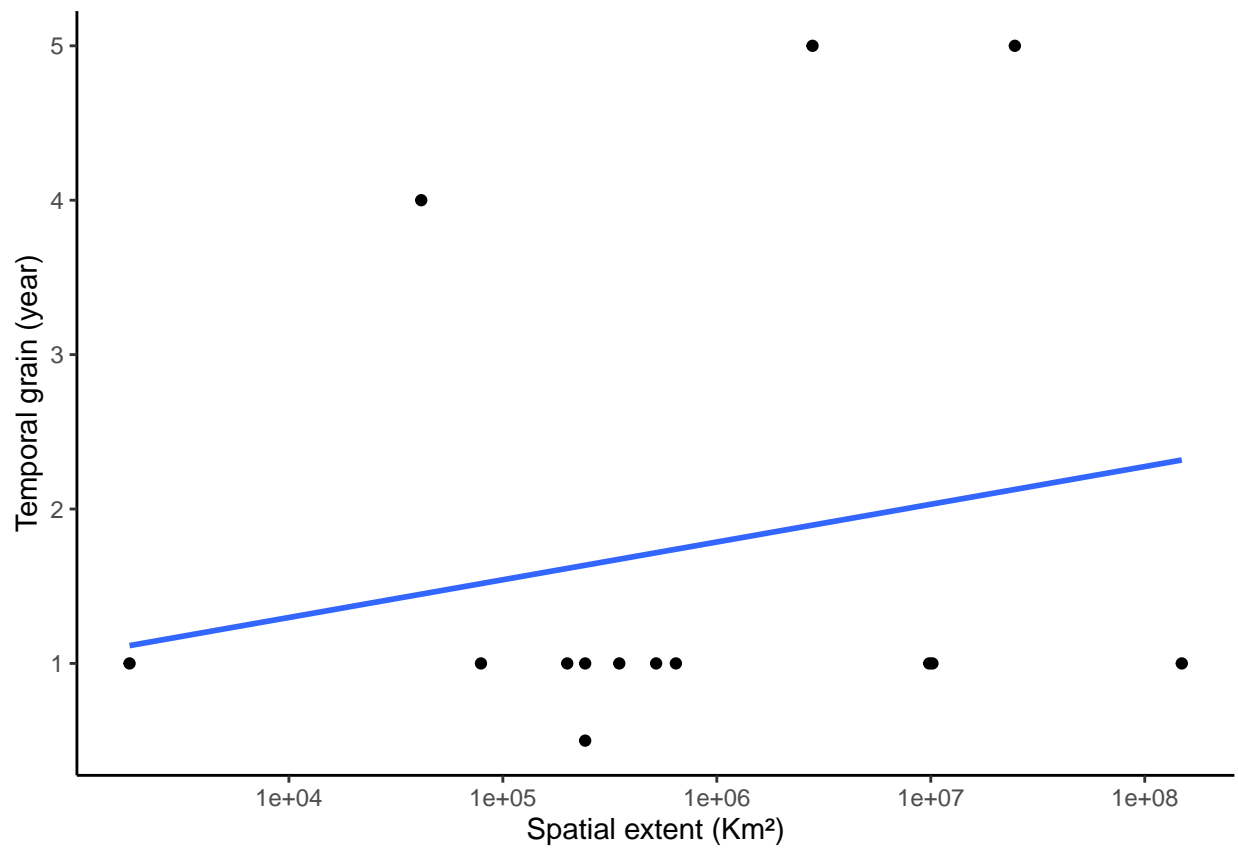


Figure 4.1: Not sure about the relevance of this figure

summed, modeled, averaged over the sampling units. According to the method, the spatial grain can vary from the sampling unit to the sampling extent and even more if extrapolation methods are used. This may seem trivial but given the importance of spatial scaling of biodiversity patterns (Storch & Gaston, 2004), one has to expect that it will be as important for its dynamic (Chase et al., 2019). By specifying systematically the spatial grain according to the metric used, we hope to facilitate the study of scaling biodiversity trends.

The importance of temporal scaling of biodiversity is known since Grinnell (1922), who used California birds to demonstrate the species-time relationship, which has since been proven to be common with other bird populations (White, 2004). Thus, as spatial grain, temporal grain is known to be important to explicit. However, there is no consensus on the definition of temporal grain and is thus specified in various ways: sometimes very precised (*e.g.* time of each census point, as in Schipper et al., 2016) and sometimes without explicit informations (*e.g.* Harrison et al., 2014, *'The sites are visited twice a year (April to early May and late May to June), during which volunteers walk two parallel 1-km-long transect lines [...]'*). The confusion becomes even more important when the trend of the metric is computed, as the temporal grain of the metric is considered to be representative of the unit time-span of the trend. In other words, when one computes and represent a trend on a figure, he usually use one point either every day, month or year. Thus, the temporal grain of the trend is different from the one of the computed metric, especially if one point on the figure embeds several census sessions. If one wants to study the temporal scaling of biodiversity trends, a clear definition of temporal grain for this context needs to be found. From the scientific literature, two definitions:

- 1) Temporal grain of the trend is the temporal grain of the computed metric. If it is so, it should be clearly specified
- 2) Temporal grain of the trend is the time span between census sessions/ time of computed metric.

6. Conclusion

Reviewing the scientific literature on this topic gives a glimpse of what still needs to be done to better understand the scaling of global avian biodiversity dynamic. As birds represent one of the most data furnished taxa of vertebrates, challenges about birds are just a part of what still need to be done for other taxa.

References

- Barnagaud, J.-Y., Gaüzère, P., Zuckerberg, B., Princé, K., & Svenning, J.-C. (2017). Temporal changes in bird functional diversity across the United States. *Oecologia*, 185(4), 737–748. <https://doi.org/10.1007/s00442-017-3967-4>
- 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., & Ferrer, E. A. (2011). Has the Earth's sixth mass extinction already arrived? [Number: 7336 Publisher: Nature Publishing Group]. *Nature*, 471(7336), 51–57. <https://doi.org/10.1038/nature09678>
- Bejček, V., & Stastný. (2016). Velké ptačí mapování. *Vesmír*. Retrieved December 10, 2020, from <https://vesmir.cz/cz/on-line-clanky/2016/04/velke-ptaci-mapovani.html>
- 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., ... Dornelas, M. (2019). The geography of biodiversity change in marine and terrestrial assemblages [Publisher: American Association for the Advancement of Science Section: Research Article]. *Science*, 366(6463), 339–345. <https://doi.org/10.1126/science.aaw1620>
- Bowler, D., Richter, R. L., Eskildsen, D., Kamp, J., Moshøj, C. M., Reif, J., Strebel, N., Trautmann, S., & Voříšek, P. (2021). Geographic variation in the population trends of common breeding birds across central Europe. *Basic and Applied Ecology*, 56, 72–84. <https://doi.org/10.1016/j.baae.2021.07.004>
- Bowler, D. E., Eichenberg, D., Conze, K.-J., Suhling, F., Baumann, K., Benken, T., Bönsel, A., Bittner, T., Drews, A., Günther, A., Isaac, N. J. B., Petzold, F., Seyring, M., Spengler, T., Trockur, B., Willigalla, C., Bruelheide, H., Jansen, F., & Bonn, A. (2021). Winners and losers over 35 years of dragonfly and damselfly distributional change in Germany [eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/ddi.13274>]. *Diversity and Distributions*, 27(8), 1353–1366. <https://doi.org/10.1111/ddi.13274>
- Butchart, S., Stattersfield, A., Baillie, J., Bennun, L., Stuart, S., Akçakaya, H., Hilton-Taylor, C., & Mace, G. (2005). Using Red List Indices to measure progress towards the 2010 target and beyond [Publisher: Royal Society]. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1454), 255–268. <https://doi.org/10.1098/rstb.2004.1583>
- 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., & Hilton-Taylor, C. (2007). Improvements to the Red List Index [Publisher: Public Library of Science]. *PLOS ONE*, 2(1), e140. <https://doi.org/10.1371/journal.pone.0000140>
- 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., & Mace, G. M. (2004). Measuring Global Trends in the Status of Biodiversity: Red List Indices for Birds (Walt V. Reid, Ed.). *PLoS Biology*, 2(12), e383. <https://doi.org/10.1371/journal.pbio.0020383>
- 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., ... O'Connor, M. (2019). Species richness change across spatial scales. *Oikos*, 128(8), 1079–1091. <https://doi.org/10.1111/oik.05968>
- Chiron, F., Princé, K., Paracchini, M. L., Bulgheroni, C., & 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. <https://doi.org/10.1016/j.agee.2013.05.018>
- Davey, C. M., Chamberlain, D. E., Newson, S. E., Noble, D. G., & Johnston, A. (2012). Rise of the generalists: Evidence for climate driven homogenization in avian communities [eprint: <https://onlinelibrary.wi>

- ley.com/doi/pdf/10.1111/j.1466-8238.2011.00693.x]. *Global Ecology and Biogeography*, 21(5), 568–578. <https://doi.org/10.1111/j.1466-8238.2011.00693.x>
- Donald, P. F., Green, R. E., & Heath, M. F. (2001). Agricultural intensification and the collapse of Europe's farmland bird populations [Publisher: Royal Society]. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1462), 25–29. <https://doi.org/10.1098/rspb.2000.1325>
- Dornelas, M., Gotelli, N. J., McGill, B., Shimadzu, H., Moyes, F., Sievers, C., & Magurran, A. E. (2014). Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss [Publisher: American Association for the Advancement of Science Section: Report]. *Science*, 344(6181), 296–299. <https://doi.org/10.1126/science.1248484>
- 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., & Vellend, M. (2013). Quantifying temporal change in biodiversity: Challenges and opportunities. *Proceedings of the Royal Society B: Biological Sciences*, 280(1750), 20121931. <https://doi.org/10.1098/rspb.2012.1931>
- Doxa, A., Bas, Y., Paracchini, M. L., Pointereau, P., Terres, J.-M., & Jiguet, F. (2010). Low-intensity agriculture increases farmland bird abundances in France [eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2664.2010.01869.x>]. *Journal of Applied Ecology*, 47(6), 1348–1356. <https://doi.org/10.1111/j.1365-2664.2010.01869.x>
- Eglinton, S. M., & Pearce-Higgins, J. W. (2012). Disentangling the Relative Importance of Changes in Climate and Land-Use Intensity in Driving Recent Bird Population Trends (R. Arlettaz, Ed.). *PLoS ONE*, 7(3), e30407. <https://doi.org/10.1371/journal.pone.0030407>
- Fraixedas, S., Lindén, A., Piha, M., Cabeza, M., Gregory, R., & Lehikoinen, A. (2020). A state of the art review on birds as indicators of biodiversity: Advances, challenges, and future directions. *Ecological Indicators*, 118, 106728. <https://doi.org/10.1016/j.ecolind.2020.106728>
- Gregory, R. D., Gibbons, D. W., Impey, A., & Marchant, J. H. (1999). Generation of the headline indicator of wild bird populations, 48.
- Gregory, R. D., & Strien, A. v. (2010). Wild bird indicators: Using composite population trends of birds as measures of environmental health. *Ornithological Science*, 9(1), 3–22. <https://doi.org/10.2326/osj.9.3>
- Gregory, R. D., van Strien, A., Vorisek, P., Gmelig Meyling, A. W., Noble, D. G., Foppen, R. P., & Gibbons, D. W. (2005). Developing indicators for European birds [Publisher: Royal Society]. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1454), 269–288. <https://doi.org/10.1098/rstb.2004.1602>
- Grinnell, J. (1922). The Role of the “Accidental”. *The Auk*, 39(3), 373–380. <https://doi.org/10.2307/4073434>
- Harrison, P. J., Buckland, S. T., Yuan, Y., Elston, D. A., Brewer, M. J., Johnston, A., & Pearce-Higgins, J. W. (2014). Assessing trends in biodiversity over space and time using the example of British breeding birds [eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12316>]. *Journal of Applied Ecology*, 51(6), 1650–1660. <https://doi.org/10.1111/1365-2664.12316>
- Harrison, P. J., Yuan, Y., Buckland, S. T., Oedekoven, C. S., Elston, D. A., Brewer, M. J., Johnston, A., & Pearce-Higgins, J. W. (2016). Quantifying turnover in biodiversity of British breeding birds [eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12539>]. *Journal of Applied Ecology*, 53(2), 469–478. <https://doi.org/10.1111/1365-2664.12539>
- Hill, J. K., & Hamer, K. C. (2004). Determining impacts of habitat modification on diversity of tropical forest fauna: The importance of spatial scale [eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.0021-8901.2004.00926.x>]. *Journal of Applied Ecology*, 41(4), 744–754. <https://doi.org/10.1111/j.0021-8901.2004.00926.x>

- Hill, M. O. (1973). Diversity and Evenness: A Unifying Notation and Its Consequences [eprint: <https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.2307/1934352>]. *Ecology*, 54(2), 427–432. <https://doi.org/10.2307/1934352>
- Inger, R., Gregory, R., Duffy, J. P., Stott, I., Voříšek, P., & Gaston, K. J. (2015). Common European birds are declining rapidly while less abundant species' numbers are rising [eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/ele.12387>]. *Ecology Letters*, 18(1), 28–36. <https://doi.org/10.1111/ele.12387>
- Isaac, N. J. B., Strien, A. J. v., August, T. A., Zeeuw, M. P. d., & Roy, D. B. (2014). Statistics for citizen science: Extracting signals of change from noisy ecological data [eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/2041-210X.12254>]. *Methods in Ecology and Evolution*, 5(10), 1052–1060. <https://doi.org/10.1111/2041-210X.12254>
- Isaac, N. J., Jarzyna, M. A., Keil, P., Dambly, L. I., Boersch-Supan, P. H., Browning, E., Freeman, S. N., Golding, N., Guillerá-Arroita, G., Henrys, P. A., Jarvis, S., Lahoz-Monfort, J., Pagel, J., Pescott, O. L., Schmucki, R., Simmonds, E. G., & O'Hara, R. B. (2020). Data Integration for Large-Scale Models of Species Distributions. *Trends in Ecology & Evolution*, 35(1), 56–67. <https://doi.org/10.1016/j.tree.2019.08.006>
- Jaccard, P. (1912). The Distribution of the Flora in the Alpine Zone.1 [eprint: <https://nph.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1469-8137.1912.tb05611.x>]. *New Phytologist*, 11(2), 37–50. <https://doi.org/10.1111/j.1469-8137.1912.tb05611.x>
- Jarzyna, M. A., & Jetz, W. (2018). Taxonomic and functional diversity change is scale dependent. *Nature Communications*, 9(1), 2565. <https://doi.org/10.1038/s41467-018-04889-z>
- Jarzyna, M. A., Zuckerberg, B., Porter, W. F., Finley, A. O., & Maurer, B. A. (2015). Spatial scaling of temporal changes in avian communities: Scale dependence of community turnover. *Global Ecology and Biogeography*, 24(11), 1236–1248. <https://doi.org/10.1111/geb.12361>
- Jiguet, F., Julliard, R., Couvet, D., & 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. <https://doi.org/10.1007/s10531-004-0448-y>
- Jiguet, F., Devictor, V., Julliard, R., & Couvet, D. (2012). French citizens monitoring ordinary birds provide tools for conservation and ecological sciences. *Acta Oecologica*, 44, 58–66. <https://doi.org/10.1016/j.actao.2011.05.003>
- Kamp, J., Frank, C., Trautmann, S., Busch, M., Dröschmeister, R., Flade, M., Gerlach, B., Karthäuser, J., Kunz, F., Mitschke, A., Schwarz, J., & Sudfeldt, C. (2021). Population trends of common breeding birds in Germany 1990–2018. *Journal of Ornithology*, 162(1), 1–15. <https://doi.org/10.1007/s10336-020-01830-4>
- 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., & Storch, D. (2012). Patterns of beta diversity in Europe: The role of climate, land cover and distance across scales [eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2699.2012.02701.x>]. *Journal of Biogeography*, 39(8), 1473–1486. <https://doi.org/10.1111/j.1365-2699.2012.02701.x>
- McGill, B. J., Dornelas, M., Gotelli, N. J., & Magurran, A. E. (2015). Fifteen forms of biodiversity trend in the Anthropocene. *Trends in Ecology & Evolution*, 30(2), 104–113. <https://doi.org/10.1016/j.tree.2014.11.006>
- McGill, B. J., Enquist, B. J., Weiher, E., & Westoby, M. (2006). Rebuilding community ecology from functional traits. *Trends in Ecology & Evolution*, 21(4), 178–185. <https://doi.org/10.1016/j.tree.2006.02.002>
- Mouquet, N., Devictor, V., Meynard, C. N., Munoz, F., Bersier, L.-F., Chave, J., Coutron, P., Dalecky, A., Fontaine, C., Gravel, D., Hardy, O. J., Jabot, F., Lavergne, S., Leibold, M., Mouillot, D., Münkemüller, T., Pavoine, S., Prinzing, A., Rodrigues, A. S. L., ... Thuiller, W. (2012). Ecophylogenetics:

- Advances and perspectives [eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1469-185X.2012.00224.x>]. *Biological Reviews*, 87(4), 769–785. <https://doi.org/10.1111/j.1469-185X.2012.00224.x>
- Normander, B., Levin, G., Auvinen, A.-P., Bratli, H., Stabbetorp, O., Hedblom, M., Glimskär, A., & Gudmundsson, G. A. (2012). Indicator framework for measuring quantity and quality of biodiversity—Exemplified in the Nordic countries. *Ecological Indicators*, 13(1), 104–116. <https://doi.org/10.1016/j.ecolind.2011.05.017>
- of the Convention on Biological Diversity, S., & Centre, U. W. C. M. (Eds.). (2006). *Global biodiversity outlook 2*. Secretariat of the Convention on Biological Diversity.
- Pereira, H. M., Navarro, L. M., & Martins, I. S. (2012). Global Biodiversity Change: The Bad, the Good, and the Unknown. *Annual Review of Environment and Resources*, 37(1), 25–50. <https://doi.org/10.1146/annurev-environ-042911-093511>
- 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., ... Haase, P. (2020). Meta-analysis of multidecadal biodiversity trends in Europe [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]. *Nature Communications*, 11(1), 3486. <https://doi.org/10.1038/s41467-020-17171-y>
- Ram, D., Axelsson, A.-L., Green, M., Smith, H. G., & Lindström, Å. (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. <https://doi.org/10.1016/j.foreco.2016.11.013>
- Reif, J. (2013). Long-Term Trends in Bird Populations: A Review of Patterns and Potential Drivers in North America and Europe [Publisher: Museum and Institute of Zoology, Polish Academy of Sciences]. *Acta Ornithologica*, 48(1), 1–16. <https://doi.org/10.3161/000164513X669955>
- Reif, J., Prylová, K., Šizling, A. L., Vermouzek, Z., Šťastný, K., & 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. <https://doi.org/10.1007/s10336-012-0900-9>
- Sauer, J. R., Link, W. A., Fallon, J. E., Pardieck, K. L., & Ziolkowski, D. J., Jr. (2013). The North American Breeding Bird Survey 1966–2011: Summary Analysis and Species Accounts. *North American Fauna*, (79 (79)), 1–32. <https://doi.org/10.3996/nafa.79.0001>
- Sauer, J. R., Pardieck, K. L., Ziolkowski, D. J., Jr., Smith, A. C., Hudson, M.-A. R., Rodriguez, V., Berlanga, H., Niven, D. K., & Link, W. A. (2017). The first 50 years of the North American Breeding Bird Survey. *The Condor*, 119(3), 576–593. <https://doi.org/10.1650/CONDOR-17-83.1>
- 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., Schippers, K., Steinmann, Z. J. N., Visconti, P., Rondinini, C., & Pereira, H. M. (2016). Contrasting changes in the abundance and diversity of North American bird assemblages from 1971 to 2010 [eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/gcb.13292>]. *Global Change Biology*, 22(12), 3948–3959. <https://doi.org/10.1111/gcb.13292>
- Shannon, C. E. (1948). A mathematical theory of communication [Conference Name: The Bell System Technical Journal]. *The Bell System Technical Journal*, 27(3), 379–423. <https://doi.org/10.1002/j.1538-7305.1948.tb01338.x>

- Simpson, E. H. (1949). Measurement of Diversity [Bandiera_abtest: a Cg_type: Nature Research Journals Number: 4148 Primary_atype: Research Publisher: Nature Publishing Group]. *Nature*, 163(4148), 688–688. <https://doi.org/10.1038/163688a0>
- 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*. [OCLC: 4713331]. I kommission hos E. Munksgaard.
- Sorte, F. A. L., & Boecklen, W. J. (2005). Changes in the diversity structure of avian assemblages in North America [_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1466-822X.2005.00160.x>]. *Global Ecology and Biogeography*, 14(4), 367–378. <https://doi.org/10.1111/j.1466-822X.2005.00160.x>
- Storch, D., & Gaston, K. J. (2004). Untangling ecological complexity on different scales of space and time. *Basic and Applied Ecology*, 5(5), 389–400. <https://doi.org/10.1016/j.baae.2004.08.001>
- Studený, A. C., Buckland, S. T., Harrison, P. J., Illian, J. B., Magurran, A. E., & Newson, S. E. (2013). Fine-tuning the assessment of large-scale temporal trends in biodiversity using the example of British breeding birds [_eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12026>]. *Journal of Applied Ecology*, 50(1), 190–198. <https://doi.org/10.1111/1365-2664.12026>
- Vaidyanathan, G. (2021). The world's species are playing musical chairs: How will it end? [Bandiera_abtest: a Cg_type: News Feature Number: 7870 Publisher: Nature Publishing Group Subject_term: Biodiversity, Ecology, Environmental sciences]. *Nature*, 596(7870), 22–25. <https://doi.org/10.1038/d41586-021-02088-3>
- Van Turnhout, C. A. M., Foppen, R. P. B., Leuven, R. S. E. W., Siepel, H., & 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. <https://doi.org/10.1016/j.biocon.2006.09.011>
- Walker, L. R., Wardle, D. A., Bardgett, R. D., & Clarkson, B. D. (2010). The use of chronosequences in studies of ecological succession and soil development [_eprint: <https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2745.2010.01664.x>]. *Journal of Ecology*, 98(4), 725–736. <https://doi.org/10.1111/j.1365-2745.2010.01664.x>
- Webb, C. O., Ackerly, D. D., McPeck, M. A., & Donoghue, M. J. (2002). Phylogenies and Community Ecology [_eprint: <https://doi.org/10.1146/annurev.ecolsys.33.010802.150448>]. *Annual Review of Ecology and Systematics*, 33(1), 475–505. <https://doi.org/10.1146/annurev.ecolsys.33.010802.150448>
- White, E. P. (2004). Two-phase species–time relationships in North American land birds [_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1461-0248.2004.00581.x>]. *Ecology Letters*, 7(4), 329–336. <https://doi.org/https://doi.org/10.1111/j.1461-0248.2004.00581.x>
- Whittaker, R. H. (1960). Vegetation of the Siskiyou Mountains, Oregon and California [_eprint: <https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.2307/1943563>]. *Ecological Monographs*, 30(3), 279–338. <https://doi.org/10.2307/1943563>
- Whittaker, R. H. (1972). Evolution and Measurement of Species Diversity [_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.2307/1218190>]. *TAXON*, 21(2-3), 213–251. <https://doi.org/10.2307/1218190>
- Wretenberg, J., Pärt, T., & Berg, Å. (2010). Changes in local species richness of farmland birds in relation to land-use changes and landscape structure. *Biological Conservation*, 143(2), 375–381. <https://doi.org/10.1016/j.biocon.2009.11.001>

Supplementary materials

Table 6.1: Supplementary informations about each article

| Reference | Spatial grain (Km ²) | Trend | Note |
|---|-------------------------------------|----------|---|
| Barnagaud et al., 2017 | Local | 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 " |
| | Local | 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 |
| D. Bowler et al., 2021 | National | Stable | Metric = MSI, as many and as intense increase (i.e. Czech Rep. and Switzerland) than decrease (i.e. Germany and Denmark) |
| Chase et al., 2019 | Local | Stable | NA |
| | Regional | Stable | NA |
| | Regional | Stable | NA |
| | Local | Increase | NA |
| | Local | Increase | NA |
| Chiron et al., 2013 | Regional | Decrease | Concerning the spatial scale, predictions are made using the spatial unit of 4 Km ² and the FBI is computed for each region of France, then meanned. Prediction with baseline scenario |
| | Regional | Decrease | FBI prediction with CAP greening cenario |
| | Regional | Decrease | FBI prediction with No Pillar I scenario |
| | Regional | Decrease | FBI prediction with biofuel scenario |
| Davey et al., 2012 | Local | Increase | Metric = Simpson.They predict the metric using a GAM with spatial resolution of 1 Km ² . Then they show the trend for the mean value of the metric per year |
| | Local | Increase | NA |
| | Local | Increase | NA |

Table 6.1: Supplementary informations about each article (*continued*)

| Reference | Spatial grain (Km ²) | Trend | Note |
|---|-------------------------------------|----------|--|
| Harrison et al., 2014 | Local | 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 |
| | Local | Stable | Farmland communities, GoF ($\lambda = -1$) = weighted towards the rare species |
| | Local | Stable | Farmland communities, GoF ($\lambda = -2$) weighted towards the common species |
| Harrison et al., 2016 | Local | Increase | Geometric mean of species abundance, they predict the abundance with resolution of 1 Km ² and then computed the metric for each 10000 Km ² cell across Great Britain, Visited twice a year |
| | Local | Stable | GoF ($\lambda = -1$) = 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 ($\lambda = -1$) |
| | Local | Stable | GoF ($\lambda = -2$) = 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 | Regional | Increase | NA |
| | Regional | Increase | NA |
| | Regional | Increase | NA |
| | National | Increase | NA |
| | Global | Decrease | NA |
| | Regional | Increase | NA |
| | Regional | Increase | NA |

Table 6.1: Supplementary informations about each article (*continued*)

| Reference | Spatial grain (Km ²) | Trend | Note |
|--|-------------------------------------|----------|--|
| | Regional | Increase | NA |
| | National | Increase | NA |
| Pilotto et al., 2020 | Global | Stable | NA |
| | Local | Stable | "Analyses of the trends in local biodiversity over large spatial scales" |
| | Local | Increase | Metric = Simpson, "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" |
| Ram et al., 2017 | Local | Increase | MSI for forest species, road of 8 Km with no limitations so assumed 200m |
| | Regional | 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 |
| Reif et al., 2013 | Local | Stable | Jaccard index, pairwise comparisons between transects |
| | Local | Stable | JPSP data, transect scale |
| | National | Stable | JPSP data, national scale |
| Schipper et al., 2016 | Local | 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 |
| | Local | Increase | Metric = Shannon |
| | Local | Increase | Metric = Simpson |
| | Local | Decrease | NA |
| | Local | Increase | NA |
| | Local | Increase | NA |
| | Local | Increase | NA |

Table 6.1: Supplementary informations about each article (*continued*)

| Reference | Spatial grain (Km ²) | Trend | Note |
|---|-------------------------------------|----------|--|
| Sorte and Boecklen, 2005 | Local | Decrease | NA |
| | Local | Decrease | Metric = evenness |
| | Local | Increase | The metric is meaned over each road. Area of the road = $50 \cdot (\pi \cdot 400^2)$ with 50 census point per road and a census radius of 400m |
| Van Turnhout et al., 2007 | Regional | Increase | For each region, the trend is computed using the mean number of species per atlas square |
| | Local | Increase | Mainly increase of SR but the proportion of negative trend were higher than for the regional scale |
| | National | Increase | National scale |
| Wretenberg et al., 2010 | Local | 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. " |
| Inger et al., 2015 | National | Decrease | NA |
| Donald et al., 2001 | National | Decrease | The metric is referred as "Mean population" and the trend is estimated for each european country |