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Opinion

Questioning the sixth mass extinction

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The idea that Earth is currently experiencing a sixth mass extinction is widespread. We critically evaluate this claim. Very few studies have tested this idea. Some studies showed that recent extinction rates are faster than fossil background rates, but extinction rates can exceed background rates outside mass extinctions. Other studies extrapolated from recent extinctions to project 75% global species loss. But these recent extinctions were mostly of island species. No cause was specified for these future extinctions, and >50% of assessed species are considered non-threatened. We find numerous other issues. Proponents of the sixth mass extinction have made invaluable contributions by highlighting recent extinctions, but these extinctions may not be equivalent to past mass extinctions or relevant to current threats.

Highlights

Over the last 500 years, humans have caused the extinction of hundreds of species and now threaten thousands more. Given such patterns, some authors have claimed that Earth is in a sixth mass extinction. Yet, there are many reasons to question this idea.

The definition of mass extinction is unclear, as is the number of species that will go extinct in the future.

Some authors have projected loss of 75% of global species diversity in hundreds of years. But <0.1% of Earth's known species have gone extinct in the last 500 years, and projections of undiscovered species loss are also limited.

Other authors have emphasized that recent extinction rates exceed background levels, but such deviations alone do not support a mass extinction.

The catastrophic loss of many more species seems imminent. But claiming a sixth mass extinction requires a quantitative criterion, and no plausible scenarios for 75% species loss have been proposed. Promulgating questionable claims about a current mass extinction risks the credibility of conservation biology and science in general.

Is Earth in a sixth mass extinction?

It has been stated that scientists 'agree that Earth is now suffering the sixth mass extinction' [1]. This may seem uncontroversial. There have been influential books on this topic [2,3] and prominent papers, each cited thousands of times [4–7]. A recent review by Cowie *et al.* [8] evaluated the evidence for this hypothesis and strongly favored it. Given this, the idea that a sixth mass extinction is currently occurring appears well established.

We disagree. Here, we critically evaluate whether a sixth mass extinction is imminent. We first mention the difficulty of identifying mass extinctions in the fossil record. We then review studies arguing for a modern sixth mass extinction and describe seven main reasons for questioning this idea.

Mass extinctions in the fossil record

Supporting a current sixth mass extinction requires finding a criterion that will identify five previous mass extinctions and showing that the current crisis also meets that criterion. However, such a criterion has proven to be slippery. Five mass extinction events have traditionally been recognized. These were initially based on marine animals across the last 541 million years [9], with five time intervals having extinction rates significantly above background levels (upper 99th and 95th percentiles). But subsequent studies have not always supported these 'Big Five,' especially given the difficulty in statistically separating mass extinctions from background rates [10]. Nevertheless, a prominent study of the sixth mass extinction used 75% global species loss as a criterion for identifying mass extinctions (Barnosky *et al.* [5]), as did many subsequent studies (see below).

Regardless of the exact number of past mass extinctions, proponents of the sixth mass extinction have argued that the current crisis is comparable to the Big Five (and not, for example, the Big 200). Most importantly, the claim for a current mass extinction requires a quantitative criterion for past mass extinctions and strong evidence that the present crisis meets that criterion. Ambiguity about defining past mass extinctions is not default support for a current mass extinction. If mass extinctions are undefinable, then one cannot claim that we are in one now.

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The evidence for the sixth mass extinction

What evidence has been used to support a sixth mass extinction? To address this, we utilized a recent review by Cowie *et al.* [8] to identify papers that argued for a sixth mass extinction. We also conducted Google Scholar searches (21 January 2024, 7 November 2024, keywords 'sixth mass extinction'). These searches identified the same papers and three more [11–13]. Surprisingly, many studies (Table 1) did not actually explain how their results supported a mass extinction [4,7,8,14,15].

Other studies used recent extinctions to project future species loss. The most well cited (Barnosky *et al.* [5]) used three approaches to test for a sixth mass extinction. First, they suggested that current extinction rates (last 500 years) are as fast as those that generated the Big Five (over thousands to millions of years). However, they showed that extinction rates were faster when measured over shorter timescales (Box 1), which makes comparison of rates at different timescales problematic. Importantly, a fast rate over a short time period might not generate levels of species loss comparable to the Big Five. Second, Barnosky *et al.* [5] asked what rates would produce extinction levels seen in the Big Five, if those extinctions occurred in only 500 years (standardizing timescales). They found that modern extinction rates were slower than the Big Five. Third, they asked how long it would take for recent extinctions to produce extinction levels equivalent to the Big Five [5]. Barnosky *et al.* [5] concluded that if all currently threatened species became extinct in the next 100 years and that same rate continued (with non-threatened species becoming extinct at the same rate), then amphibians, birds, and mammals would reach the mass extinction threshold of 75% species loss in 240–540 years.

Table 1. Major studies that invoke a sixth mass extinction

Study	Organisms	Criterion for sixth mass extinction
Barnosky *et al.* [5]	Vertebrates	Compared extinction rates of Big Five mass extinctions with current extinction rates; projected time to 75% species loss based on extinction rates (or IUCN threat categories)
Ceballos *et al.* [6]	Vertebrates	Showed current extinction rates above fossil background rates
Ceballos *et al.* [7]	Vertebrates	None; showed decreases in species' population sizes and geographic ranges
Ceballos *et al.* [13]	Vertebrates	Showed current extinction rates above fossil background rates
Ceballos and Ehrlich [23]	Vertebrates	Showed current extinction rates above fossil background rates
Cowie *et al.* [15]	Mollusks	None; estimated recent extinctions of mollusk species
Cowie *et al.* [8]	Animals and plants	None; but mentioned 75% species loss and deviations from background extinction rates
McCallum [16]	Vertebrates	Compared recent extinction rates with fossil record; projected future extinction of all vertebrate groups (18 000–97 000 years)
McCallum [17]	Turtles	Compared recent extinction rates with fossil record; projected future loss of all turtles in 5 031–14 706 years
Payne *et al.* [20]	Fish, mollusks	Compared projected percentage of genera lost with that in past mass extinction events; used IUCN categories to project future extinction
Penn and Deutsch [12]	Marine animals	Projected percentage of species loss under different climate change scenarios and compared with previous mass extinctions
Régnier *et al.* [14]	Mollusks	None; estimated that 7% of land snails have gone extinct
Rull [11]	Plants and animals	Projected time to 75% species loss based on recent extinction rates (400 000–800 000 years given ~2 million described species; 3.6 million years for projected 8.7 million)
Wake and Vredenburg [4]	Amphibians	None; suggested that roughly one-third of amphibian species are at risk of extinction

Other studies concluded instead that a sixth mass extinction would take much longer. McCallum [16] used recent extinction rates to project loss of all vertebrate species in 18 000–97 000 years and all turtles [17] in 5 031–14 706 years. Based on recent extinctions across plants and animals, Rull [11] suggested that it would take 400 000–800 000 years to lose 75% of all 2 million currently described species and 3.6 million years to lose 75% of 8.7 million projected species (based on conservative projections of undescribed species [18,19]). These analyses assumed that non-threatened species will disappear as quickly as recently extinct species (see below).

Two studies of marine organisms also projected future extinction levels. Payne *et al.* [20] forecasted loss of 24–40% of all marine vertebrate and mollusk genera. Their pessimistic scenario assumed that genera containing any threatened or near-threatened species (using classifications from the International Union for Conservation of Nature, IUCN[i]) would go entirely extinct, leading to extinction levels close to the end-Cretaceous mass extinction. However, this assumption seems problematic: a larger genus may be more likely to contain at least one near-threatened species, but should also be less likely to lose all its species (all else being equal). Their inference of a sixth mass extinction hinged on this assumption.

Penn and Deutsch [12] focused on climate change effects on marine organisms, using physiological models. They suggested that by 2300, under the worst-case scenario, the percentages of species lost globally would be equivalent to past mass extinctions (20–60%). However, the worst-case scenario involved incredible levels of warming: an increase in global mean temperature of >15°C by 2300. Current efforts aim to keep warming below 2°C, and even a 4°C increase is controversial [21,22].

Other prominent studies [6,8,13,23] compared recent extinction rates (last 100–500 years) with background extinction rates in the fossil record (from [5]). However, these studies did not specify

Box 1. The problem of comparing recent and fossil extinction rates

Here we describe several problems associated with comparing recent extinction rates and fossil background rates to infer a sixth mass extinction. Rates measured over very short timescales tend to be faster than those measured over longer timescales (Figure I). Barnosky and colleagues [5] demonstrated this problem and focused on species loss (75% criterion) rather than on extinction rates. Yet, subsequent studies compared recent extinction rates measured over hundreds of years with those from Cenozoic mammals measured over millions of years [6,8,13,23]. They found that recent rates were higher (5–100 times) but did not correct for different timescales.

To illustrate the timescale problem, Spalding and Hull [27] plotted fossil extinction rates against the time intervals measured. They showed that recent extinction rates are within expected confidence intervals from regressing time and rate from fossil data, even when rates are >100 times higher than the background rate from Cenozoic mammals (see Figure I).

There are many other complications associated with these rate comparisons. The species most likely to go extinct are least likely to be preserved as fossils, especially those with small range sizes [56]. Therefore, past extinction rates from fossils may be underestimated, artificially increasing differences between current extinction rates and fossil background rates. Conversely, there are anthropogenic ‘dark extinctions’: species that disappeared before being described [57]. Quantitative analyses suggest that dark extinctions could double the number of recent extinctions [58]. Yet, considering the millions of undescribed species [18,19,50,51] can dramatically lower modern extinction rates (i.e., smaller percentage of species going extinct per time interval). This factor might increase the projected time to 75% species loss (from current extinction rates) into the millions of years [11]. Finally, species numbers (and extinctions) from fragmentary fossils may not be comparable to those for extant species. Taken together, these issues (and others) may not have a simple solution, but addressing them is necessary before claiming a sixth mass extinction is here or imminent.

Cowie *et al.* [8] suggested that recent extinction rates were underestimated by not focusing on invertebrates, which tend to be small, rare, and locally distributed. They extrapolated from estimated terrestrial gastropod extinctions (7.5%–13.0%, last 500 years) to all described species to estimate current extinction rates. These were ~8–130 times the background rate from fossil mammals. But the background extinction rates should also be from groups in which most species are small, rare, and locally distributed (not mammals). These groups will have higher extinction rates but are less represented in the fossil record [56].

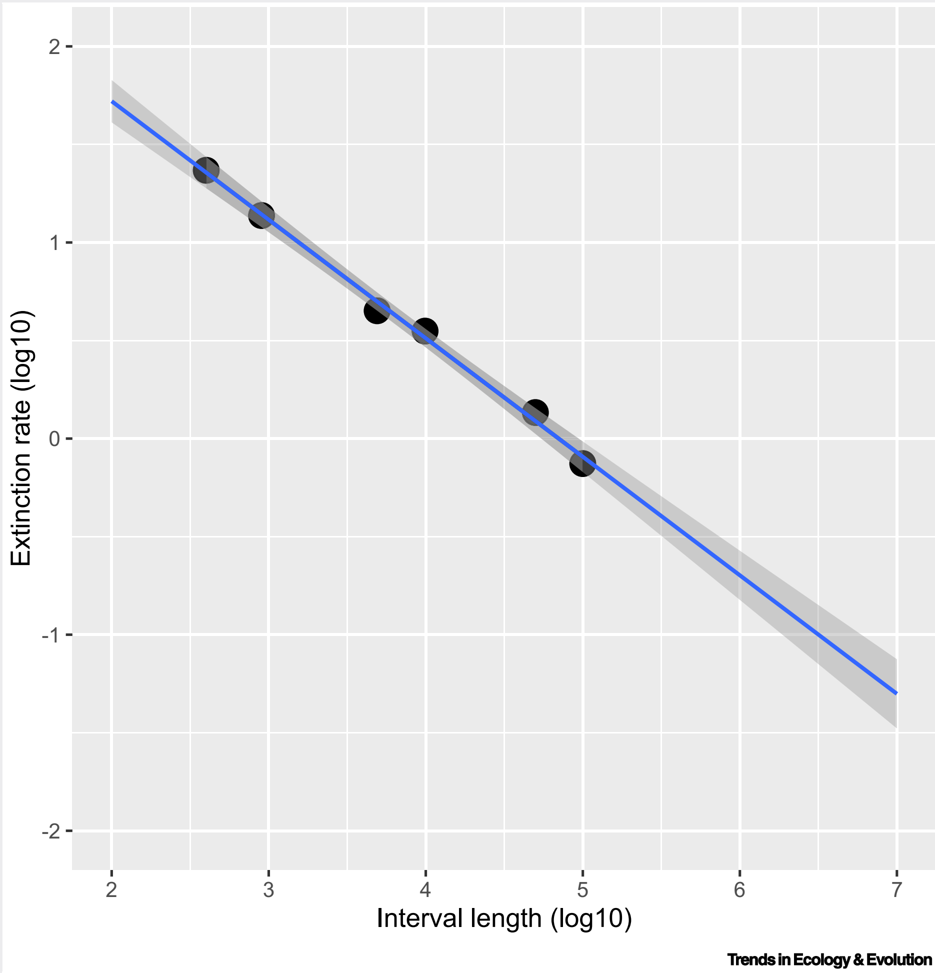

Figure I. Recent mammalian extinction rates estimated at different timescales. Species-level extinction rates (from [5]) were plotted against the duration of the time intervals over which they were measured. This illustrates the problem of comparing recent rates with background extinction rates from millions of years ago: much faster rates are expected over shorter timescales. Extinctions are in units of E/MSY (extinctions per million species-years). Time intervals range from 100–10 000 000 years. Further details, discussion, and two additional examples are provided in the supplemental information online.

the deviation from background rates that would support a mass extinction. Other studies made these rate comparisons without invoking mass extinction [24], and some have cautioned about comparing these recent and fossil rates [25–27]. We address these rate comparisons below and in Box 1.

Finally, some authors have discussed 'Anthropocene defaunation' (human-related population declines [28,29]) and linked this to mass extinction [7,29]. However, declining populations can rebound, whereas extinct species cannot. These declines might mimic species loss in the future fossil record [25], but this is questionable evidence for a current sixth mass extinction.

Skepticism for the sixth mass extinction

We are convinced that Earth is on the brink of major biodiversity loss [30]. But we are skeptical that the current biodiversity crisis is a mass extinction event. We list and describe seven reasons why below. We focus primarily on the two most prominent studies, which projected recent extinction rates into the future and compared recent and background extinction rates [5,6].

Reason 1: when will the sixth mass extinction happen?

Numerous studies have suggested that the sixth mass extinction is currently happening now, not in the distant future [1,4–7]. But in the most well-cited study on the sixth mass extinction [5], the time frame for reaching the 75% threshold for mass extinction is unclear. The only scenario yielding 75% species loss in hundreds of years only occurred if all currently threatened species went extinct in the next 100 years and then that same extinction rate continued unabated for hundreds of years. If non-threatened species disappeared at the same rate as threatened species, this would mean that IUCN categories are meaningless (but their predictions were otherwise based on IUCN categories). Their other predictions suggested that 75% species loss would not be reached for thousands of years [5], as have other studies [11,16,17]. These studies assumed that non-threatened species will disappear at the same rate as extinct or threatened species, but with no cause given for these projected extinctions. We expand on this further below (see Reason 4).

We recognize that mass extinctions can occur over thousands of years [5,10]. But the 75% threshold is currently very far away: <0.1% of known species have gone extinct over the last 500 years[i]. The idea that this threshold might not be reached until thousands [11,16,17] or millions of years [11] from now makes a very weak case for using the sixth mass extinction to justify urgent conservation action today.

Reason 2: elevated extinction rates alone do not support a mass extinction event

Some studies found that recent extinction rates are higher than mean background extinction rates from Cenozoic mammal fossils and used this difference as evidence for a sixth mass extinction [6,8,13]. But plots of fossil extinctions over time show many spikes in extinction rates above background levels outside the Big Five [9,10,31–34]. We illustrate this with published data [35,36] from fossil marine animal genera in Figure 1 (other analyses show the same pattern [9,10,31–34]). Whatever criterion is used to argue for a sixth mass extinction event, that criterion must support only five previous mass extinction events. Given that large deviations from mean background rates are common, only exceptional deviations are potential evidence for a mass extinction.

The classic paper that proposed the Big Five [9] identified exceptional, statistically significant deviations from background rates from marine animal families across the Phanerozoic. Studies of the sixth mass extinction have used background rates from North American Cenozoic mammals [6,8,13]. It is unclear how extinctions in that group, place, and time are directly comparable with extinctions in Phanerozoic animals, but they must be to infer a sixth mass extinction. Furthermore, these comparisons [6,8,13] were not statistical, and so do not account for variability in recent rates or background rates. Again, background extinction levels can vary extensively over time [9,10,31–34]. Indeed, data from Cenozoic mammals (Table S1 in the supplemental information online) show differences in extinction rates up to 23-fold between intervals of similar length (1–2 million years) and >200-fold when including the Late Pleistocene (~100 000 years).

A related problem is that rates measured over hundreds of years may be orders of magnitude faster than those measured over millions of years because of the effect of timescales on rates (Box 1). But this is exactly the timescale comparison that has been used to argue for a sixth mass extinction. We explain this and other problems related to these rate comparisons in Box 1 and the supplemental information online.

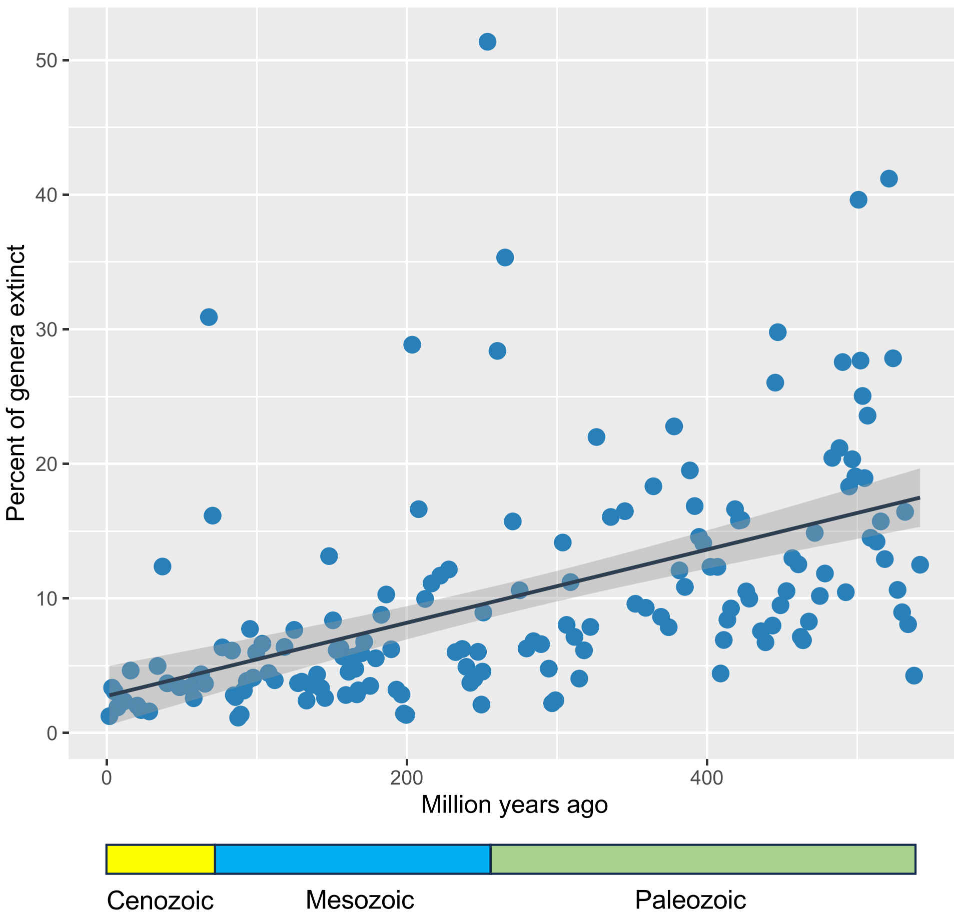

Figure 1. The percentage of marine animal genera going extinct at each time period over the last 540 million years. There is substantial variability in extinction levels outside of mass extinction events, including a tenfold range within the Cenozoic (1.25% to 12.37%) and a 14-fold range within the later Mesozoic (1.14% to 16.15%). Comparisons of recent and background extinction rates need to account for the variability in background and recent extinction rates. We excluded the Holocene. The black line shows the regression between extinction (percentage of genera going extinct) and time period, with gray indicating the 95% confidence interval. Data are from Rohde and Muller [36] (see supplemental information online), who modified the data from Sepkoski [35]. Other analyses that also correct for the incompleteness of the fossil record show the same pattern: dramatic variation in extinction rates outside of mass extinction events and considerable ambiguity about the Big Five [32,34]. This variation makes it problematic to infer a sixth mass extinction from variation in extinction rates (without statistical analysis), and ambiguity about the Big Five mass extinction events makes it problematic to infer a sixth.

De Vos *et al.* [37] used molecular phylogenies to estimate background extinction rates (instead of fossils), yielding much lower background rates. Yet, the problem of comparing rates at different timescales remains (Box 1), and high short-term rates alone are not evidence of mass extinction. Importantly, the magnitude of current species loss is low (Figure 2), regardless of rates (~955 species extinct out of 2.157 million described species[i,ii], <0.1%; or 285 out of 35 042 among well-assessed land vertebrates, 0.8%; Dataset S6 in the supplemental information online). Some authors have suggested that dark extinctions might double current numbers of extinct species (Box 1), but this still yields very small absolute numbers. Furthermore, large numbers of extinct, undescribed species may be associated with large numbers of undescribed species overall, which can actually reduce the overall percentage of extinct species.

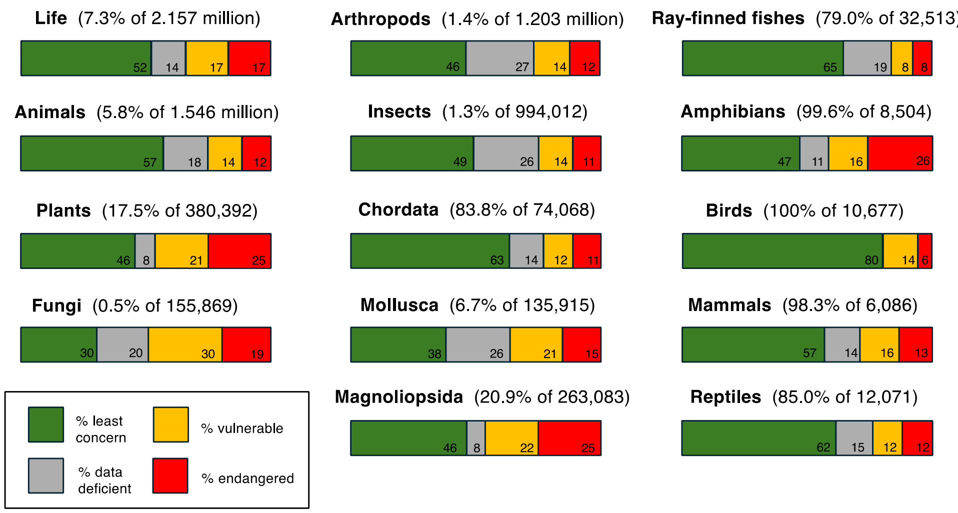

Figure 2. Summary of the conservation status of living organisms. For each major group, we give the percentage of species that were assessed by the International Union for Conservation of Nature (IUCN) relative to the total number of accepted, extant species in each group[ii]. We then give the percentage of assessed species in each threat category (colored bars, with percentage in the lower right corner). We combined several categories to make them easier to visualize. First, we combined 'endangered' and 'critically endangered' (as 'endangered'). Second, we combined 'vulnerable' and 'near-threatened' species as a separate category ('vulnerable'). The relatively small number of species classified as 'lower risk' were also placed in the vulnerable category. The number of extinct species is limited (n = 955; including both 'extinct' and 'extinct in the wild'). These were removed from the total number of species when calculating the proportion of species in other categories. For the categories 'least concern' and 'data deficient,' we used the numbers without modification. We only show large groups and groups with large numbers of assessed species. Most literature on the sixth mass extinction focuses on tetrapods (amphibians, birds, mammals, non-avian reptiles). Data source: IUCN[i], downloaded on February 16, 2024.

Reason 3: recent extinctions are highly biased

Most studies on the sixth mass extinction hinge on projecting recent extinction rates into the future. Across all plants and animals, most recent extinctions occurred on islands (~75%), even though only ~20% of all species occur on islands [38]. Furthermore, the causes of extinction differ: island extinctions were most frequently related to invasive species, whereas invasive species are far less important for mainland extinctions and as current threats [39]. Given this, these recent island extinctions should not be extrapolated to project future extinction rates on the mainland, where most species occur.

Reason 4: not all species are threatened

A particularly disconcerting assumption in most studies of the sixth mass extinction is that extinction will continue at the same rate, even after every currently endangered and vulnerable species has gone extinct [5,6,8,11]. There is no explanation for how and why this would happen. Projections of 100% vertebrate extinction in 18 000–97 000 years [16] might seem silly, but they illustrate why this assumption is problematic. More broadly, this literature generally does not relate future extinction to specific threats (but see [12]).

Major projected threats to biodiversity include habitat destruction and climate change [24,40–42]. Global analyses of future land-use change [40] suggest that 8.8% of 19 400 assessed species of land vertebrates will be imperiled by these changes by 2070. Climate change may also drive future extinctions, even in protected habitats. Yet, even under a pessimistic global warming scenario (~4°C increase), climate change alone might only cause the extinction of ~20–30% of extant species in the next ~50–100 years [41,42]. Taken together, these losses would be catastrophic, but very far from 75%.

What is needed is to consider multiple threats across thousands of plant and animal species. Such analyses do not predict 75% species loss. For example, one estimate [30] warned of losing 1 million species to human impacts out of 8.1 million projected terrestrial animal and plant species overall [18]. Clearly, 12% loss is not 75%.

Across all groups >50% of assessed species[i] are classified as 'least concern' for conservation (Figure 2). In the most thoroughly assessed major group (chordates), 63% of species are classified as least concern (Figure 2). It seems highly problematic to simply assume their future extinction without even a specified cause.

We acknowledge that a lower criterion for species loss for mass extinctions would make a modern mass extinction more plausible (i.e., <75%). For example, Stanley [43] estimated that some mass extinctions involved only ~32–42% species loss. Yet, many other analyses of marine animals [10,31] suggest that the Big Five involved loss of ~30–60% of genera, and thus many more species. Again, ambiguity about defining mass extinctions is not *de facto* support for a sixth mass extinction.

Reason 5: mass extinction versus conservation

There are now major efforts to protect species and their habitats, and investments in conservation reduce biodiversity declines in vertebrates [44]. Conservation has protected numerous vertebrate species from extinction, thereby slowing recent extinction rates [45,46]. Claims of a sixth mass extinction have been based primarily on past extinctions in land vertebrates [5,6]. Although species continue to become threatened (and sometimes extinct [46]), it seems misleading to ignore existing conservation efforts when projecting future species loss. Furthermore, habitat preservation that benefits vertebrates might also be valuable for protecting plants, invertebrates, and other organisms (e.g., in global biodiversity hotspots).

Reason 6: will current threats persist for hundreds of years?

Under many climate change scenarios, global warming will peak in the next 50 years and then decline [47]. Similarly, human population growth may start to decline around 2080 [48]. Consumption in developing countries is increasing, but so is biodiversity protection [49]. Threats to biodiversity will doubtless continue past 2100, and new ones may arise, but treating past extinction rates as constant (and known) for hundreds and thousands of years into the future seems problematic.

Reason 7: sixth mass extinction studies generally ignore most global biodiversity

Most papers on this topic have focused on land vertebrates (Table 1), which include only a tiny fraction of known animal diversity (~2.4%) and overall macroscopic diversity[ii]. Modern mass extinction would depend on insects, which were generally not addressed (Table 1). Insects include half of Earth's 2 million living, described species[ii], with ~5–20 million projected undescribed species [50,51]. Loss of 75% of extant (macroscopic) species would depend on insects, not vertebrates (or snails [8]). There have been dramatic declines in insect abundance [52], but it remains unclear how many species might eventually be lost, especially in tropical regions where most species occur.

A non-scientific argument for the sixth mass extinction?

One argument for using the phrase 'sixth mass extinction' is that it can potentially galvanize non-scientists to conserve biodiversity. But we find that the scientific evidence for a sixth mass extinction is questionable. Given this, continuing to use this phrase risks the credibility of conservation biology and science in general. Similarly, rejecting scientific scrutiny of the sixth mass extinction because of fears regarding media coverage seems particularly inappropriate. Science that cannot be scrutinized is not science at all.

Concluding remarks

The idea that Earth has entered a sixth mass extinction has garnered considerable attention. However, we describe numerous problems associated with comparing recent and fossil extinction rates and in projecting recent extinction rates into the distant future. Current projections of future extinction seem more consistent with ~12–40% species loss, which would be catastrophic but far from the 75% criterion used to argue for a sixth mass extinction. Furthermore, as a conservation goal, stopping 75% species loss over thousands of years seems neither ambitious nor urgent (e.g., what about trying to stop all current species losses instead?). Rather than studying past extinctions and projecting them forward for millennia, we think that a more useful focus is on identifying (and ameliorating) the largest current and impending threats to global biodiversity (see Outstanding questions) and pinpointing and preserving the most imminently imperiled species [53–55].

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Declaration of interests

The authors declare no competing interests.

Resources

[i] www.iucnredlist.org

[ii] https://catalogueoflife.org

Supplemental information

Supplemental information associated with this article can be found online at https://doi.org/10.1016/j.tree.2025.01.002.

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Outstanding questions

Are extinctions from the past 500 years relevant to current and future threats to biodiversity? Many forecasts of a sixth mass extinction hinge on projecting recent extinctions into the future. But these past extinctions were typically of island species and were often caused by invasive species, and seem unrelated to current threats to mainland species, like habitat destruction and climate change.

What will threats to biodiversity be like hundreds (or thousands) of years in the future? Studies of the sixth mass extinction have often extrapolated recent extinction rates for hundreds or thousands of years into the future. Human populations and global temperatures may start to level off and decline in the next ~50 years, but it is unclear if this means that many species will be out of danger, will face the same threats, or face new threats.

How do recent extinction rates vary among clades, among habitats, and over time? Projections of a sixth mass extinction have generally involved extrapolating extinction rates from tetrapods (or snails) over the past 500 years to all other organisms. Whether these extrapolations are valid depends on how extinction rates vary among taxa, over time, and among habitats.

What is the current extinction rate? The current extinction rate is an important variable for conservation and biodiversity studies, but is largely unknown. Some key uncertainties that must be resolved to calculate this rate include the number of species that have gone extinct, the number of living species on Earth, and the number of species that have gone extinct without being described (dark extinctions).

How should mass extinctions be defined? We think that this is an important question for paleontology, but of limited relevance to conservation.

We think that the key questions instead are: **What are the most important current threats to biodiversity? How many species will be lost to human impacts over the coming**

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