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Perspective

Is local biodiversity declining or not? A summary of the debate over analysis of species richness time trends☆

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ABSTRACT

Recently, a debate has developed over how biodiversity is changing across the planet. While most researchers agree species extinctions are increasing globally due to human activity, some now argue that species richness at local scales is not declining as many biologists have claimed. This argument stems from recent syntheses of time-series data that suggest species richness is decreasing in some locations, increasing in others, but not changing on average. Critics of these syntheses (like us) have argued there are serious limitations of existing time-series datasets and their analyses that preclude meaningful conclusions about local biodiversity change. Specifically, authors of these syntheses have failed to account for several primary drivers of biodiversity change, have relied on data poor time-series that lack baselines needed to detect change, and have unreasonably extrapolated conclusions. Here we summarize the history of this debate, as well as key papers and exchanges that have helped clarify new issues and ideas. To resolve the debate, we suggest future researchers be more clear about the hypotheses of biodiversity change being tested, focus less on amassing large datasets, and more on amassing high-quality datasets that provide unambiguous tests of the hypotheses. Researchers should also keep track of the contributions that native versus non-native species make to biodiversity time trends, as these have different implications for conservation. Lastly, we suggest researchers be aware of pros and cons of using different types of data (e.g., time-series, spatial comparisons), taking care to resolve divergent results among sources to allow broader conclusions about biodiversity change.

1. Introduction

Over the past few years, a scientific debate has developed over how biodiversity is changing across the planet. Most researchers agree that species extinctions at the global scale are occurring much faster than what is 'normal' in the fossil record (Barnosky et al., 2011). The majority of researchers would also agree that biodiversity is generally declining at most locations across the planet, especially in areas that have experienced direct human impact. This view is, in fact, sufficiently ingrained in the minds of biologists that select disciplines (e.g., Conservation Biology) and fields of study (e.g., Biodiversity and Ecosystem Functioning) often take local species extinctions as a given, and a primary motivation for their work. But a group of ecologists has recently begun to claim they have amassed a body of evidence showing that species richness is, in fact, not declining at local spatial scales across the globe, and that the objectives of conservation need to be re-examined (Dornelas et al., 2014; Hillebrand et al., 2018; McGill et al., 2015; Vellend et al., 2013).

The claim that local diversity is not in decline stems primarily from analysis of time-series data of biological monitoring programs. While the data themselves are not controversial, the analyses of the data and conclusions that have followed have been controversial, which has led to a series of exchanges between proponents and critics of the use of time-series to quantify local diversity change (Cardinale, 2014; Dornelas et al., 2014; Gonzalez et al., 2016; Hillebrand et al., 2018; McGill et al., 2015; Vellend et al., 2013; Vellend et al., 2017b). But the exchanges have taken place at an assortment of working groups and meetings, and been dispersed across a variety of journals (mostly ecological). The goal of this paper is to provide practitioners of biodiversity conservation with some background on the debate, summarize the key

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papers and exchanges to date that help clarify new ideas, and then offer our perspective on how to move forward towards a resolution. A successful resolution is critically important to the field of conservation biology, as well as other fields of study, where the effectiveness of management decisions depends on our ability to accurately predict how biodiversity is changing at various scales across the planet.

2. Background

The foundation for the current debate over biodiversity change traces back to papers addressing the countervailing effects of human induced species loss and invasion on local biodiversity (McKinney and Lockwood, 1999; Olden and Poff, 2003; Sax and Gaines, 2003; Sax et al., 2002). Sax and Gaines (2003) were among the first to show that rates of species introductions into large regions (e.g., islands, mainland ecosystems) sometimes equal or exceed rates of species extinctions. When introductions equal or exceed extinctions, species richness can remain constant or even increase, rather than decline as has often been presumed by those who cite the negative impacts of invasive species on biodiversity (Clavero and Garcia-Berthou, 2005; Molnar et al., 2008; Wilcove et al., 1998). If species gains outpace extinctions in ecosystems, and we accept that species extinctions are exceeding rates of speciation at the global scale, then the relationship between species diversity at different scales of observation [gamma (γ) = alpha (α) × beta (β)] suggests that beta-diversity - the turnover of species among locations on the planet – is generally in decline (Whittaker, 1960). The resulting prediction is that the world's biota is being homogenized as non-indigenous and locally expanding species replace local biota (Olden et al., 2004).

Since publications by Sax and the ensuing discussion about biotic homogenization, it has been increasingly argued that loss of beta-diversity deserves more attention by practitioners and managers in biodiversity conservation (Gering et al., 2003; Magurran, 2016; Olden, 2006). But even as attention has turned towards better quantification of changes in local diversity (α) and species turnover (β), it has become clear that we generally lack the types of datasets that are needed to broadly assess alpha- and beta-diversity for the average location on Earth. Indeed, several authors have emphasized the paucity of long-term monitoring programs that assess a broad range of organisms across the terrestrial land surface, and oceans of the planet (Duarte et al., 1992; Green et al., 2005; Henry et al., 2008; Pereira and Cooper, 2006; Sheil, 2001). Of the programs that do exist, most have been uncoordinated, non-uniform in methods and coverage, and are not easily accessible by scientists attempting to perform data syntheses.

In an effort to overcome these limitations, several studies began collating the data needed to quantify local changes in biodiversity around the globe, and to determine the extent to which communities are changing. Though these studies and working groups share a common goal, they have taken different approaches. Some have focused on estimating diversity change using spatial comparisons in which measures of species diversity in reference sites are compared to measures of diversity in habitats that have been modified by human activities. This was the approach taken by meta-analyses that made spatial comparisons between disturbed and undisturbed reference sites (e.g., Alroy, 2017; Aronson et al., 2014; Benayas et al., 2009; Gerstner et al., 2014; Moreno-Mateos et al., 2017; Murphy and Romanuk, 2014), and in the PREDICTS project (Projecting Responses of Ecological Diversity In Changing Terrestrial Systems – www.predicts.org.uk), which collated data from published studies to compare biodiversity from sites that differ in the nature or intensity of human impacts relating to land use (Hudson et al., 2014). Studies that have used spatial comparisons to contrast human-impacted sites to reference sites have generally corroborated the historical view that local species richness is in decline, but the magnitude of decline varies with the type and severity of human impact (Aronson et al., 2014; Benayas et al., 2009; Moreno-Mateos et al., 2017; Murphy and Romanuk, 2014; Newbold et al., 2016; Newbold et al., 2015).

In contrast to efforts that have used spatial comparisons, a second group of data syntheses has taken a different approach in which researchers have collated time-series data from studies that have made repeated measurements of biodiversity at individual locations around the planet (Dornelas et al., 2014; Elahi et al., 2015; Hillebrand et al., 2018; Vellend et al., 2013). Studies focused on analysis of time-series datasets have generally come to a different conclusion. While these analyses have confirmed extensive turnover in species composition across locations, and across time at single locations, they have not found evidence of systematic declines in local species richness. Rather, these data syntheses have shown that species richness in some locations has increased through time, whereas in other locations it has declined. These opposing trends have been offsetting such that there has been no net change in local species richness at the average location represented in the datasets.

Because of the surprising results and their publication in prominent journals, data syntheses by those like Vellend et al. (2013) and Dornelas et al. (2014) received considerable attention in the popular media. For example, a write-up of the Dornelas et al. (2014) paper in *Science World Report* stated: "*As our climate changes, species are disappearing-or that's what's commonly assumed. Now, though, it looks like that might not be the case. Scientists have re-examined data from 100 long-term monitoring studies done around the world and have found that the number of species hasn't changed much, or has actually increased over time* (Griffin, 2014)." Authors of the original syntheses wrote in follow-up papers their analyses had overturned the long-standing view that species richness at local scales across the globe is declining, contrary to what many ecologists and conservation biologists have claimed (McGill et al., 2015). *Vellend (2017)* took this message to the public in a subsequent OpEd in *American Scientist* magazine, writing: "*It is unsettling to have one's view of the world called into question—in this case I had to face evidence that is contrary to the conventional wisdom in conservation biology imparted to me in the 1990s. Biodiversity is not generally declining at all spatial scales: Declines at the global scale are not generally seen at the regional scale and occur only in particular scenarios at the local scale.*"

Despite the claim that historical views on biodiversity loss have been overturned, this claim has been controversial. Several critiques and criticisms of the Vellend et al. (2013) and Dornelas et al. (2014) data syntheses have been published (Cardinale, 2014; Gonzalez et al., 2016; Isbell et al., 2015), and working groups organized at the Integrative Biodiversity Research Center in Germany, the Biodiversity Research Center in Canada, and the Quebec Center for Biodiversity Science in Canada have brought together the original authors and their critics to debate key issues in person. Unfortunately, this exchange has occurred in scattered venues and publications, making the debate hard to follow for those who have not been directly involved in the exchange.

We believe the outcome of the debate over local biodiversity change is critically important to the field of conservation biology. If, as analyses of time-series datasets suggest (Dornelas et al., 2014; McGill et al., 2015; Vellend et al., 2017a; Vellend et al., 2013), species richness is not generally in decline at local scales as has long been presumed, the historical tools used for biodiversity conservation may need to be revised, and the trends reported in many textbooks need to be rewritten. If, however, critics are correct about the limitations of conclusions drawn from time-series data, then it may be premature to suggest that historical views about biodiversity loss have been overturned. In the remainder of this paper, we summarize the key papers and exchanges that have helped clarify new issues and ideas, after which, we offer some suggestions on how to move towards a resolution.

3. Summary of the debate

In this section we summarize key arguments from four primary papers that exemplify the current debate (Dornelas et al., 2014;