

**Are We in a Sixth Mass Extinction?
The Challenges of Answering and Value of Asking**

Federica Bocchi, Alisa Bokulich, Leticia Castillo Brache,
Gloria Grand-Pierre, Aja Watkins

Abstract

In both scientific and popular circles it is often said that we are in the midst of a sixth mass extinction. Although the urgency of our present environmental crises is not in doubt, such claims of a present mass extinction are highly controversial scientifically. Our aims are, first, to get to the bottom of this scientific debate by shedding philosophical light on the many conceptual and methodological challenges involved in answering this scientific question, and, second, to offer new philosophical perspectives on what the value of asking this question has been — and whether that value persists today. We show that the conceptual challenges in defining ‘mass extinction’, uncertainties in past and present diversity assessments, and data incommensurabilities undermine a straightforward answer to the question of whether we are in, or entering, a sixth mass extinction today. More broadly we argue that an excessive focus on the mass extinction framing can be misleading for present conservation efforts and may lead us to miss out on the many other valuable insights that Earth’s deep time can offer in guiding our future.

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1. Introduction

In scientific and popular circles it is often said that we are in the midst of a sixth mass extinction. This phrase was popularised in the mid-1990s and cemented in the public's consciousness with Elizabeth Kolbert's ([2014]) Pulitzer Prize winning book *The Sixth Extinction*.¹ Although the urgency of our present environmental crises is not in doubt, such claims of a present mass extinction are highly controversial scientifically. Many palaeontologists have argued for decades that claims of a sixth mass extinction are scientifically unjustified. Despite the protestations of palaeontologists, many environmentalists and biologists have persisted in making use of 'mass extinction' rhetoric. Are we really in a sixth mass extinction? In this paper, we draw the following three conclusions: First, we argue that there are a number of conceptual and methodological challenges—both on the side of paleodiversity and contemporary biodiversity—that undermine any facile answer to this question. Second, we show that, on one possible definition of mass extinction and analysis, our best current evidence suggests that we are *not* in a sixth mass extinction, though we emphasise there are further 'incommensurabilities' and grant that other definitions and analyses may lead to other conclusions. Third, we conclude that the time has come to reframe the debate and start asking a different set of questions.

Section 2 of the paper will begin with a brief history of the Sixth Mass Extinction debate. As we will show, the scientific concept of a mass extinction in palaeontology actually emerged hand-in-hand in the 1950s and 60s with concerns over the present environmental crisis. As palaeontologists in the 1980s and 90s came to better understand the nature and magnitude of the so-called 'Big Five' mass extinctions, they were increasingly resistant to classifying current extinctions as being on par. This created a rift between these palaeontologists, on the one hand, and some ecologists and biologists, on the other, who saw rejection of the Sixth Mass Extinction idea as undermining the urgency of our current environmental crises (Sepkoski [2020]). This controversy has not abated.

To answer whether we are in the midst of a sixth mass extinction, we must first confront the conceptual challenges involved in defining 'mass extinction'. Intuitively, a mass extinction is a catastrophic drop in global biodiversity; however making this concept precise and scientifically useful is challenging. A historical review of various definitions, along with their respective strengths and weaknesses, will be discussed in section 3. Even after settling on a definition of mass extinction, a number of issues remain concerning various gaps and biases in the fossil record, making the proper interpretation of paleodiversity data nontrivial (e.g., Bokulich [2018]). Challenges arising from paleodiversity data are discussed in section 4. As we will see, they raise significant questions about how many mass extinctions have occurred in Earth's past.

¹ The Sixth Mass Extinction is also referred to as the Holocene or Anthropocene extinction.

Substantive questions about current biodiversity data also complicate the assessment of a current mass extinction. Here, too, we find several challenges, such as incomplete data on the number of extant species and current extinction rates. These challenges are the focus of section 5. In section 6, we examine a third class of challenges to answering whether we are in a sixth mass extinction, which fall under the umbrella of what we call the *incommensurability problem* (Bocchi [MS]).

In light of the many challenges highlighted, one might think that answering the question of whether we are in the midst of a sixth mass extinction is hopeless. In section 7 we show that there are in fact steps that can be taken to partially ameliorate some of these challenges, although doing so still does not get us a definitive answer concerning whether we are in a sixth mass extinction. In section 8 we conclude by reassessing the value of asking whether we are in the midst of a sixth mass extinction. We argue that although it may not be possible to definitively say whether we are in, or approaching, a sixth mass extinction, research on this topic has demonstrated more broadly the importance of looking to Earth's deep past for guidance about how we might shape Earth's future.

By digging down into the technicalities of defining 'mass extinction,' and by making comparisons between paleo and contemporary biodiversity data, we hope that this paper will advance the Sixth Mass Extinction debate. In particular, this paper should be of interest to anyone who has heard about the Sixth Mass Extinction, but wondered about the nature of the evidence supporting this hypothesis. These readers will benefit from the paper's historical analysis of the mass extinction concept, review of the methodological and conceptual challenges involved in measuring past and present biodiversity, and our discussion of how to make these past and present data more comparable. Another way in which this paper contributes to existing research programs is by expanding the increasingly richer agenda in philosophy of the historical sciences. As of yet, philosophers who have been interested in general epistemological or methodological questions in the historical sciences have focused almost exclusively on how the past is reconstructed using trace evidence (among other methods) in the present.² Rather than focusing on how to use the present as a guide to the past, however, in this paper we are more focused on *how to use the past as a guide to the future*, namely how to interpret and address current biodiversity decline in light of what we know about past biodiversity crises (see, for example, Currie ([2018]), Page ([2021]), Watkins ([MS]), Bocchi ([MS]) and Dresow ([forthcoming])). Indeed the mass extinction debate provides an interesting case study for expanding the methodological focus of the philosophy of the historical sciences from trace-based reasoning to how the historical sciences can be engaged in prediction.³

² For example, see Cleland ([2001, 2002, 2011, 2013]), Currie & Turner ([2016]), Currie([2019a]), Finkelman ([2019]), Havstad ([2019]), Turner ([2019]), and A. Wylie ([2019]).

³ Thanks to an anonymous referee for helping us to clarify our intended audience of the paper.

2. A Brief History of the Sixth Mass Extinction Debate

Surprisingly, the history of the Sixth Mass Extinction idea is almost as old as the coining of the term ‘mass extinction.’ Our modern understanding of mass extinctions is indebted to the work of John Phillips (1800-1874), nephew and apprentice of William Smith,⁴ who undertook the project of compiling as much data as he could find on extinct taxa and organising them according to geologic time. Phillips’ ([1860]) *Life on the Earth, Its Origin and Succession* was a milestone in three respects: it contains the first Geologic Time Scale⁵, the first paleodiversity curve, and the first application of data-correction methods to address biases in the fossil record. In his chapter ‘Varieties of Forms of Life in Successive Periods,’ Phillips counts the number of fossil taxa in the Paleozoic, Mesozoic, and Cenozoic and notes that raw fossil taxon counts are biased by the differing amounts of sedimentary rock (corresponding to different periods of time) that happen to be preserved and are available at outcrop — more rock, more fossils — a bias palaeontologists still struggle to correct today (see section 4). Remarkably, Phillips goes on to adjust or correct the raw paleodiversity numbers by determining a relative number of species to be expected on average in a given thickness. As historian David Sepkoski notes, ‘this is one of the earliest examples of ‘bias correction’ in the history of analytical paleontology’ (Sepkoski [2013], p. 426). Moreover, Phillips uses this method on two different data sets, obtaining largely the same result.⁶

Based on these analyses he concludes that the ‘variety of life’, or what we would today call ‘species richness’ (which he distinguishes from ‘abundance’) has — despite appearances to the contrary in the raw data — increased in more recent periods.⁷ Phillips notes that on a finer scale, the variety of life has waxed and waned, which he depicts in a diagram ‘by a continuous curve, which corresponds to the numerical prevalence of life, and represents its rise and fall’ (p. 65):

⁴ Smith drew one of the first geologic maps of Britain in 1815 using fossils, helped found biostratigraphy, and coined the word ‘stratigraphy’ (Rudwick 2014, pp. 140-141).

⁵ Although Phillips’ earlier book ([1841]) is credited as containing the first geologic time scale, because he refers to the divisions as “strata” instead of “periods” (as he does in [1860]), it is better thought of as a chronostratigraphic chart. Indeed, the 1860 book is the first to reference it as ‘Geological Scale of Time’ (p. 51).

⁶ This is an example of complementary use of data sets; see Bokulich and Parker ([2021]), Section 4.3.

⁷ ‘Species richness’ and ‘species abundance’ are two indicators of ‘biodiversity’ (section 5). Of course, the claim that biodiversity has increased over time is itself up for debate; for an argument that the trend may be either a genuine signal or an artefact of better preservation, see Jackson and Johnson ([2001]).

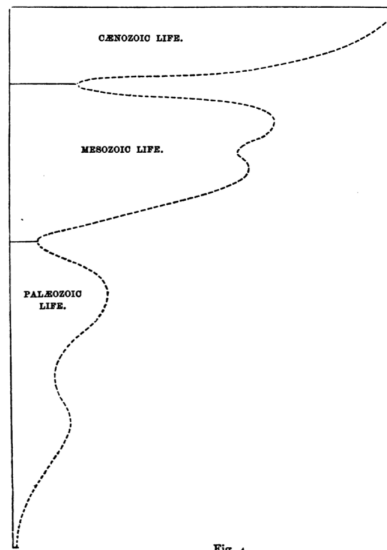


Fig. 4.

Fig. 1: The first known paleodiversity curve, by John Phillips ([1860], Fig. 4, p. 66) representing the waxing and waning of marine fossil taxa, and revealing the end-Permian and end-Cretaceous mass extinctions, which he used to define the Paleozoic and Mesozoic Eras. Figure available in the public domain.

This graph is remarkably similar to paleodiversity curves used today, such as the famous Sepkoski curve (Raup and Sepkoski [1982]), which we discuss in section 3). Even with the very limited fossil data available in the mid-19th century and the most elementary data correction methods employed, Phillips was able to identify the end-Permian mass extinction, which was the worst mass extinction of the Phanerozoic (last 500 million years), and the end-Cretaceous mass extinction, which wiped out the nonavian dinosaurs. He uses these mass extinctions to define the boundaries of Paleozoic, Mesozoic, and Cenozoic Eras and argues that they were nonarbitrary chapters in the history of life. He moreover notes the depression in the Paleozoic series 'corresponding to the Devonian period' as a third 'zone of least life,' which today is counted as one of the 'Big Five' mass extinctions.

Despite Phillips' remarkable start, the topic of mass extinctions would be largely ignored until the work of Norman Newell in the 1950s and '60s. This was likely in part

due to the sway that uniformitarianism⁸ — especially as espoused by Charles Lyell and Charles Darwin — held over geology and biology from the mid-19th to the mid-20th century. For Lyell and Darwin, any dramatic drops in paleodiversity of the sort Phillips had discovered were nothing more than artefacts of an imperfect fossil record.⁹ It is telling that Newell’s early defences of mass extinctions described them as ‘catastrophes . . . [that] are not sudden but gradual’ (Newell [1963], 77). Regardless of the reasons for their neglect, Newell is remembered for being a lone ‘voice crying in the wilderness’ in explaining the evolutionary importance of mass extinctions ‘at a time when no one else in the field was talking about them’ (Pearce [2005], quoting Eldredge).¹⁰

Newell was curator of invertebrate palaeontology at the American Museum of Natural History and a professor of Stephen Jay Gould and Niles Eldredge. Newell’s ([1952]) paper seems to be the first publication to use the term ‘mass extinction’ in its palaeontological sense. A broader defence of the existence and importance of mass extinctions appears in his ([1963]), where he introduces the idea of a *current* mass extinction alongside his discussion of mass extinction events in Earth’s geologic history. As David Sepkoski ([2020]) cogently argues, palaeontologists’ research on mass extinctions was part of a broader ‘extinction imaginary’ that included cultural fears about nuclear annihilation. The key point for our project is that, rather than being a latecomer, the Sixth Mass Extinction idea emerged hand-in-hand with modern mass extinction studies.

Despite their co-origin, it has not proven to be an association that palaeontologists are always willing to embrace. The first use of the phrase ‘sixth extinction’ was not by a palaeontologist, but rather by biologist Edward O. Wilson in his book *The Diversity of Life* (Wilson [1992], p. 32). The expression rapidly caught on, with Richard Leakey and Roger Lewin titling their [1995] book *The Sixth Extinction*, in which they argue that the rate of species loss today — even on a conservative estimate — is comparable to the rate of species loss in the Big Five mass extinctions. As we will explain in section 5, these estimates are problematic. While ecologists and biologists embraced the Sixth Mass Extinction idea as an effective tool for advancing their environmental agenda, palaeontologists increasingly became uncomfortable with the claim that our present environmental crises were of the same nature and magnitude as mass extinctions in the deep past. In response to these claims of a sixth mass extinction, palaeontologist David Jablonski, writes ‘Direct comparison of ancient extinctions to the present-day situation is difficult. . . . Extensive as today’s species losses probably are, they have yet to equal any of the Big Five mass extinctions’ (Jablonski

⁸ Uniformitarianism is the idea that all geologic processes operate at a uniform, gradual rate. For finer distinctions within uniformitarianism, see Gould ([1987], Chapter 4), Page ([2021]), and Dresow ([forthcoming]).

⁹ See, e.g., Chapter 10 of the *Origin* (Darwin [1859]).

¹⁰ Eldredge’s obituary for Newell notes: ‘It is Norman’s focus on mass extinctions which may prove to be his most lasting gift to us all. In the mid-twentieth century, it is fair to say that Norman D Newell was the most prominent. . . scientist of any sort who saw that mass extinctions are real events’ (Eldredge [2005]). The other key figure at this time arguing for the importance of mass extinctions was Otto Schindewolf, who coined the term ‘neo-catastrophism’ in 1963 (see, e.g., Rudwick ([2014], pp. 266-267).

[1994], p. 11). Difficulties with comparing past and present biodiversity data will be discussed further in section 6, and a more careful assessment of the extent of these problems can be found in section 7.

This debate about whether we are in the midst of a sixth mass extinction has not abated. In [2020], conservation biologists Gerardo Ceballos, Paul Ehrlich, and Peter Raven confidently assert ‘Life has now entered a sixth mass extinction’ (p. 13596).¹¹ However, even sympathetic biologists, such as paleoecologist Anthony Barnosky and colleagues write, ‘the recent loss of species is dramatic and serious but does not yet qualify as a mass extinction in the paleontological sense of the Big Five’ (Barnosky et al. [2011]). Similarly, invertebrate palaeontologist Douglas Erwin remarks,

‘Many of those making facile comparisons between the current situation and past mass extinctions don’t have a clue about the difference in the nature of the data, much less how truly awful the mass extinctions. . . actually were. . . . I do think that as scientists we have a responsibility to be accurate about such comparisons’ (Erwin quoted in Brannen [2017], p. 245).

What then are these differences between paleontological and ecological data? What exactly is a mass extinction? In the following sections we lay out and assess the many conceptual, methodological, and datic¹² challenges that must be resolved before such comparisons can be responsibly made.

3. What is a Mass Extinction?

Before we can determine whether we are in a sixth mass extinction, we must first define what a mass extinction is. Although the concept is intuitively clear, articulating a scientifically rigorous definition of ‘mass extinction’ has proven surprisingly difficult. At the centre of modern mass extinction studies is the work of Jack Sepkoski, known for his compilation of marine fossil data and iconic paleodiversity curve (the ‘Sepkoski Curve’) identifying the ‘Big Five’¹³ mass extinctions (Raup and Sepkoski [1982]; see Figure 2).

¹¹ Note that Ceballos et al. ([2015]) only say that we are ‘entering’ a sixth mass extinction, not that we are already in one. Even in their ([2020]), they leave open the possibility that there is a chance to reverse course, but say that ‘the window of opportunity is almost closed’ (p. 13601).

¹² Since there does not yet exist an adjectival form of the noun datum/data, we are here coining a new adjectival form — ‘datic’ — meaning ‘of, pertaining to, data.’ By ‘datic challenges’ we mean challenges related to the collection, processing, and/or interpretation of data.

¹³ Although their figure labels five mass extinctions, they note that only four (excluding the Devonian) are statistically significant.

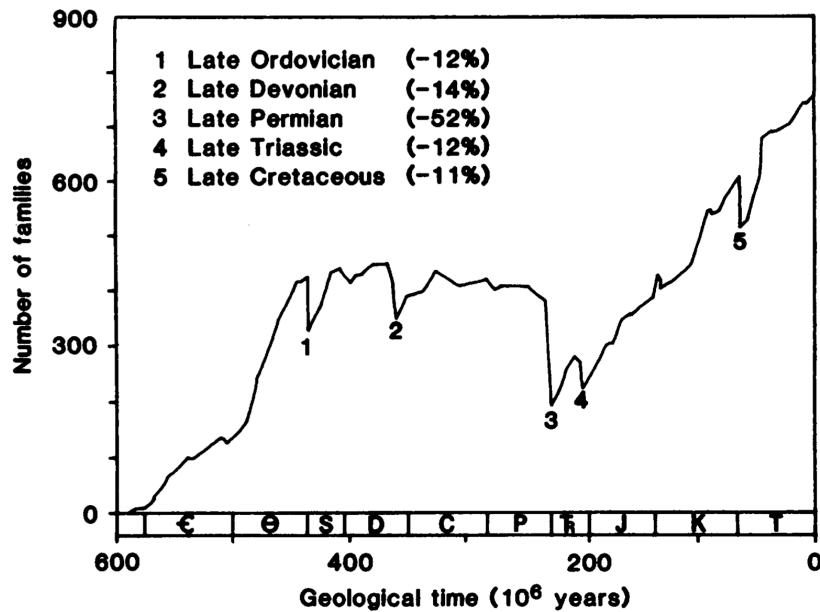


Fig. 2: The Sepkoski Curve, representing marine diversity at the taxonomic level of families over the last 600 million years. The 'Big Five' mass extinctions are labelled at the troughs of the diversity curve, with the relative magnitude of the drop given in parentheses in upper left (from Raup & Sepkoski [1982], p. 1502, Fig. 2; with permission from AAAS).

A few years later, Sepkoski offers the following theoretical definition:

‘A mass extinction is any substantial increase in the amount of extinction (i.e., lineage termination) suffered by more than one geographically wide-spread higher taxon during a relatively short interval of geologic time, resulting in an at least temporary decline in their standing diversity’. (Sepkoski [1986], p. 278)

As many — including Sepkoski himself — have noted, this definition is vague. However, Sepkoski’s definition is not as weak as it might appear. First, it highlights that it must be due to increased *extinction* or lineage termination, not other factors that can produce a drop or change in diversity profile, such as an evolutionary turnover in taxa. As palaeontologist Richard Bambach argues, Sepkoski’s definition rules out ‘the progressive turnover in dominant taxa that characterises the entire Devonian . . . [which] is not a mass extinction, even though many ‘geographically wide-spread taxa’ suffer a ‘decline in their standing diversity’ (Bambach [2006], p. 128). For many, however, such a qualitative definition is

unsatisfactory, and in the subsequent decade many palaeontologists searched for a *quantitative* definition of mass extinction that would make the scientific concept more precise.

A quantitative definition of a mass extinction involves two components: first, a unit by which the intensity of an extinction event is measured, and second, a cut-off value, above which an extinction event qualifies as a *mass* extinction. One obvious quantitative definition of a mass extinction is in terms of the raw number of extinctions, E , in a particular interval. A mass extinction, then, would be defined as any extinction event in the history of the Earth where the raw number of extinctions exceeds some threshold, x . One drawback of this definition is that it does not take into account the standing diversity at the start of the extinction event (Jablonski [1994], p. 12). This objection is significant because, as Phillips ([1860])'s and Raup and Sepkoski ([1982])'s paleodiversity curves make clear, the overall trend throughout the Phanerozoic seems to have been that biodiversity (as species richness) has been significantly increasing, mass extinctions notwithstanding.

An alternative way to quantitatively define mass extinctions tries to take the variation in standing diversity into account by using the *proportion* of taxa becoming extinct, E/D . Although a theoretically superior alternative, E/D introduces additional uncertainty because the standing global diversity, D , is itself imperfectly known. Alternative quantitative definitions try to take into account how quickly an extinction event is happening — a slow trickle of extinctions over a geologically extended period of time (even if cumulatively large) does not seem to be the same sort of beast as a large number of extinctions happening relatively rapidly. One such quantification is the extinction *rate* (E/t), but as Jablonsky ([1994]) explains, extinction peaks depend on the timescale used and make problematic assumptions about extinctions being 'randomly distributed throughout the time interval' (p.12; more in section 7). Hence, there are also several problems associated with this extinction-rate definition. Finally, one might use a *per-taxon* extinction rate ($E/D/t$). However, as Norman Gilinsky ([1991]) argues, although $E/D/t$ has the strongest theoretical appeal, it suffers from the greatest uncertainty, since all three quantities are difficult to infer from the imperfect fossil record (see section 4). In short, even apart from the question of how 'big' is big enough to count as a mass extinction, there is also no consensus on what quantitative definition should be used.

Another group of challenges for defining mass extinctions concerns distinguishing them from related concepts, such as background extinctions, mass depletions, and differentiating between biodiversity crises and ecological crises. Each of these will be discussed in turn.

Throughout geologic time, taxa go extinct all the time. As Raup ([1991a]) famously pointed out, if one considers all the extinctions that have ever happened, over 90% have happened at times *other than* a mass extinction. Thus, even if there were no mass extinctions, there would still be a normal 'background extinction' rate. In determining the severity of a mass extinction, one should subtract this background extinction rate from the

overall extinction rate to get the mass extinction rate, otherwise the severity of the mass extinction will be exaggerated (Stanley [2016]).

Another complication arises when one realises that the standing diversity at any point in time is the joint product of not just continuing diversity and extinction, but also *origination*. Origination rates describe how frequently new taxa come into existence. The Cambrian explosion, for example, was a period when origination rates were particularly high. It is important to note that both processes — extinctions and originations — are always happening to varying degrees. Thus, a dramatic drop in paleodiversity can be due either to elevated extinctions or to reduced originations. In their analyses of the ‘Big Five’ mass extinctions, Bambach and colleagues (Bambach, Knoll, & Wang [2004]; Bambach [2006]) propose the generic term ‘mass depletion’ and argue that only three of the Big Five qualify as ‘mass extinctions’ per se, leaving the other two as ‘mass depletions’:

‘When origination and extinction data are compared for . . . (the big five mass extinction events), only three (the end-Ordovician, end- Permian, and end-Cretaceous) appear to be unambiguous extinction-driven global events. The other two. . . (the Late Devonian and the end-Triassic) . . . are as much a product of attrition from reduced origination as they are of elevated extinction. . . . In this limited sense there are just three unambiguous mass extinction events’. (Bambach [2006], p. 131)

A dramatic drop in paleodiversity should only be counted as a mass extinction if it is driven primarily by extinctions; otherwise, if due to reduced originations, it should be called a ‘mass depletion’.

As palaeontologists have come to a better understanding of the nature of the various events traditionally referred to as ‘mass extinctions,’ there has been an increasing recognition that they form a very heterogeneous group. In addition to Bambach et al. 's distinguishing of mass extinction from other mass depletions due to reduced origination, one can also categorise the events by the differing nature of their consequences. The palaeontologist Grzegorz Racki, for example, has proposed distinguishing between *biodiversity* crises and *ecological* crises. He writes,

‘Major global events assigned to the mass extinctions are considered as: (1) biodiversity crises, determined primarily by significantly increased extinction rates, and (2) ecological crises, when the ecosystem consequences of the biospheric perturbation were disproportionately large when compared to the biodiversity loss alone’. (Racki [2021], p. 615)

The motivation here is the recognition that the ecological and taxonomic severity of an event can become decoupled. In a *biodiversity* crisis a large number of taxa go extinct in a geologically short period of time. In an *ecological* crisis, certain ecologically key taxa go extinct, profoundly altering the ecosystem in its wake.

Recognizing that the percentage of genera lost (taxonomic severity) does not always track the ecological impact of an event (ecological severity), can lead to differing ways of ranking the severity of the ‘Big Five’ events. Stanley explains,

‘The ecological consequences of mass extinctions have not always reflected their magnitudes. . . . [T]he Ashgillian crisis [late Ordovician], which ranks second numerically [in terms of percentage of genera lost] . . . had a relatively minor ecological impact . . . only the trilobites failed to recover. . . . On the other hand, . . . [t]he Famennian event [second of two Late Devonian crises], which was very small in overall percentage of genera lost, nonetheless entailed the virtual disappearance of placoderm fishes, which previously had been voracious top predators. . . . Food webs in the ocean must have been profoundly altered by this event’. (Stanley [2016], p. E6333)

Racki proposes a three part classification scheme for the events traditionally labelled mass extinctions: 1. Biodiversity crises, 2. Ecological crises, 3. Mass extinctions *sensu stricto*, which were both biodiversity *and* ecological crises. Table 1 summarises how the various crisis events in geologic history rank by taxonomic severity, ecological severity, and how they should be classified. When events are ranked by taxonomic severity, the estimates of what percentage of genera were lost in each mass extinction event vary from author to author, depending on what methods they use to correct for the biases in the fossil record; these issues will be discussed more in section 4. Table 1 only cites one recent source for percentage of genera lost, Stanley ([2016]) — although the numerical values change, the ranking of events by taxonomic severity typically does not.

Events Ranked by Taxonomic Severity (Stanley 2016)	Classification	Events Ranked by Ecological Severity (McGhee et al. 2004)	Classification
end-Permian (62% Genera Lost)	Mass Extinction (<i>sensu stricto</i>)	end-Permian	Mass Extinction (<i>sensu stricto</i>)
end-Ordovician (42.5% Genera Lost)	Major Biodiversity Crisis	end-Cretaceous	Mass Extinction (<i>sensu stricto</i>)
end-Cretaceous (39% Genera Lost)	Mass Extinction (<i>sensu stricto</i>)	end-Triassic	Major Ecological Crisis
end-Devonian (19% Genera Lost)	Major Ecological Crisis	end-Devonian	Major Ecological Crisis

Table 1: Ranking and classification of mass extinction events by taxonomic and ecological severity. Note, for example, how the end-Ordovician is the second worst crisis (beating out the end-Cretaceous) when measured by taxonomic severity, but does not even rank in the top four when measured by ecological severity. Redrawn after Racki ([2021], Table 1, p. 604).

As table 1 indicates, depending on whether one uses a conception of mass extinction, biodiversity crisis, or ecological crisis that is based on taxonomic severity or a conception that is based on ecological severity, a different verdict will be reached both about *which* events count as well as *how severe* each of these events were. For example, the end-Ordovician event is second only to the end-Permian when measured by taxonomic severity, but doesn't rank at all according to a measure of ecological severity. Likewise, the end-Triassic does not count as a crisis at all when taxonomic severity is used as the measure of crisis.

Different ways of defining 'mass extinction' — and whether one distinguishes them from 'mass depletions' or 'major ecological crises', etc. — will lead to different conclusions about how many mass extinctions there have been. Table 2 lists a sample of the various number of mass extinctions since the Cambrian that have been proposed by different researchers, depending on how data are processed and 'mass extinction' is defined and measured.

Proposed by	Number of Mass Extinctions
Phillips ([1860])	2
Newell ([1963])	8 (including the current one)
Raup & Sepkoski ([1982])	4-5 (4 are statistically significant)
Sepkoski ([1993])	5
Bambach ([2006])	3 (consensus) or 18 (on Sepkoski definition)
Racki ([2021])	2

Table 2: Far from there being a consensus on the Big Five, different researchers have counted different numbers of mass extinctions, depending on which criteria and definitions they use.

There are three broad conclusions to draw from this section: First, what we have traditionally called ‘mass extinctions’ are in fact a very heterogeneous groups of events; second, there is no consensus on how to rigorously define a mass extinction; and third, before asking whether we are in a sixth mass extinction, it is not even clear there have been exactly five mass extinctions preceding. As we will see, in addition to the conceptual and definitional problems raised in this section, there are also significant problems arising from uncertainties in the paleodiversity data.

4. Challenges from Paleodiversity Data

The previous sections discussed conceptual challenges in defining ‘mass extinction’ and distinguishing it from other concepts, such as background extinctions and mass depletions. This section focuses on methodological and datic problems in palaeontology and on how uncertainties in paleodiversity data contribute to challenges in identifying and defining mass extinctions. The difficulties we discuss are mostly due to the incomplete fossil record, from which we extract all information about past extinctions. Darwin ([1859]), following Lyell ([1837]), uses the following metaphor to illustrate the scarcity of fossil data: the geologic record is like a book of which we only possess a few pages and of the few pages only a few lines with incomplete sentences, and of those sentence fragments only incomplete words (p. 344). It is no easy task for paleobiologists to reconstruct what was written in the book.¹⁴ In this section, we follow a taxonomy of ‘filters’ that bias paleodiversity data: biological and ecological filters, geologic filters, and sampling or anthropogenic filters. We further identify a fourth source of bias, temporal biases, and look into datic challenges that come with measuring background extinctions.

4.1 Biological, Geological, and Sampling Filters

Biological filters are biases that result from differential preservation of certain types of organisms. These biases are affected by species’ prevalence, abundance, and location (Smith [2007]). Regarding prevalence, we can expect more fossils from taxa that are abundant and widespread, than from taxa that are scarce and local (Jablonski [1994]). There are also ecological biases arising from the environment in which the organisms lived. For example, when it comes to marine species, the marine environment makes it easier to infer species’ abundance because of the way marine species fossilise.

¹⁴ For a philosophical discussion of how ‘traces’ are used to reconstruct the past, see Currie ([2018], [2019]).

Likewise, taphonomic filters affect which organisms get preserved (Shipman [1981]). Taphonomy is the study of burial and fossilisation, and explains why fossils of soft-bodied organisms are so rare. Preservation depends on species' morphology and environment. For example, species with shells that live in a sedimentary marine environment are more likely to be preserved. Some marine depositional environments have less erosion, weaker currents, etc. and are thus ideal for preserving a representative sample. However, in continental shelves and lacustrine environments, from which more fossils are excavated, erosion predominates, such that deposition is no longer proportional to preservation. When possible, palaeontologists focus on depositional environments more conducive to representative sampling. When it comes to terrestrial species, analysing abundance is harder; what gets preserved is a poor indication of abundance.

The rock record also strongly biases the available data. Accounting for this geologic filter requires figuring out the influence of sediment deposition, preservation, and erosion. The amount of sedimentary rock deposited and preserved affects the number of fossils found — the less rock deposited and preserved, the fewer places to find fossils, and vice versa. However, this relationship is not so simple. The problems include not only the conditions under which they are formed, but also patterns of uplift and exposure. Palaeontologists sometimes 'subtract' these sorts of biases from the rock record, but how to do this properly is controversial (Bokulich [2018]).

The incompleteness of the fossil record makes it difficult to know when the first or last organism of a species appears. In particular, the Signor-Lipps effect involves a 'stretching out' of last appearance data over time, explaining how extinctions can appear to be much more gradual than they actually were (Signor and Lipps [1982]). The Signor-Lipps effect thus adds uncertainty to calculations of background extinction rates and mass extinction rates that needs to be accounted for. Palaeontologists adopt different methods to deal with the Signor-Lipps effect and report the reliability of the data (e.g., see Wang & Marshall [2016]).

The fossil record may also trick us into thinking a species is extinct, when there could still be living species members we have not encountered. When such species are rediscovered, they are called 'Lazarus taxa' (Jablonski [1986]). Additionally, there are 'Elvis taxa', which occur when a taxon is misidentified as reemerging in the fossil record, but is merely a similar taxon, perhaps resulting from convergent evolution, meaning the original taxon is, in fact, still extinct (Erwin and Droser [1993]). These problems with obtaining accurate paleodiversity data are important to recognize when trying to determine whether an episode counts as a mass extinction.

Sampling filters are challenges arising from limitations in how we collect and organise fossil data. For instance, fossil preparators have to 'interpret' the raw fossil material, and different preparation choices can affect whether new species are identified (C. Wylie [2021]). Additionally, funding availability dictates which sites are excavated and to what extent. Taxonomic uncertainty is also pervasive. Palaeontologists collect and

describe data at the species level but usually analyse data at the genus level, because species-level data tend to be short-lived, highly volatile, and contain substantial ‘noise’. One source of noise is a lack of agreement about how to characterise a species, which can lead to conflicting taxonomies or redundant names (synonymity). These problems can be addressed by analysing data at the genus level, since all species of a genus are included regardless of particular taxonomic practices. We will further discuss taxonomic uncertainty in section 6.

Another sampling filter that plays a role in determining mass extinctions is taxonomic ‘splitting’ versus ‘lumping’. Splitters adopt more stringent criteria for two specimens to belong to the same species, while lumpers adopt looser criteria for determining membership in a species, resulting in fewer species counted. Splitting produces greater diversity than lumping, which influences the paleodiversity curve obtained. As Raup ([1991b]) explains, ‘errors in taxonomic judgement could cause bias in the same or opposite direction: oversplitting of genera makes survivorship curves steeper, and lumping makes them less steep. Unfortunately, these biases are not rigorously measurable’ (p. 43).

Sampling filters also include anthropogenic biases. What is found and identified depends on scientists’ interests and site accessibility. Traditionally, most scientists have been collecting fossils primarily in European and North American countries, and their colonies. Only recently have many fossils from China come to be included in the Western scientific community’s ‘fossil record’. As researchers have shown, the legacy of colonialism has also biased the fossil record (Raja et. al. [2021]).

4.2 Temporal Biases

How precisely paleodiversity fluctuations can be analysed over time intervals is another important datic issue. Not all extinction events occur within commensurable timespans, yet data must be analysed consistently over equal time intervals. Palaeontologists solve this problem by standardising their analysis with fixed “portions” of geologic time known as ‘time bins’, which serve the purpose of snapshotting the naturally varying fauna into equal intervals for comparison. The question remains how coarse or fine-grained the resolution of time bins should be to get reliable data; longer time bins make it harder to study processes that happen at smaller scales. Sometimes there can be gaps between one stratigraphic layer and another, which make estimates of extinction magnitude and dating difficult.

In synoptic studies, e.g., Sepkoski ([1986]) or Alroy ([2008]), time bins are coarse (~10 million years) or sometimes uneven. However, as the use of databases increases, scientists can use finer time bins. For example, Fan. et al. ([2020]) were able to analyse data at a resolution of 26 ± 14.9 thousand years. As Barnosky et al. ([2011]) note, ‘the maximum E/MSY [extinction per million species-years] and its variance increase as

measurement intervals become shorter' (p. 53). In general, then, when extrapolating rates of extinction, one has to be aware of this dynamic so as to interpret the results correctly.

Even if various biasing filters highly complicate examining paleodata in relation to mass extinctions, not all is lost. By understanding how these filters work, we can move towards finding solutions for dealing with these biases (Smith [2007]; Smith & McGowen [2007]; Bokulich [2018]). For example, Smith ([2007]) summarises four different approaches used to obtain higher resolution data of the fossil record: gap analysis, ghost lineage analysis, rate modelling of originations and extinctions, and rock record analysis. All of these are ways to reduce the impact that filters have on paleodata. These solutions will continue to develop as the field expands and more information is obtained.

4.3 Measuring Background Extinctions

The filters and biases discussed thus far apply to measuring mass extinction rates, but they also apply to measuring rates of background extinction to which mass extinction rates must be compared. In palaeontology, background extinction rates are typically calculated either by counting the number of extinction events in the period of time preceding a mass extinction (e.g., Stanley [2016]) or by calculating taxon survival durations. Above and beyond the issues caused by filters and biases mentioned above, an additional problem with the latter method is that the durations of various genera vary widely, making any average uninformative (Jablonski [1994], p. 13).

Indeed, Raup has argued that there is a continuum of extinction intensities, meaning 'the simple binary classification of extinction is not warranted' (Raup [1986], p. 1529). Of course a difference of degree does not mean there is no difference at all. Raup draws a parallel to other phenomena in the geosciences, such as earthquakes and storms, that can similarly have a continuum of intensities. The palaeontologist describing extinctions can either be like the seismologist, using a continuous intensity scale such as the Richter scale, or be like the meteorologist and draw an arbitrary boundary above which one passes from one kind to another, such as the meteorological threshold of a hurricane with windspeed of greater than 32.7 m/s (Raup [1991b], p. 46).

5. Challenges from Biodiversity Data

We have illustrated the complexity of estimating the severity of *past* mass extinction events; this section analyzes and problematizes how *current* 'biodiversity loss' is conceptualised and measured. Estimating with a high degree of certainty the status of present biodiversity loss poses significant difficulties that sometimes are not properly acknowledged in contemporary literature. We divide this section into conceptual challenges for assessing the present status of biodiversity and methodological and datic challenges. However, the issues are interrelated: conceptual issues determine the methodologies for measuring biodiversity and the kind of data attained.

5.1 Conceptual challenges

The current biodiversity crisis is typically conceptualised as a taxonomic and ecological catastrophe. But what scientists mean by ‘biodiversity’ is far from settled, as philosophers of science have long pointed out (see Takacs [1997], Sarkar [2005], Maclaurin and Sterelny [2008], Santana [2014], [2018], to name but a few). As Carlos Santana ([2014]) has highlighted, ‘biodiversity’ conveys a plurality of meanings, which vary from species richness and relative abundance to populations’ genetic composition. For example, Darwin ([1859]) thought that the ‘diversity of life’ simply amounted to the total number of species or to phenotypic variability. With the development of molecular biology as a new tool for taxonomy, the idea that diversity is also encapsulated in evolutionary history and species’ function was introduced. Today, to offer guidance on biodiversity monitoring and assessment, the Group on Earth Observations Biodiversity Observation Network, put forward by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, has developed a list of ‘Essential Biodiversity Variables’, understood as necessary and sufficient parameters to be included when estimating biological diversity. The list comprises six classes:

- Genetic Composition;
- Species Populations;
- Species Traits;
- Community Composition;
- Ecosystem Structure;
- Ecosystem Function.

Each of these parameters captures a dimension of what is normally meant by ‘biodiversity’, a complex concept comprising genetic, taxonomic, and ecological aspects (Pereira et al. [2013]).¹⁵

Consequently, no univocal metrics have been developed to quantify biodiversity as a whole and biodiversity indices abound (see Daly et al. [2018]). Nonetheless, ecologists and conservation biologists adopt a pragmatic approach to measuring biodiversity and use

¹⁵ Philosophers of ecology have supported different views about which of the above variables, if any, best captures what is normally meant by ‘biodiversity’ in conservation biology, and what ought to be measured and preserved accordingly. Sahotra Sarkar ([2005]), for example, has defended the view that biodiversity should be understood as all and only the aspects of diversity that are being prioritised by conservation biology. He calls these aspects ‘true surrogate’ and he lists, for example, species richness, traits, and ecosystems. Christopher Lean and James Maclaurin ([2016]) have instead defended the view that phylogenetic diversity is the best parameter to capture biodiversity. Phylogenetic diversity is operationalized by constructing and measuring cladograms. A cladogram is a phylogenetic diagram representing ancestry relationships among populations and the time since evolutionary divergence. Other philosophers have adopted the radical position that, since there seems to be no unique dimension to biodiversity, the word should be eliminated from the conservation literature (Santana [2014]). Philosophical literature on the topic abounds and a deeper analysis is beyond the scope of this paper. Two of the most recent volumes devoted to the topic are Casetta et al. ([2019]) and Garson, Plutynski, and Sarkar ([2017]).

species richness (taxonomic diversity) and evenness (how balanced or unbalanced populations are in a specific ecosystem). Treating biodiversity mono-dimensionally is controversial because it assumes that species richness and evenness are proxies for overall biodiversity, such that a decline in these parameters covaries with overall biodiversity decline. Only empirical research can prove this assumption; the obstacles in accurately assessing taxonomical decline are discussed below.

Another conceptual disclaimer before we turn to the methodological and datic issues in measuring today's taxonomic decline: not only is 'biodiversity' a tricky term, 'crisis' is too. The difficulty lies in the absence of a sharp distinction between biodiversity *loss* and biodiversity *alterations* (Pereira et al. [2012]). Biodiversity loss refers to extinction of entire species, populations, or gene pools, whereas alterations include non-severe decline in gene pool, species abundance, and community structure. Alterations are *business as usual* and, even if they might cause problems for ecosystem services, are not irreversible or drastic like biodiversity losses. The distinction here is subtle, but correctly identifying the current situation of biodiversity loss as crisis or alteration will offer different justificatory strength to the claim that we are living in a mass extinction.

5.2 Methodological and datic challenges

If we assume that a biodiversity crisis would be measured by taxonomic loss, then we must measure how bad taxonomic loss is today. But just like measuring paleodiversity, measuring today's taxonomic loss is difficult. Complexities arise on several fronts, for instance in estimating how many species there are and how many extinctions have been occurring in terms of rate and magnitude.

First, the projected magnitude of extinction and current extinction rate hinges on a reasonable extant species' count. Estimates vary from 2 million to 100 million species globally (Mora et al. [2011]; Erwin [1982]) with a consensus around 8.7 million (of which only 1.3 million have been named). Approximately 86% of all species on land and 91% of those in the seas have yet to be discovered, described, and catalogued (Mora et al. [2011], p. 2). The uncertainty surrounding these estimates originates from conceptual and empirical factors that might ultimately lead to scepticism about whether an accurate global inventory of species is attainable. We turn next to these sources of uncertainty.

Classification criteria pose the most straightforward issue when assessing how many species there are. There is no unique criterion for species membership: taxonomists, depending on their field, employ 26 species concepts (Wilkins [2009]) that lead to different inventories. Even if biologists adopt a rather flexible, pluralistic attitude, the proliferation of species concepts is problematic in extinction studies. As Agapow et al. ([2004]) have pointed out, classifying species using a phylogenetic species concept (PSC) results in a proliferation of the number of species, if compared to the adoption of non-PSC types, like the biological or the phenotypic species concepts. Agapow et al. conclude that 'the increasing use of the PSC in taxonomy could thus lead to an apparent increase in extant

species numbers, producing “new” group’ (Agapow et al. [2004], p. 164), which would result in a drop of the rate and magnitude of current extinction.

Additionally, other sources of uncertainty preclude a global species quantification. We only have ‘indirect estimates [which] rely on assumptions that have proven highly controversial’ (Mora et al. [2011], p. 1). Some estimates of total species richness, for example, result from extrapolating from small samples using the species-area relationship (Erwin [1983]; Grassle & Maciolek [1992]); or extrapolating from well known taxonomic groups by applying the body-size frequency distribution curve (May [1988]). These inferences assume a scaling up or scaling down function with questionable empirical justification (see Mora et al. [2011] for a detailed discussion). Moreover, these estimates are biased toward best-known taxa and toward specific areas.

Second, documenting current extinctions is no easy task. The International Union of Conservation of Nature (IUCN)’s compilation of extinct and threatened species constitutes the best relevant, publicly-available database, but it is far from precise and unbiased. Firstly, it only reports the extinction status of a fraction (around 3%) of all named species. Moreover, the IUCN estimates are recognized to be highly biased towards groups that receive more attention — charismatic or rare species in particular — localised in strategic areas, mostly North America (Clark & May [2002] provide a list of biases in conservation research). Secondly, cases of ‘false extinctions’, when a species considered extinct is detected, are frequent. Other cases of presumed extinction can be explained by the rarity of a species rather than by a real die-off, and rare species are more likely to be declared extinct. In general, absence of sightings is not definitive evidence that a species is extinct. If for a species to be extinct all members must have died out, it might be impossible to provide a decisive number of how many species are gone.

In the past, extrapolation methods were used to calculate the current extinction rate. Wilson ([1992]) estimated, for example, that the rate of extinction might be as high as 27,000 species/year (74 species/day). These estimates are still being used even though they ‘were at best based on educated guesses about the number of currently existing species’ (Sepkoski [2020], p. 246). Today, scientists use advanced analytical techniques to gauge global species’ richness and the current extinction rate. Ceballos et al. ([2015]) extrapolated a current extinction rate 100 to 10,000 times higher than the background extinction rate obtained from fossil evidence. Calculations like these have faced the accusation of being purely speculative predictions conducted using theoretical tools, instead of being grounded in observational data. The theoretical tool is the species-area curve, which predicts how species richness proportionally increases as a function of the sample size. Calculations of extinction rate reverse the species area relationship backwards and predict how many species are likely to get extinct based on how much habitat will be lost. The most frequent criticism to the estimates is that extrapolation performed using the species-area relationship tends to overestimate (He and Hubbel [2013]) or underestimate (Rybacki and Hanski [2013]) the number of lost species.

Lastly, even if accurate measures of species extinction rate and magnitude were available, justification for an ongoing mass extinction also needs to account for speciation rate, which could compensate for extinction events. Ecological theory predicts that habitat loss will be the main driver of speciation rate decline because: ‘species with larger geographical ranges speciate faster; and loss of area drives up extinction rates, thus reducing the number of species available for speciation’ (Rosenzweig [2001], p. 5404). However, documenting the current origination rate is challenging: for instance, identifying young taxa would require consensus on what it means for a new species to diverge and would require considerable empirical effort. For this reason, the current speciation rate remains unknown (Otto [2018]).

To sum up, this section develops some conceptual obstacles to defining and operationalizing biodiversity *qua* taxonomic decline. These obstacles only add to the methodological and datic challenges of counting total species numbers and result in uncertain estimates of current background extinction rates and magnitudes.

6. Incommensurabilities of Past and Current Extinctions

We have pointed out difficulties with defining and assessing past mass extinctions in terms of both magnitude and rates, as well as some issues with estimating the current biodiversity crisis. To justify the claim that current biodiversity loss is analogous to that of past mass extinctions, one must be able to compare the current status of the putative crisis to some known past state of non-crisis or an analogous past state of crisis. This section introduces another category of methodological and datic problems that emerge in the comparison of data about the present loss of species and data about past fluctuations in biodiversity. We show that the nature of the data expressing current biodiversity measurements and data about extinctions is such that the two measures are *incommensurable*, meaning literally that they lack a common measure. To be more precise, ‘incommensurability’ here refers to the absence of a common standard according to which the status of current loss and the status of past extinction events can be properly compared. The lack of a common standard between the two values is exemplified both at the datic and at the conceptual levels: not only do past datasets differ significantly from datasets about the present status of biodiversity, as we will better elaborate here, but the definitional choices made about what counts as both ‘mass extinction’ and ‘biodiversity’ make them hard to compare.¹⁶ In comparing the current status of biodiversity and past

¹⁶ The word ‘incommensurability’ has entered philosophy thanks to Thomas Kuhn and Paul Feyerabend, who adopted it to express the relationship of incompatibility between two distinct scientific paradigms. *Incommensurable* can apply to the aims, the guiding questions, and the methods of historically competing paradigms. Incommensurability has since been redefined to mean various possible relationships at the theoretical, methodological, or datic level of analysis (see, for example, Sankey et al. [2001]). By ‘incommensurability,’ we simply mean a lack of common conceptual and metric standards that biodiversity and paleodiversity research and data are held to. Bocchi [MS] has more radically suggested that biodiversity

taxa fluctuations (paleodiversity), the type of information available is not about the same target or *measurand* (i.e., object of measurement). Weighing biodiversity against paleodiversity is like comparing apples with oranges. Similar considerations have been noticed by Raup (as discussed in Sepkoski [2020], p. 270-1). More recently, Barnosky and colleagues ([2011]) have been concerned about data incommensurability and classify the comparison problems into geographic, taxa availability, taxonomic, extinction assessment, and time. We will likewise briefly analyse these sources of paleodata and biodiversity data incommensurabilities.

Representativeness of paleodata and current biodiversity data is central to making inferences about the all-encompassing character of extinctions now and in the past. But we do not have samples that are geographically and taxonomically representative and analogous for paleodiversity and biodiversity. Paleodiversity and biodiversity are extrapolations from unequal samples. As discussed in section 4, marine environments represent most of the past ecological information, as shelled marine species fossilise easily. In synoptic studies of mass extinctions meant to generate diversity curves (like Sepkoski [1982], [2002] and Alroy [2008]), these taxa tend to be over-represented. On the contrary, upland-environment and tropical species are under-represented (Barnosky et al. [2011], p. 52) and do not take central stage in paleodiversity curves, but are of high importance for comparative studies since most contemporary species loss is allegedly occurring in the tropics, which house most of Earth's current species diversity. Assuming that Sepkoski's or Alroy's paleo-curves represent *global* paleodiversity swings is unjustified.

Current extinction and risk assessments, on the contrary, are geographically biased toward North America and European terrestrial species, as well as species from oceanic islands. From this geographically incomplete survey, the IUCN has assessed around 134,400 species for extinction risk most of which are terrestrial, charismatic species, whereas most aquatic species are labelled 'data deficient'. Accordingly, the IUCN estimate that 28% of *global* species are threatened with extinction is a projection from terrestrial ecosystems. Both geographical factors and species representativeness hence generate a practical problem for comparing present species to past species fluctuations.

As mentioned in section 4, the classification of fossils carries a certain level of uncertainty due to taxonomic theoretical commitments and fossil preparation. To overcome uncertainty in taxonomy, Forey et al. ([2004]) suggest that analysis of fossils should not be conducted at a more fine-grained level than the genus or family level. Accordingly, Sepkoski's curves of marine invertebrate fluctuations ([1982], [2002]) and Alroy's Phanerozoic diversity curve ([2008]), even if based on species data, perform their analysis using families and genera.¹⁷ Unfortunately, there is no consensus on how to predict species

and paleodiversity are incommensurable at a theoretical level. We don't need to endorse this stronger sense of incommensurability for our main argument.

¹⁷ Some studies are conducted on shorter time intervals and at higher taxonomic resolution: Fan et al. ([2020]) is an example investigating fluctuations of marine invertebrates at the species and genus level from the Cambrian to the Early Triassic. These rare types of studies require sophisticated computations. Nonetheless,

fluctuations from curves at a higher classificatory level (Lane and Benton [2003]). How taxonomically fine-grained the paleodiversity curves are poses a serious issue for comparing them to contemporary estimates of *species* loss. The current catastrophism about the ongoing biodiversity crisis was triggered by acknowledging high terrestrial species loss (800 extinctions of species documented in the past 400 years, of which 100 in the twentieth century and 27 between 1984-2004; see Pereira [2012]). However, only a handful of genera extinction have been recorded in the last 500 years.¹⁸

Without additional qualification on how paleodiversity curves express fluctuations in species' extinction, comparing current species die-off to past extinction events is not feasible, as the two datasets are based on incommensurable classificatory levels.

The temporal resolution at which fossils are analysed against information about extant species is another source of incommensurability. Past mass extinction events have been measured over disparate timescales, which impacts the calculated rate of extinction (see section 7). On the contrary, the putative current crisis is still ongoing and the temporal resolution at which it should be measured is still underdetermined.

We conclude that paleodata and data on current biodiversity are incommensurable. The information we have about paleodiversity trends, namely that they mostly represent marine genera and geographically biased samples, is hardly comparable with what we know — or should know — about the present status of biodiversity. In the next section, we investigate ways in which these data incommensurabilities can be attenuated.

7. Making the Comparisons More Compatible

As we have shown, data on past and present extinctions are incommensurable, making the question, 'Are we in a sixth mass extinction?' particularly difficult to answer. Nevertheless, comparisons between past and present data are not futile, depending on the research question asked. Such comparisons may be useful for answering questions about patterns of extinction over geologic time, even if we cannot determine whether we are in a sixth mass extinction. Moreover, various data gathering or processing strategies can be used to partially mitigate the incommensurability associated with these data and methodological challenges. Any such strategy will involve making explicit, somewhat arbitrary decisions,

Fan et al. describe past fluctuation of marine invertebrates, which are categorised as data deficient by the IUCN, making the data incommensurable.

¹⁸ In the IUCN database, for example, the most recent genus extinction is that of *Psephurus*, a freshwater fish taxon, which is documented between 2005-2010 (Zhang et al. [2020]). The most recent marine genera extinction documented by the IUCN dates back to 1841 (genus *Cylindrapsis*). We were unable to find any marine arthropod or bivalve genera extinction recorded by the IUCN in the past 500 years> these organisms would be the more appropriate for comparison with the fossil record. We are grateful to Thomas Hegna for helpful feedback on genera extinctions.

for example concerning which metric to use to measure extinctions (e.g., rates or magnitudes) or which taxa on which to focus data collection efforts.

Let us give a few examples of possible ways to mitigate the various sources of incommensurability. First, data may be aggregated on present extinctions in ways that are more similar to the data about past extinctions. Data on current extinctions are usually collected at the species level, whereas we have good reason to use genera-level data from the fossil record. To make past and present extinction data more commensurable, we should gather genera-level data for contemporary extinctions or develop means of estimating species-level extinctions from the fossil record (as is done in Fan et al., [2020], for example). Contemporary biodiversity data could also use the morphological species concept, rather than the biological species concept (see Barnosky [2011] for discussion). Additionally, paleodata that are used to study extinctions are centred on the more complete fossil record of marine taxa. However, data on contemporary extinctions are largely terrestrial, and biased heavily toward more familiar taxa (e.g., mammals). An exception is mollusks, for which both contemporary and paleodata are available; efforts have been made to compare past and present mollusk biodiversity measures (e.g., Régnier et al. [2010], Cowie et al. [2022]), and these may serve as a template for more commensurable studies. Systematically collecting present marine data, and changes in sampling methods, would help address the incommensurability between present and paleodata. The incomplete fossil record limits the available paleodata, but we can artificially replicate this incompleteness in our present biodiversity data to make reasonable comparisons. Doing so requires collecting more data and in different ways, or adjusting the data by, for example, using rarefaction or subsampling methods (Raup [1975]; Alroy [2010]; for discussion, see Bokulich [2018]).

Second, data processing techniques can increase the compatibility of paleodata and contemporary extinction data. Paleodata need to be processed to correct for the incompleteness of the fossil record (e.g., Bokulich [2018]). Data on contemporary extinctions also need to be corrected. For example, abundance data collected locally need to be multiplied to obtain global estimates. Of course, this is more difficult than just multiplying the local measurement over a larger geographic region, because different ecosystems and species ranges have to be considered. Researchers need to correct for the *location* (the tropics have more biodiversity than higher latitudes) and for which taxa have been measured (some families are more or less diverse). Additionally, ecosystems such as rainforests that are unusual throughout the history of Earth need to be accounted for (Sepkoski [2020], p. 275, citing correspondence between Raup and Wilson).

There is a further incommensurability arising from the fact that paleodata and contemporary data are analysed at different temporal scales. We have the ability to monitor the present at a higher temporal resolution than we can measure the past, which is constrained by sedimentation rates. Durations over which the magnitudes of the ‘Big Five’ mass extinctions were measured in Sepkoski ([2002]), alongside more recent estimates, are

reproduced in table 3. These durations are *vastly* different from the durations over which we collect contemporary extinction data, which are usually annually resolved.

Extinction event	Duration (million years) from Sepkoski 2002	Rate (genera per year) - using Sepkoski 2002 durations	Duration (years) from recent estimates	Rate (genera per year) - using recent estimates of duration
Ordovician-Silurian	5.3	6.81132×10^{-5}	5.3 ¹⁹	6.81132×10^{-5}
Devonian	47.8	1.01674×10^{-5}	24.48 ²⁰	1.98529×10^{-5}
Permian-Triassic	9.4	4.91489×10^{-5}	0.06 ²¹	0.0077
Triassic-Jurassic	16.9	3.00592×10^{-5}	0.292 ²²	0.00174
Cretaceous-Tertiary	5.1	3.23529×10^{-5}	0.032 ²³	0.005156

Table 3: A comparison between durations and rates for the ‘Big Five’ mass extinctions using synoptic data from Sepkoski ([2002]), as well as more recent estimates of durations (magnitudes remain largely the same). These durations and rates are not definitive, but illustrate that rates are inversely correlated with durations.

For the sake of demonstration, say that a consensus has been reached according to which we should measure extinctions by extinction rates (e.g., genera per year). As soon as a rate is involved, temporal resolution of the data becomes important. Rates of processes with ‘ups and downs’, like changes in biodiversity, are not independent of the durations over which those rates are measured. There is a systematic relationship between rates and durations for such processes: longer durations produce lower rates, and vice versa (this

¹⁹ Deng et al. ([2021]); the Late Ordovician Mass Extinction (LOME) was actually two extinction pulses between 448.7 and 443.4 mya.

²⁰ Fan et al. ([2020]); the late Devonian mass extinction is 392.72-368.24 mya.

²¹ Burgess et al. ([2014]) estimate 60±48 thousand years, consistent with Fan et al. ([2020]).

²² Lindström et al. ([2017]) estimate 201.566 to 201.274 mya.

²³ Renne et al. ([2013]) estimate that the impact and mass extinction occurred within at most 32,000 years of each other (closer to 20,000 years for some low-diversity fauna). The actual extinction episode most likely took far less time than this.

relationship can be seen in table 3). To compare rates of extinction in the past with those in the present, we need to correct the data for durations. A process called ‘temporal scaling’ adjusts rates measured over a certain duration to what they would be if they were measured over other durations.²⁴ Temporal scaling should be used to compare past and present extinction rates, to account for the different durations over which paleodata and contemporary data are gathered (for an early attempt at applying temporal scaling to mass extinctions, see Foote [1994]).

Again, assume for the sake of argument that we all agree that rates are the best way to measure extinctions (as should be clear from sections 3 and 4, this is a big assumption!). We can then apply temporal scaling to the data in table 3. If we extrapolate from the extinction rates of the ‘Big Five’, then the equivalent rate of extinction measured at an annual resolution is ~ 1.77 genera/year (using Sepkoski’s durations) or ~ 2.11 genera/year (using recent duration estimates)²⁵ – *much* higher than the rates in table 3 – and much higher than we expect based on contemporary data. While there have been a handful of genera-level extinctions in the past 500 years, it does not seem likely that current genera extinction rates are anywhere between the ~ 1.77 - ~ 2.11 genera/year of the Big Five mass extinctions.²⁶ Although we would need contemporary genus-level data to make this comparison explicitly, it is unlikely that contemporary extinctions are occurring at anywhere near this rate.

In sum, efforts can be taken to make the data about past and present extinctions more compatible for particular uses. Some steps in that direction would include adjusting our data collection methods on extant taxa to more closely mirror data from the fossil record, as well as using data processing techniques that allow for better comparison between the past and present. Only once we take these steps to reduce incommensurability between past and present diversity data, including making some conceptual decisions regarding which definition of a mass extinction to operationalize, can we provide a more rigorous answer to the question of whether we are in a sixth mass extinction. Until and unless these steps are taken, we prefer to remain agnostic about this question, and we certainly advise against taking any confidently affirmative stance.²⁷ More importantly, however, it would be a mistake to suppose that we must reach the level of a mass extinction event before action is required.

²⁴ Temporal scaling applies to rates of sedimentation (Sadler [1981], [1993]), morphological evolution (Gingerich [1983], [1984], [1985], [1993], [2001]), cultural evolution (Perreault [2012]), and climate change (Kemp et al. [2015]; Gingerich [2019]).

²⁵ This extrapolation is performed by plotting the past rates on a log-log plot of rates (y-axis) by durations (x-axis) and assuming a linear relationship, paralleling the established procedure for measuring fractal dimension.

²⁶ We are aware that a more precise estimate would require calculating the uncertainty derived from lack of data about marine genera in the IUCN records (see Régnier et al. [2009] for a critical assessment of the IUCN Red List of Threatened Species).

²⁷ Note that, unlike Santana ([2019])’s argument that we are not in the Anthropocene, our argument does not simply depend on the position of the ‘future palaeontologist.’

Despite our inability to definitively determine whether we are in a mass extinction event, it might sometimes still be useful to compare past and present biodiversity data, for example when making predictions about the timing or patterns of ecological recovery from more localised extinction events. A comparison with the past may also be useful for enabling us to recognize that current climatic changes *could* lead to a mass extinction in the near future. As we will suggest in the conclusion, rather than continuing to pursue the sixth mass extinction framing, the time has come to start asking broader questions about how Earth's deep history can inform our future.

8. Conclusion: Rethinking the Value of Asking

Although many have heard of the Sixth Mass Extinction idea, few outside of a small community of palaeontologists and conservation biologists are aware of the assumptions and evidence on which such a claim is based. In this paper we have given the first extended critical analysis of the Sixth Mass Extinction idea, bridging the philosophical and scientific literatures. More broadly, we have provided the first comprehensive historical and philosophical analysis of the concept of a 'mass extinction', tracing its history and pointing out that it is not, nor has it ever been, a fully unified concept—there are a plurality of ways that mass extinctions are defined and measured. We further showed that, somewhat surprisingly, the Sixth Mass Extinction idea emerged hand in hand with mass extinction studies.

In addition, we reviewed the ways in which past and present biodiversity data are currently incommensurable. Framing the contemporary biodiversity crisis as a mass extinction event blurs the important differences between how palaeontologists and conservation biologists both conceptualise and measure biodiversity. We outlined several ways in which this incommensurability could be mitigated going forward. Finally, we showed that if one defines extinction in terms of extinction rates (number of genera lost per year), and temporally scales the paleodiversity and biodiversity data to be more commensurable, the current biodiversity crisis — as devastating and urgent as it is — is nowhere near the extinction rates of the traditional 'Big Five' mass extinctions. The big five lost 1-2 genera *every year*, while the current biodiversity crisis has recorded *not even a single* genus being lost in the last 500 years. Although we make no definitive claim on the broader question, on this measure and with the currently available data at least, the evidence suggests we are *not* in a sixth mass extinction.

One might object, however, that what was intended by the Sixth Mass Extinction rhetoric is that we are *approaching* or *nearing* a sixth mass extinction, not that we are already in one. While this is a distinct question from the one we address here, it is fraught with many of the same conceptual, methodological, and datic difficulties that we have highlighted throughout this paper. The main ground for the present concern that we are approaching a sixth mass extinction is our current anthropogenic climate crisis, driven by

massive carbon emissions and leading to a rapidly warming world. Will this likely lead to a mass extinction? One way of beginning to answer this question is by looking at past episodes of deep time, where the Earth experienced a similar massive influx of atmospheric carbon and entered a ‘hothouse’ state. Such an episode can be found in the Paleocene-Eocene Thermal Maximum (PETM) around 56 million years ago, in which comparable magnitudes of carbon emission (though naturally caused) led to a hothouse Earth.²⁸ When we look at the fossil evidence from this period, however, we somewhat surprisingly do *not* see the PETM being accompanied by a mass extinction.²⁹ In other words, it is possible for us to undergo a climate catastrophe without a corresponding mass extinction, although it is clearly not a world we would want to live in. This underscores again that a mass extinction is the wrong bar to set for urgent environmental action. As we emphasise below, cases like this show the importance of not limiting our studies of deep time to only the mass extinction episodes.

In conclusion, we offer a brief reassessment of the value of asking, ‘Are we in a sixth mass extinction?’ Historically, the concept of a mass extinction has been immensely valuable for palaeontology, by focusing attention on a handful of key episodes in the vastness of geologic time, and leading to numerous insights about the nature and dynamics of evolution, geology, the climate system, and their various interactions. Moreover, mass extinction studies have taught us that catastrophes do indeed happen and that ecosystems are not infinitely resilient. As mass extinction studies have progressed, however, there has been a growing recognition that the various events in geologic history grouped together under this label are, in fact, heterogeneous. For example, the mass extinction framing led to the presumption that there is a single unitary event to be explained, an assumption which, as we saw, has often been overturned. Some even argue that what we might call the ‘mass extinction framing’ is now more likely to mislead than inform (Padian [2018]). For instance, this framing can tempt researchers to suppose that all mass extinctions have a common cause: Newell believed all mass extinctions were caused by sea-level change, the discovery of the end-Cretaceous asteroid impact led many palaeontologists to suppose all mass extinctions had extraterrestrial causes (Raup and Sepkoski [1984]; Raup [1991a]), and today volcanic activity from large igneous provinces is a preferred explanation. The mass extinction framing has also led researchers to suppose these episodes had a similar tempo and effect, whereas today we know that no two mass extinctions are identical.

Similarly, one can argue that the more specific Sixth Mass Extinction framing was also initially useful, not only in gaining the public’s attention, but in demonstrating the importance of looking to Earth’s deep past for guidance about our future. However, it too has arguably outlived its utility, being more likely to mislead than inform. One concern is

²⁸ Regarding using ‘paleoclimate analogues’ for contemporary climate change, see Lear et al. ([2021]) and Tierney et al. ([2020]).

²⁹ Although there was no major mass extinction event associated with the PETM, there was a more localised deep-sea extinction event (e.g., Thomas [1990]; McInerney & Wing [2011]).

that the ‘doomism’ of the Sixth Mass Extinction framing may not in fact be what is most effective at motivating public action, despite this often being cited as the justification for its use. As both the climate optimism (e.g., Mann [2021], p. 179) and ocean optimism (e.g., Knowlton [2017], p. 271) movements have argued, doomism and despair-mongering may ultimately backfire, leading to either apathy or distrust of science. What the best method is for motivating and sustaining public action is arguably an empirical question and one worthy of future research, but ultimately is outside the scope of this paper. Another concern is that, as the PETM case illustrates, there are many more lessons to be learned from deep time for guiding our future and helping us address planetary crises today than are just to be found in the mass extinction episodes. More broadly, the ability to contextualise our own experiences and actions in the vastness of geologic time — while still appreciating the ability of humans to significantly affect Earth’s systems at global and long-term scales — is an attitude that geologist Marcia Bjornerud ([2018]) calls ‘timefulness’. We believe that adequately addressing our biological and environmental crises today is going to require embracing timefulness in this broader sense. Furthermore, increased collaboration between conservation biologists and palaeontologists for this purpose will be needed, and may be facilitated by setting aside the controversial Sixth Mass Extinction framing. In sum, although determining whether we are in a sixth mass extinction is a fraught question, due to the conceptual, methodological, and datic challenges discussed herein, asking these sorts of questions more broadly enables scientists and the public to better situate themselves in geologic time, a perspective that will be increasingly necessary to confront the obstacles to come.

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Federica Bocchi¹, Alisa Bokulich¹, Leticia Castillo Brache¹, Gloria Grand-Pierre¹, Aja Watkins¹

¹Department of Philosophy,
Boston University,

Corresponding Author: Federica Bocchi (fbocchi@bu.edu)

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