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Fifteen forms of biodiversity trend in the Anthropocene

Brian J. McGill[1], Maria Dornelas[2], Nicholas J. Gotelli[3], and Anne E. Magurran[2]

[1] University of Maine, Orono, ME, USA
[2] University of St Andrews, St Andrews, UK
[3] University of Vermont, Burlington, VT, USA

Humans are transforming the biosphere in unprecedented ways, raising the important question of how these impacts are changing biodiversity. Here we argue that our understanding of biodiversity trends in the Anthropocene, and our ability to protect the natural world, is impeded by a failure to consider different types of biodiversity measured at different spatial scales. We propose that ecologists should recognize and assess 15 distinct categories of biodiversity trend. We summarize what is known about each of these 15 categories, identify major gaps in our current knowledge, and recommend the next steps required for better understanding of trends in biodiversity.

The Anthropocene and trends in biodiversity

'How bad is the biodiversity crisis?' is a question many professional ecologists have been asked in some form by lay acquaintances. Rephrased in scientific terms, this is a question about trends in biodiversity: is biodiversity improving (going up) or worsening (going down)? Not coincidentally, governments have posed the same question and identified policy goals for trends in biodiversity. The 2002 United Nations Convention on Biological Diversity (CBD) [1] set out 'to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level'.

Most people assume that biodiversity trends must be strongly negative for a simple reason: we live in the Anthropocene. The movement to name a new geological era 'the Anthropocene' [2] is a recognition of the degree to which humans are now the dominant driver of patterns in global biogeochemistry and biodiversity. Humans have [3]: (i) modified as much as 50% of terrestrial land cover; (ii) consumed roughly 40% of the Earth's primary productivity every year; (iii) doubled the annual conversion of nitrogen from inert atmospheric sources into biologically reactive forms and mined so much phosphorous that the drainage of synthetic fertilizers into the oceans has created giant anoxic dead zones; (iv) released enough CO_2 through the burning of fossil fuels that a doubling of the atmospheric concentration is likely in the lifetime of some people alive today; (v) increased the concentrations of CO_2 and other greenhouse gases with the result that short-term increases in global temperature will overshadow normal annual- to millennial-scale variation; and (vi) hunted and fished to such a degree that dominant top predators are absent or endangered on land and sea. The cumulative impact of a population of over 7 billion humans clearly warrants the geological label of Anthropocene.

For ecologists, it is both an interesting intellectual challenge and a pressing question of sustainability, ethics, and policy to understand and predict the effects of these changes on biodiversity. Given the enormous impacts humans are having, it is conventional wisdom that the changes in biodiversity must be large and negative. According to the International Union for Conservation of Nature (IUCN) Red List of threatened and endangered species, one-quarter of mammal species, one-eighth of bird species, and over 40% of amphibian species are threatened; although much less is known about invertebrates and plants, thousands of these species are also at risk [2,4] [IUCN (2014) *The IUCN Red List of Threatened Species Version 2014.2* (http://www.iucnredlist.org)]. The Living Planet Index suggests that vertebrate populations now have 52% fewer individuals than 40 years ago [5]. There are discussions of an impending sixth major mass extinction analogous to the previous five documented mass extinctions [6,7]. The great negative impact of humans is so well accepted that many ecologists have largely moved on to exploring questions of the implications for humans of this impending decline of biodiversity [8,9].

However, if we examine the literature on empirically documented trends in biodiversity, a complex picture emerges with many contradictory results. For example, total biodiversity on many oceanic islands, often perceived as among Earth's most fragile ecosystems, has stayed steady or even increased, despite repeated waves of extinction that have accompanied the arrival of humans on islands [10]. There is considerable empirical evidence that continental biodiversity at regional or local scales is also holding steady or increasing [11]. Three recent analyses [12–14] that collectively assembled published data from hundreds of biodiversity inventory studies found that local diversity is, on average, constant. Indeed, almost all human impacts can have positive as well as negative effects on biodiversity (Box 1). Over much longer timescales, paleontological data show that life is surprisingly resilient [15,16]. Many of the most dire projections of biodiversity

Corresponding author: McGill, B.J. (mail@brianmcgill.org).
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Glossary

We define these terms in the context of species-based metrics of biodiversity, but many can also be applied to genetic and ecosystem diversity. The focus is on defining the concepts rather than discussing the many metrics that currently exist to quantify them.

Types of diversity

Alpha (α) diversity: the number of species present (e.g., the number of colors in one community Figure I).

α-diversity trend: change in α diversity through time (plotting α diversity for one community over time (e.g., the four blue lines on the right of Figure I).

Spatial beta (β) diversity: change in community composition across space (e.g., comparing similarity between communities a–d for one time period). This is usually plotted as similarity versus distance (distance decay), as in the three red lines at the top of Figure I labeled β (note that communities are almost always less similar the further apart they are, but the rate of decay can differ, as is the case here for each of the three time periods).

Spatial β-diversity trend: temporal change in spatial β diversity (plots the rate of decay of similarity with distance versus time period; top red line in Figure I). One common example is when the decay constant decreases through time (i.e., spatial β diversity decreases through time), as in Figure I. This type of trend is often referred to as biotic homogenization.

Temporal β diversity or turnover: change in community composition through time, usually quantified as the similarity between each time step and the time-series baseline. Usually represented as a plot of similarity versus time of separation (the four red trend lines on the right of Figure I) and measured by the rate of decay.

Spatial scales

Biogeographical: a scale within which speciation and global extinction are dominant processes [64].

Global: the entire planet.

Local: a scale dominated by species interactions and environmental constraints.

Meta-community: a scale that includes spatial heterogeneity and within which dispersal is the dominant process.

Species classification

Extinction and colonization dynamics: the recurring process of species entering and exiting a community of interest, leading to a dynamic equilibrium [65].

Losers: species that are decreasing in their abundance, range, and/or occupancy through time, the extreme being extinctions (red lines, left and middle columns in Figure 3 in main text).

Winners: species that are increasing in their abundance, range, and/or occupancy through time, the extreme being globally invasive species (green lines, left and middle columns in Figure 3 in main text).

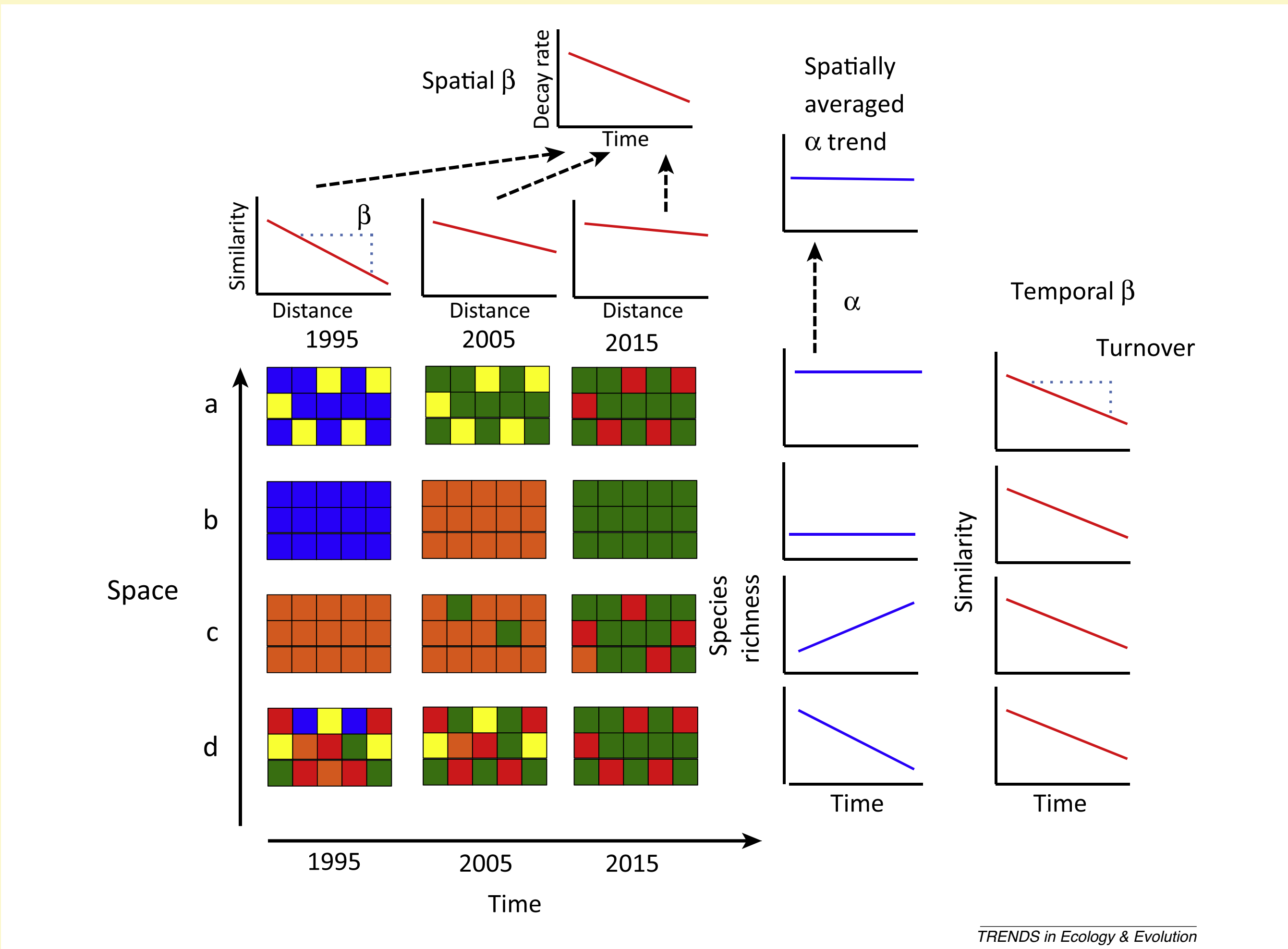

Figure I. Illustration of key types of biodiversity that can be measured. This figure follows four hypothetical communities (a–d) through three time periods (1995, 2005, 2015) (community abundance is constant, colors represent distinct species) demonstrating all of the major types of trends of α and β diversity.

loss are based on simple models of habitat change that are extrapolated to forecast future loss [6,7,17] rather than empirical observation of current trends in biodiversity and species richness. While in no way arguing that biodiversity is not in grave danger, we do argue that it is time for a measured and careful assessment of empirically quantified trends. In the following sections we suggest how best to organize this empirical assessment.

Reasons for mixed results

We suggest, as have Sax and Gaines [11] previously, that the apparently contradictory results of biodiversity-monitoring