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**To ease the shock from my edits, see this:** <https://twitter.com/JulesBass6/status/1355281902463148033>

# Introduction

Our life quality is intrinsically linked to the state of ecosystems that we live in. Ecosystem services to humans (Diaz et al. 2018), as well as their inner functioning, involve a spectrum of mechanisms including nutrient cycles or ecosystem stability ([Pereira, Navarro, and Martins 2012](#ref-pereira_global_2012)). Some of these functions, such as seed dispersal, control of pests, scavenging, or pollination, depend on birds and their diversity. Birds also have a significant esthetical value, with most countries having numerous iconic/charismatic species of conservation interest (https://www.iucnredlist.org/). Unfortunately, anthropogenic stressors like habitat loss, over-exploitation, pollution, or introduction of invasive species are a threat to birds and their biodiversity (1-2 REFS), with concerns that they could face a sixth mass extinction ([Barnosky et al. 2011](#ref-barnosky_has_2011)).

**Problems & challenges.** We have reasons to suspect that the global alteration of biodiversity due to anthropogenic stressors is unprecedented, and political goals have been declared in order to limit it (*e.g.* [Convention on Biological Diversity and Centre 2006, 2010, 2002](#X9d9998b2a18109011522d670b75978c5cd32ed0)). However, data-driven basis for these policies remains a challenge, mainly due to severe gaps and biases in empirical biodiversity data (Meyer et al. 2015). To complicate matters further, current scientific literature has shown that temporal trends of local biodiversity can be opposite to trends at larger spatial scales (*e.g.* Keil et al. 2011, 2018, [Chase et al. 2019](#ref-chase_species_2019)). Thus, we should expect changes in biodiversity to be far more complex than a simple global decrease. Finally, biodiversity can be measured by many metrics, and these can differ in their temporal trends (McGill et al. 2015); for instance, while there may be small average net change in local species richness, ecosystems can still undergo significant changes in species composition ([Blowes et al. 2019](#ref-blowes_geography_2019); [Dornelas et al. 2013](#ref-dornelas_quantifying_2013); [Vaidyanathan 2021](#ref-vaidyanathan_worlds_2021)).

\*\*\*For a publication, I’d put a conceptual figure/cartoon illustrating the scaling concepts here, i.e. grain, extent, SAR, TAR, STAR, and maybe a re-print of the scale-dependent change form a paper.\*\*\*

**Scale.** Particularly the issue of scale is critical (Levin 1992). Since [Arrhenius](#ref-arrhenius_species_1921) ([1921](#ref-arrhenius_species_1921)) and [Grinnell](#ref-grinnell_role_1922) ([1922](#ref-grinnell_role_1922)), we know that spatial and temporal scaling of biodiversity affects macroecological patterns. Even though particularly the *static* spatial scaling of biodiversity has been of great interest (*e.g.* [Storch, Marquet, and Brown 2007](#ref-storch_scaling_2007)), wonders persist about how *temporal* trends of biodiversity are linked to the spatial and temporal scales. In other words: why and how is the scaling of biodiversity trends important? Here, the term “spatial grain” is also used to refer to the spatial scale of biodiversity, *i.e.* the area at which the metric of biodiversity is assessed (Dungan et al. 2002). One should be careful to not confuse spatial grain with the spatial extent of a study, *i.e.* the total area of the ecosystem studied (Dungan et al. 2002). The same terminology is applied for the temporal scale: temporal grain refers to the temporal unit of the measured biodiversity. This review will, in part, show how this definition has still no consensus in the scientific literature.

To investigate the link between spatio-temporal grains and trends of biodiversity, birds are a relevant taxon. Thanks to the many ornithological monitoring initiatives and surveys, we have a large number of high-quality time series on bird populations ([Bejček and Stastný 2016](#ref-bejcek_velke_2016); [Sauer et al. 2013](#ref-sauer_north_2013); [Kamp et al. 2021](#ref-kamp_population_2021)…). This is because birds are easy to observe, easy to identify and thus many volunteers are motivated to participate on citizen-science projects (cite eBird, iNaturalist) or to conduct standardized sampling (e.g. REF). Given their ability to quickly move between of locations, their presence is also a good indicator for ecosystem health and thus several standardized metrics have been created to assess their populations.

**Objectives of this review**. Here, we review articles assessing the temporal trends of avian biodiversity, with species focus on the variety of metrics that they use, and spatial and temporal scales at which temporal trends have been assessed. We consider the most common macroecological indicators used to assess biodiversity at the community level and higher, such as diversity indexes (*e.g.* species richness, functional diversity) or population indexes ([McGill et al. 2015](#ref-mcgill_fifteen_2015)). We highlight a lack of consensus about specifications and definitions of both spatial and temporal grains (respectively) of trends, we demonstrate that the scaling of trends is seldom considered, leading to confused messages about overall trends. Moreover, we show that studies lack spatial replication that would make reported trends robust and general. We believe that this review will improve the current knowledge on spatio-temporal scaling of trends biodiversity, and will also be useful for the ornithological field community.

# Metrics and indicators

**A few sentences introducing the metrics section.**

**Classical metrics.** Studying biodiversity can be confusing, as several choices must be done. Firstly, the type of biodiversity must be chosen (*e.g.* taxonomic, functional, phylogenetic diversity). Secondly, one must choose the metric(s). There are many facets of biodiversity that can be measured by different metrics, depending on the objective of the study. Measures of static biodiversity are commonly used such as local species richness ( diversity), regional richness (γ diversity) ([Whittaker 1960](#ref-whittaker_vegetation_1960)), by indices that consider abundances (e.g. [Shannon 1948](#ref-shannon_mathematical_1948), [Simpson 1949](#ref-simpson_measurement_1949)), or by Hill numbers ([Hill 1973](#ref-hill_diversity_1973)). On the other hand, change of species composition in space and time can be expressed as , or by pairwise dissimilarity among locations or time periods (Koleff et al. 2003). All these metrics assess species-based metrics, *i.e.* they use the species as a 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](#ref-mcgill_rebuilding_2006); [Mouquet et al. 2012](#ref-mouquet_ecophylogenetics_2012); [Webb et al. 2002](#ref-webb_phylogenies_2002)).

**Multi-species indicators.** Other metrics of great interest are the abundance-based or population-based metrics (Example REFs here). As individuals react to stress or disturbances, the population trends reflect ecosystems health. Before going locally extinct, populations go through steps that are not captured by species-based metric. Thus, population trends are usually efficient at assessing biodiversity declines. Although overall populations are impossible to assess, abundance of few indicator species can reflect processes in an entire ecosystem ([Richard D. Gregory et al. 2005](#ref-gregory_developing_2005)). This has led to a proposition of a family of metrics called the *multi-species indicators* (MSI, Reference). An example is the farmland bird indicator, woodland bird indicator or Wildland Bird Indicator which summarizes the latter two ([Richard D. Gregory et al. 1999](#ref-gregory_generation_1999); [Richard D. Gregory and Strien 2010](#ref-gregory_wild_2010)). These metrics 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 features. They are called the *composite indicators*. The most known ones are the Red List Index ([Stuart H. M. Butchart et al. 2007](#ref-butchart_improvements_2007); [S. h. m. Butchart et al. 2005](#ref-butchart_using_2005); [Stuart H. M. Butchart et al. 2004](#ref-butchart_measuring_2004)) or the Biodiversity Change Index ([Normander et al. 2012](#ref-normander_indicator_2012)).

# Quantitative literature review

For this review, we focused on articles assessing temporal trends of the most common metrics of avian biodiversity and specifying spatial and temporal scales, which are at the same time consistent with broader macroecological scaling and theory (Storch et al. 2007, McGill et al. 2015), and thus can be compared across studies and scales. Namely, these were: XXX, YYY.

We only considered articles for which there were spatial replicates, *i.e.* where the trend of the metric was assessed at several locations at a given spatial grain. With these replications, the trend reported at one spatial grain is more reliable and general. However, at larger spatial grains (*i.e.* national, continental or global scales), spatial replicates are rare. Thus, we considered these trends from a single location only were based on a large set of observations from smaller spatial scales.

We 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 these articles were reviewed. In additionwe scanned the references of these articles for other potentially relevant literature When the temporal trend was explicitly reported (either in a graph or text), we extracted from the material and methods the type of *metric*, the *spatial grain* of the trend (*i.e.* the area at which the metric trend is assessed), its *temporal grain*, the *spatial extent* (*i.e.* the entire area on 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). We discretized spatial grain sizes discretized into four levels: *local* , *regional* , *national* when an entire country was considered, and *global* at the worldwide scale (grain = extent = the entire Earth’s mainland).

Concerning the trend assessment, different papers contain the *p-value* or directly specify the significance of a trend of a metric. However, some papers give only graphical representations of the trend. For those, the standard error was used when displayed. If a study only gave the trend, this is noted in the column *Note* of the Table 6.1. 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.

We found 31 references in which authors were both determining the temporal trend of a metric and explicitly defining the grain size. However, XXX of them were from a single location (see the supplementary text XXX), and only 17 of them used spatial replicates and were thus relevant for this study (Table 2.1). We used the following classes of the metrics: *Species richness, Evenness, Abundance, Diversity, Temporal beta-diversity, Spatial beta-diversity, Functional diversity, Functional evenness, Functional richness*. Some of these classes contain several different indexes. For instance, the class *Diversity*, which contains either the Shannon or Simpson index, or the class *Abundance*, which contains various multi-species indicators (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 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| \cite{barnagaud\_temporal\_2017} | Evenness | Local | 1.0 | 9,834,000 | 41 | 1970-2011 | USA | Increase |
|  | SR | Local | 1.0 | 9,834,000 | 41 | 1970-2011 | USA | Increase |
| \cite{bowler\_geographic\_2021} | Abundance | National | 1.0 | 520,475 | 27 | 1990-2016 | Czech Rep., Switzerland, Denmark, Germany | Stable |
| \cite{chase\_species\_2019} | SR | Local | 5.0 | 2,800,000 | 30 | 1982–2011 | USA, Canada | Stable |
|  | SR | Regional | 5.0 | 2,800,000 | 30 | 1982–2011 | USA, Canada | Stable |
|  | SR | Regional | 5.0 | 2,800,000 | 30 | 1982–2011 | USA, Canada | Stable |
|  | SR | Local | 5.0 | 2,800,000 | 30 | 1982–2011 | USA, Canada | Increase |
|  | SR | Local | 5.0 | 2,800,000 | 30 | 1982–2011 | USA, Canada | Increase |
| \cite{chiron\_forecasting\_2013} | Abundance | Regional | 1.0 | 643,801 | 14 | 2007-2020 | France | Decrease |
|  | Abundance | Regional | 1.0 | 643,801 | 14 | 2007-2020 | France | Decrease |
|  | Abundance | Regional | 1.0 | 643,801 | 14 | 2007-2020 | France | Decrease |
|  | Abundance | Regional | 1.0 | 643,801 | 14 | 2007-2020 | France | Decrease |
| \cite{davey\_rise\_2012} | Diversity | Local | 1.0 | 242,495 | 13 | 1994-2006 | UK | Increase |
|  | Evenness | Local | 1.0 | 242,495 | 13 | 1994-2006 | UK | Increase |
|  | SR | Local | 1.0 | 242,495 | 13 | 1994-2006 | UK | Increase |
| \cite{harrison\_assessing\_2014} | Abundance | Local | 1.0 | 200,000 | 18 | 1994-2011 | Great Britain, UK | Increase |
|  | Abundance | Local | 1.0 | 200,000 | 18 | 1994-2011 | Great Britain, UK | Stable |
|  | Abundance | Local | 1.0 | 200,000 | 18 | 1994-2011 | Great Britain, UK | Stable |
| \cite{harrison\_quantifying\_2016} | Abundance | Local | 0.5 | 242,495 | 20 | 1994-2013 | UK | Increase |
|  | Abundance | Local | 0.5 | 242,495 | 20 | 1994-2013 | UK | Stable |
|  | Abundance | Local | 0.5 | 242,495 | 20 | 1994-2013 | UK | Stable |
| \cite{jarzyna\_taxonomic\_2018} | SR | Regional | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | SR | Regional | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | SR | Regional | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | SR | National | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | SR | Global | 1.0 | 148,940,000 | 45 | 1969-2013 | World | Decrease |
|  | Temporal beta-diversity | Regional | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | Temporal beta-diversity | Regional | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | Temporal beta-diversity | Regional | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | Temporal beta-diversity | National | 1.0 | 9,834,000 | 45 | 1969-2013 | USA | Increase |
|  | Temporal beta-diversity | Global | 1.0 | 148,940,000 | 45 | 1969-2013 | World | Stable |
| \cite{pilotto\_meta-analysis\_2020} | Abundance | Local |  | 10,180,000 |  | NA | Europe | Stable |
|  | Diversity | Local |  | 10,180,000 |  | NA | Europe | Increase |
|  | SR | Local |  | 10,180,000 |  | NA | Europe | Increase |
|  | Temporal beta-diversity | Local |  | 10,180,000 |  | NA | Europe | Stable |
| \cite{ram\_what\_2017} | Abundance | Local | 1.0 | 350,000 | 18 | 1998-2015 | Sweden | Increase |
|  | SR | Regional | 1.0 | 350,000 | 18 | 1998-2015 | Sweden | Increase |
| \cite{reif\_changes\_2013} | Spatial beta-diversity | Local | 1.0 | 79,000 | 23 | 1982-2004 | Czech Rep. | Stable |
|  | SR | Local | 1.0 | 79,000 | 23 | 1982-2004 | Czech Rep. | Stable |
|  | SR | National | 1.0 | 79,000 | 23 | 1982-2004 | Czech Rep. | Stable |
| \cite{schipper\_contrasting\_2016} | Abundance | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
|  | Diversity | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
|  | Diversity | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
|  | Functional diversity | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Decrease |
|  | Functional evenness | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
|  | Functional richness | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
|  | SR | Local | 5.0 | 24,710,000 | 40 | 1971-2010 | Canada, USA, Mexico | Increase |
| \cite{sorte\_changes\_2005} | Abundance | Local | 1.0 | 9,834,000 | 36 | 1968-2003 | USA | Decrease |
|  | Evenness | Local | 1.0 | 9,834,000 | 36 | - | USA | Decrease |
|  | SR | Local | 1.0 | 9,834,000 | 36 | 1968-2003 | USA | Increase |
| \cite{van\_turnhout\_scale-dependent\_2007} | SR | Regional | 4.0 | 41,543 | 28 | 1973-2000 | Netherlands | Increase |
|  | SR | Local | 4.0 | 41,543 | 28 | 1973-2000 | Netherlands | Increase |
|  | SR | National | 4.0 | 41,543 | 28 | 1973-2000 | Netherlands | Increase |
| \cite{wretenberg\_changes\_2010} | SR | Local | 1.0 | 1,800 | 11 | 1994-2004 | Sweden | Decrease |
| \cite{inger\_common\_2015} | Abundance | National | 1.0 | 10,180,000 | 22 | 1980-2001 | Europe | Decrease |
| \cite{donald\_agricultural\_2001} | Abundance | National |  | 10,180,000 | 21 | 1970-1990 | Europe | Decrease |

# Spatial scale vs temporal trends

**Overall trends.** The median spatial extent of the 17 articles is 5.20475^{5} , with the smallest area of 1800 and the greatest representing the global emerged surface (*i.e.* 1.4894^{8} ). These articles reported XXX combinations of scales and metrics. From these, there were 11 *Decreases*, 31 *Increases* and 14 *Stable* trends across the literature. In our case, local scales are more represented than the others and the number of articles 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 the other hand, the proportion of *Decrease* is larger at regional scales than at local scales. At the global scale, no *Increase* was found. One has to keep in mind that these trends may not be representative of the overall trend, since taking only articles with spatial replicates reduces the number of studies and thus doesn’t reflect the overall dynamic of biodiversity. Meta-analysis by [Fraixedas et al.](#ref-fraixedas_state_2020) ([2020](#ref-fraixedas_state_2020)) indicates that around half of bird related indicators are declining and that only of them are increasing.

**Trends by metric.** Among the different metrics, most of the examined studies deal with temporal trends of species richness and abundance (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 -diversity was found most of the time increasing and never decreasing. The use of the other metrics was rare.

**Trends by spatial grain.** In the studies that we reviewed, at **local scales**, species richness mostly increased (Figure 3.3). In contrast, evenness indices, *i.e.* taxonomic and functional evenness were mostly increasing. Concerning the abundance indices, we found mostly no trend, or increases. At **regional scale**, abundance metrics always decreased, temporal -diversity always increased, and species richness increased. At **national and global scales**, studies analyzing multiple locations are rare, and most trends reported here for these two spatial scales are not replicated. Exceptions are [D. Bowler et al.](#ref-bowler_geographic_2021) ([2021](#ref-bowler_geographic_2021)) and [Donald, Green, and Heath](#ref-donald_agricultural_2001) ([2001](#ref-donald_agricultural_2001)). The former showed negative trends in abundance indices for Denmark and Germany, and positive trends for Switzerland and Czech Republic, i.e. no clear direction of the trend (here referred as *Stable*). However, for [Donald, Green, and Heath](#ref-donald_agricultural_2001) ([2001](#ref-donald_agricultural_2001)), trends of mean population size were computed for 30 European countries and the majority was negative. Global trends only come from [Jarzyna and Jetz](#ref-jarzyna_taxonomic_2018) ([2018](#ref-jarzyna_taxonomic_2018)), who report XXX YYY ZZZ.

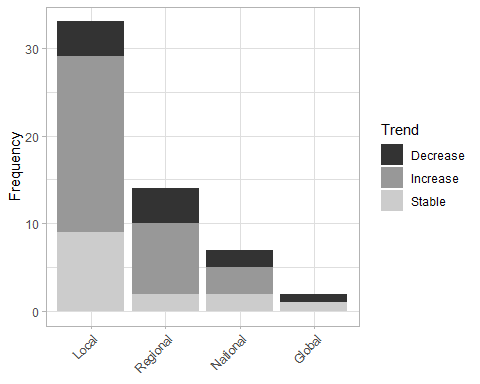


Figure 3.1: Proportion of Increase, Decrease or Stable trends for each spatial grain.

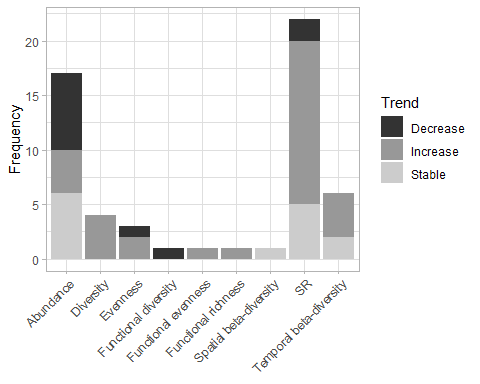


Figure 3.2: Proportion of Increase, Decrease or Stable trends for each of the metric.

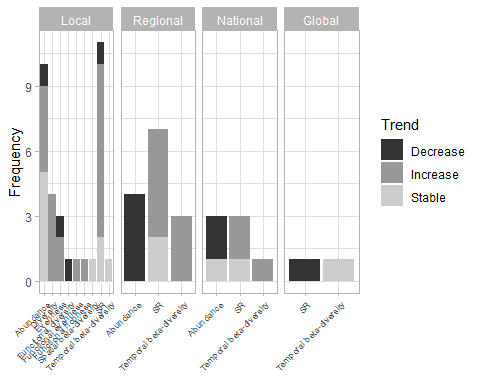


Figure 3.3: Proportion of Increase, Decrease or Stable trends for each metric. Each panel represent one spatial scale.

However, concerning species richness, we can see that the decrease is global, but that this decrease is rare at finer spatial scales. In fact, increases are more often observed, confirming the high perturbations that biodiversity is undergoing ([Dornelas et al. 2014](#ref-dornelas_assemblage_2014); [Vaidyanathan 2021](#ref-vaidyanathan_worlds_2021)). This analysis goes along with the temporal -diversity which is always observed either stable or increasing, sign of the disturbances of the ecosystems.

# Temporal scale vs temporal trends

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 in the studies in Table 1 was complicated. Usually, the temporal grain of the sampling was specified, but sometimes with inaccuracies (*e.g.* “in the early morning”). Moreover, the temporal grain of the sampling 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, such as in [Van Turnhout et al. 2007](#ref-van_turnhout_scale-dependent_2007)). Analogically, the temporal grain should have also been summed over XXX, but this was never the case.

Another problem arises when the trend is computed. Usually, one computes the metric for a time and considers the value to be representative of the time-span between and (*e.g.* a day, 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 of XXX is determined out of model (e.g. [Harrison et al. 2014](#ref-harrison_assessing_2014)), it is easier to assess the temporal grain, since predictions allow one to extrapolate the data from the sampling temporal grain to a wanted one. Thus, for these cases, 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.

We found longest temporal grains in studies with large spatial extent (Figure 4.1, ). This is because data used in the selected article are mainly structured data, *i.e.* data following a well established sampling plan. This type of survey is sparse since it needs resources and organization. Increasing the total area to be sampled thus increases both the temporal extent and the temporal grain. However, this positive correlation between spatial extent and temporal grain is only related to the constraints of the sampling. This limitation can be overcome thanks to citizen science data, which have increasingly been used (*e.g.* [D. E. Unclear.](#ref-bowler_winners_2021)

[Bowler et al. 2021](#ref-bowler_winners_2021); [Isaac et al. 2020](#ref-isaac_data_2020), [2014](#ref-isaac_statistics_2014)). The opportunistic nature of these data make allows for short census times, even over a large area. These data, with high temporal grain resolution for large spatial scales, could in future be used to explore in more details the temporal scaling of biodiversity trends.

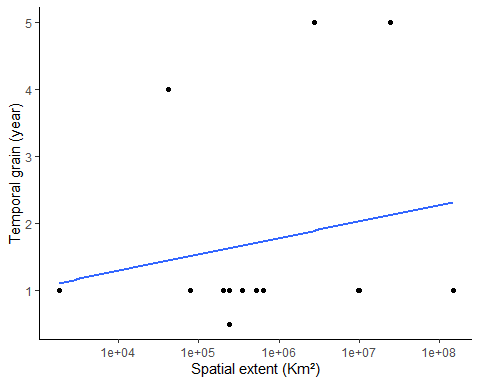


Figure 4.1: Not sure about the relevance of this figure

# Lack of spatial replication

Articles reporting trends from more than a single location are uncommon (we only found XXX), either due to a lack of data, or because the trend was assessed for the spatial extent of the data. For instance, the US Breeding Bird Survey (*e.g.* [Sauer et al. 2013](#ref-sauer_north_2013); [Kamp et al. 2021](#ref-kamp_population_2021)) follows a standardized sampling plan with spatial replications (*i.e.* multiple census plots). However, not all the trends reported for the BBS are summarized at their specific grain, and were sometimes aggregated over their respective national scales, reducing 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.* [Frederic Jiguet et al. 2005](#ref-jiguet_modeling_2005); [Frédéric Jiguet et al. 2012](#ref-jiguet_french_2012); [Eglington and Pearce-Higgins 2012](#ref-eglington_disentangling_2012); [Doxa et al. 2010](#ref-doxa_low-intensity_2010); [Sauer et al. 2017](#ref-sauer_first_2017)). These analyses are practically useful for conservation, and are common ([Fraixedas et al. 2020](#ref-fraixedas_state_2020)): they give inform about ecosystem health at national extent, and are thus useful for decision-makers.

Another common type of study uses the **space-for-time substitution** ([Walker et al. 2010](#ref-walker_use_2010)) to assess the trend of a metric (one of the best example is [J. K. Hill and Hamer 2004](#ref-hill_determining_2004)). One could think that using theses studies could increase significantly the spatial replicates. However, the space-for-time substitution is mainly used to assess the impact of a processes (*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 fewer articles computed the trends of metrics with spatial replicates across more than one spatial grain. So far this was the case for only [Chase et al.](#ref-chase_species_2019) ([2019](#ref-chase_species_2019)) and [Jarzyna and Jetz](#ref-jarzyna_taxonomic_2018) ([2018](#ref-jarzyna_taxonomic_2018)). Importantly, [Jarzyna et al.](#ref-jarzyna_spatial_2015) ([2015](#ref-jarzyna_spatial_2015)) did iterative 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.

# Metric heterogeneity

In contrast to macroecology, applied ecology has offered multiparametric indices that aim to reflect multiple components of an ecosystem, the so-called **composite indicators**. Examples are the **red list index** ([Stuart H. M. Butchart et al. 2007](#ref-butchart_improvements_2007)) or **biodiversity change indices** ([Normander et al. 2012](#ref-normander_indicator_2012)). The latter have proven effective for conservation policies (REF). For birds, these indices have been widely used (see review by [Fraixedas et al. 2020](#ref-fraixedas_state_2020)), while the use of simpler macroecological indices (species richness, beta diversity) is uncommon.

# Future directions

A striking but expected (see Meyer et al. 2018), was the lack of studies form outside of the high-income global North. Out of 17 papers, 5 were located in North America and 12 in Europe. This is gap was also reported by [Fraixedas et al. (2020](#ref-fraixedas_state_2020)). Yet, biodiversity dynamic in Europe may not be representative of global dynamic, and studies of biodiversity trends at several spatio-temporal scales are needed outside of Europe. These studies are needed on local grains, as well as at the spatial grain of continents (e.g. as has been done by Alroy 2015 for amphibians and reptiles).

The spatial grain of biodiversity trends is critical, yet this has not always been specified. One should consider the way a metric was computed, *e.g.* if it was 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 is used. Given the importance of spatial scaling of biodiversity patterns ([Storch and Gaston 2004](#ref-storch_untangling_2004)), one has to expect that it will be also important for its dynamic (*e.g.* [Chase et al. 2019](#ref-chase_species_2019)). We thus argue that authors should pay extra attention to specifying the spatial grain for every metric of biodiversity trends.

The importance of temporal scaling of biodiversity is known since [Grinnell](#ref-grinnell_role_1922) ([1922](#ref-grinnell_role_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](#ref-white_two-phase_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](#ref-schipper_contrasting_2016)) and sometimes without explicit information (*e.g.* [Harrison et al. 2014](#ref-harrison_assessing_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 […]’*). As for the spatial grain, the temporal grain can vary according to the metric and the way it is computed. The confusion intensifies when temporal trend of a metric is assessed, as the temporal grain of the metric is considered to be representative of the unit time-span of the trend (*i.e.* time-span between and ). In other words, when computing a trend, one usually uses a single point either every day, every month or every year. Thus, the temporal grain of the trend is different from the one of the computed metric, especially if one point of the represents 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 emerge:

**1)** Temporal grain of the trend is the temporal grain of the computed metric. This definition of the temporal grain is similar to the definition of spatial grain. It has the advantage to be very precise. In this case, it should be clearly specified by the authors, according to the method used to compute the metric. However, finding it in the articles is complicated.

**2)** Temporal grain of the trend is the time-span between two assessment of the metric. This definition makes the temporal grain easier to assess, but with a lack a precision compared to the temporal grain of the sampling plan.

In order to study the temporal scaling of trends of biodiversity, as the first definition is often very complicated to determine in the scientific literature, the second definition can be used by keeping in mind that it represents an approximation.

# Conclusion

Reviewing the scientific literature on avian biodiversity trends give us a glimpse of what needs to be done to better understand the scaling of biodiversity dynamic. The first challenge is to find a common definition of spatial and temporal grain when computing the trend. We showed that these definitions are **1)** metric-related and **2)** vary according to the way the metric is computed. Whilst spatial grain of a trend is intuitive, temporal grain is confusing as it can be considered at two levels: at the metric level or at the temporal trend level. Finally, as birds are one of the most data-rich taxa of vertebrates, the challenges highlighted here will be even more severe for other groups.

# Supplementary materials

Table 6.1: Supplementary informations about each article

| Reference | Spatial grain (Km²) | Trend | Note |
| --- | --- | --- | --- |
| \cite{barnagaud\_temporal\_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\*400\^2) with a road of 40 Km with point counts spaced by 0.8 Km and a census radius of 400m |
| \cite{bowler\_geographic\_2021} | National | Stable | Metric = MSI, as many and as intense increase (i.e. Czech Rep. and Switzerland) than decrease (i.e. Germany and Denmarl) |
| \cite{chase\_species\_2019} | Local | Stable |  |
|  | Regional | Stable |  |
|  | Regional | Stable |  |
|  | Local | Increase |  |
|  | Local | Increase |  |
| \cite{chiron\_forecasting\_2013} | Regional | 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 |
|  | Regional | Decrease | FBI prediction with CAP greening cenario |
|  | Regional | Decrease | FBI prediction with No Pillar I scenario |
|  | Regional | Decrease | FBI prediction with biofuel scenario |
| \cite{davey\_rise\_2012} | Local | Increase | Metric = Simpson.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 |
|  | Local | Increase |  |
|  | Local | Increase |  |
| \cite{harrison\_assessing\_2014} | Local | Increase | To assess the metric, they use a GAM to predict the abundance over the entire area of interest (spatial resolution = 1 Km²) and then compute the geometric mean of species abundance = Multi Species Index (as in \cite{studeny\_fine-tuning\_2013}) from the prediction. Data used to learn the GAM are sampled from plots of 1 Km². 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 |
| \cite{harrison\_quantifying\_2016} | Local | 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 |
|  | 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 |
| \cite{jarzyna\_taxonomic\_2018} | Regional | Increase |  |
|  | Regional | Increase |  |
|  | Regional | Increase |  |
|  | National | Increase |  |
|  | Global | Decrease |  |
|  | Regional | Increase |  |
|  | Regional | Increase |  |
|  | Regional | Increase |  |
|  | National | Increase |  |
|  | Global | Stable |  |
| \cite{pilotto\_meta-analysis\_2020} | 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" |
| \cite{ram\_what\_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 |
| \cite{reif\_changes\_2013} | Local | Stable | Jaccard index, pairwise comparisions between transects |
|  | Local | Stable | JPSP data, transect scale |
|  | National | Stable | JPSP data, national scale |
| \cite{schipper\_contrasting\_2016} | Local | Increase | The metric (i.e. geometric mean) is meaned over each road. Area of the road = 50\*(pi\*400\^2) with 50 census point per road and a census radius of 400m |
|  | Local | Increase | Metric = Shannon |
|  | Local | Increase | Metric = Simpson |
|  | Local | Decrease |  |
|  | Local | Increase |  |
|  | Local | Increase |  |
|  | Local | Increase |  |
| \cite{sorte\_changes\_2005} | Local | Decrease |  |
|  | Local | Decrease | Metric = evenness |
|  | Local | Increase | The metric is meaned over each road. Area of the road = 50\*(pi\*400\^2) with 50 census point per road and a census radius of 400m |
| \cite{van\_turnhout\_scale-dependent\_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 |
| \cite{wretenberg\_changes\_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. " |
| \cite{inger\_common\_2015} | National | Decrease |  |
| \cite{donald\_agricultural\_2001} | National | Decrease | The metric is referred as "Mean population" and the trend is estimated for each european country |

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