EMBO reports

Biodiversity crisis or sixth mass extinction?

Does the current anthropogenic biodiversity crisis really qualify as a mass extinction?

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Five centuries ago, new technologies made overseas travel significantly safer and more efficient, and allowed European explorers to travel to and colonize almost any corner of the planet no matter how remote. Travel and colonization caused large and irreversible ecological modifications of the visited lands, involving landscape changes and the extinction of native species. Since, anthropogenic extinction has not stopped but has been accelerated to what is usually referred to as the current anthropogenic biodiversity crisis owing to overexploitation of natural resources, habitat destruction/fragmentation and other destructive alterations. These ongoing changes, along with global climate change, will most likely exacerbate the rate of extinctions in the future.

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A couple of decades ago, some scientists suggested that the ongoing anthropogenic biodiversity crisis is similar in terms of scope to the five major mass extinctions that occurred in past geologic times and coined the term "sixth extinction" (Leakey & Levin, 1995). This term and its equivalent "sixth mass extinction" have become popular in both scientific and nonscientific debates and are frequently used by scientists, environmentalists, popular writers, journalists, politicians, and others. Many people now uncritically accept the reality of a sixth mass extinction, but others contend that this is an unrealistic exaggeration by environmental alarmists (Lomborg, 2001). This essay therefore attempts to clarify the issue on the basis of the available scientific evidence. The first part discusses the main features of anthropogenic extinctions that have occurred since 1,500. These numbers are then compared with the five mass extinctions during the Phanerozoic—the last 540 million years—to determine whether the magnitudes are similar. First, however, it seems necessary to stress that extinction, rather than something intrinsically bad, is a common phenomenon and essential for evolution, as diversification rates result from the balance between the rates of species origination (speciation) and disappearance (extinction).

Background extinction

In the context of this discussion, it is important to distinguish between background extinction and episodic extinctions. Background extinction is a normal process that depends on ecological and biogeographical factors—competition, predation, diseases, habitat loss, climatic changes, dispersal, range shifts, and so on—under the rule of natural selection. This type of extinction continuously balances speciation during the generation of net spatiotemporal biodiversity patterns.

A common measure of extinction rates is the number of extinctions per million species-years (E/MSY), which is inversely proportional to the duration of species within a given group (Pimm *et al*, 1995). For example, the average duration of mammalian species is estimated to be 10^6 years and their background extinction rate is therefore 1 E/MSY, meaning one extinction per million species per year, or one extinction per 1,000 species per century. In the case of marine invertebrates, whose average species duration is 10^7 years, background extinction is 0.1 E/MSY. Most taxonomic groups have intermediate durations (Lawton & May, 1995); hence, background extinction rates fluctuate between 0.1 and 1 E/MSY for most animal groups.

Episodic extinction significantly exceeds background extinction and occurs unexpectedly when a major force causes an abrupt extinction burst. For example, if an extinction burst reduces the average duration of mammalian species to 10^5 years, then E/MSY values increase to 10 ($10^6/10^5$), which exceeds background extinction rates by at least an order of magnitude. It should be stressed, however, that not all episodic extinction events qualify as mass extinctions, as I discuss later.

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Anthropogenic extinctions

Coming back to the central issue of this essay, the most reliable source to assess the magnitude and patterns of current anthropogenic extinctions is the IUCN (International Union for Conservation of Nature)

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Red List of threatened species (https://www.iucnredlist.org/; retrieved 16 October 2021). It currently contains nearly 140,000 well-documented species, of which 900 have already gone extinct since the year 1,500 and almost 80 are extinct in the wild. Species that are threatened with extinction are grouped into three categories: critically endangered, endangered, and vulnerable.

The focus here is on the 900 extinct species, most of which (86%) are animals; the remaining 14% are mostly flowering plants, except for a few fern and moss species. Among animals, one-third of the extinct species are mollusks, followed by birds, mammals, fishes, insects, amphibians, and reptiles. Crustaceans, arachnids, worms, and myriapods account for around or below 1% (Fig 1). Most of these extinctions occurred in the Pacific islands and the Americas (30% each) and tropical Africa (20%); Eurasia, Australia and the Indomalayan region have each lost less than 10% of these species. The causes for their extinction were mostly anthropogenic, including overhunting, replacement by introduced species, deforestation, habitat destruction, increased land use, and/or introduction of alien pathogens. Size and connectivity constraints make oceanic islands especially sensitive to these disturbances (Rull, 2021).

The above numbers may be larger if we take into account so-called dark extinctions, that is, the extinction of a species before it is discovered and named. Although this is difficult to quantify, a recent study estimated that dark extinction in birds could increase the IUCN extinction numbers by 150% (Boehm & Cronk, 2021). No similar studies exist for other groups. The numbers may further increase when considering prehistoric extinctions, which are only detectable in the fossil record. However, the incompleteness of the fossil record and the difficulties in attributing extinctions to human actions make it difficult to reliably estimate such prehistoric extinctions. This is, for example, the case for the disappearance of the global megafauna that occurred between 50,000 and 10,000 years ago, the cause of which—climatic and/or anthropogenic—remains unresolved (Koch & Barnosky, 2006).

More reliable estimates exist for faunal extinctions predating historical records. The most complete study is that of oceanic Pacific islands where, based on subfossil bone records from archaeological sites, more than 2,000 bird species have gone extinct owing to anthropogenic causes even before European contact (Steadman, 1995). Once more, these estimates are based on birds and are regional rather than global. The IUCN Red List is therefore still the best reference for the number of extinctions during the past 500 years.

The Encyclopedia of Life (EOL) has documented 1.9 million living species on Earth and estimates a total of 8.7 million species (https://www.eol.org/; retrieved 16 October 2021). The 900 IUCN-documented extinct species would therefore represent 0.5% of the known species and 0.01% of Earth's estimated total biodiversity. In temporal terms, the IUCN extinctions have an average rate of 180 extinctions per century (1.8 extinctions per year). How does this anthropogenic biodiversity depletion compare to the five major mass extinctions in the geological past?

Comparison with past mass extinctions

The Big Five mass extinctions have been defined on the basis of the fossil record of marine animals, which is considered to represent global biodiversity trends, at least in relative terms (Fig 2). These mass extinctions have been attributed to endogenous and exogenous biospheric causes, notably meteorite impacts; global climate changes and/or atmospheric/oceanic biogeochemistry; recurrent marine transgressions coupled or not with eutrophication and deep-water anoxic events; and generalized increase in volcanism, uplift and weathering episodes, among others. By convention, the condition for an episodic extinction burst to be considered a mass extinction is that 75% or more of the living species disappear within a couple million years or less, sometimes even faster (Barnosky *et al*, 2011).

If we take these estimates as a measure, the current anthropogenic biodiversity crisis does not qualify as a comparable mass extinction, as the number of species that went extinct during the past 500 years ranges between 0.5 and 0.01% of the documented and the estimated number of living species, respectively. However, if we consider the average rate of 180 extinctions per century, 75% of the total known species (1.4 million species) would be extinct in 800,000 years, and 75% of the total estimated species (6.5 million species) would be extinct in 3.6 million years. Thus, the rate of the current biodiversity loss is within the range of a mass extinction. If we added dark and prehistoric extinctions, of which we have no reliable estimates, extinction rates would be even greater and the time for reaching the 75% extinction boundary would be shorter. However, the situation might be even worse, as the IUCN extinction records seem to underestimate the period before 1,800.

Although data on the time of extinction are not available for about one-third of the 900 IUCN-documented extinctions, 90% of

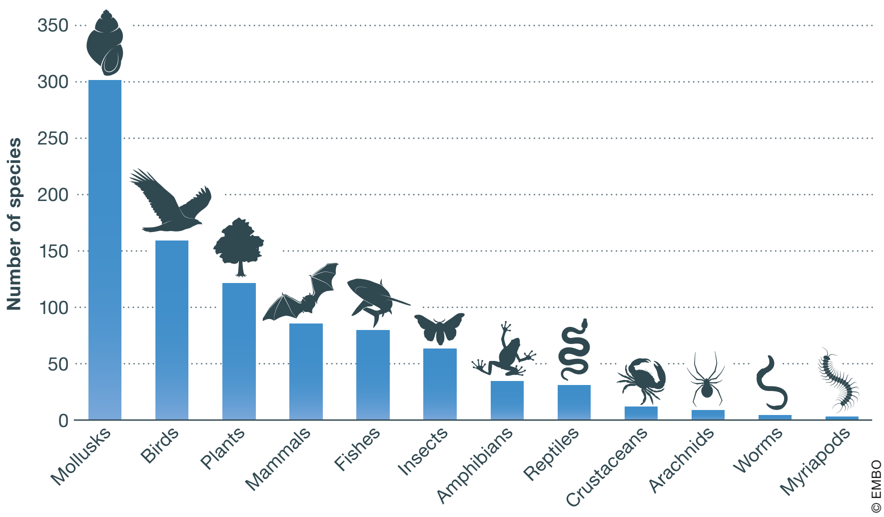

Figure 1. Anthropogenic extinctions, last 500 years.
Taxonomic distribution of the 900 species that have gone extinct since 1,500, according to the IUCN Red List of threatened species (https://www.iucnredlist.org/, retrieved 16 October 2021).

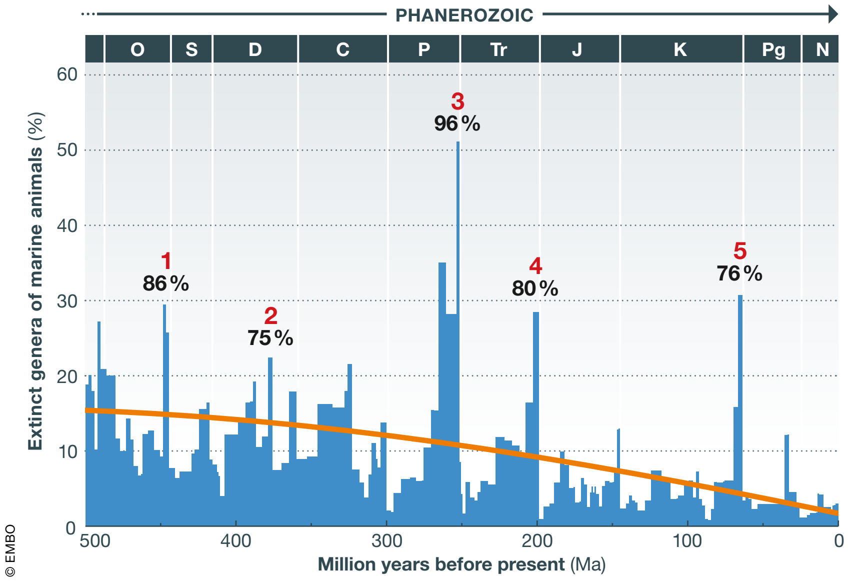

Figure 2. The Big Five mass extinctions of the Phanerozoic.
The five mass extinctions of the Phanerozoic, as defined by the percentage of extinct genera of marine animals. Each mass extinction is highlighted by a red number (1–5) and the percentage of extinct species with respect to the total. The orange line represents the background extinction rates (note that not all extinction bursts above background rates are considered mass extinctions). Geological periods: O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous; P, Permian; Tr, Triassic; J, Jurassic; K, Cretaceous; Pg, Paleogene; N, Neogene. Based on Raup and Sepkoski (1982).

the documented species went extinct during the past two centuries, which could be attributed to a "taxonomy effect." As modern taxonomy has its roots in the binomial system of Carl Linnaeus, which was generally adopted in the early 19th century, the period between 1,500 and 1,800 has been called the pretaxonomic period: most current species were described only after 1,800 (Boehm & Cronk, 2021). Extinction rates before the 19th century are therefore difficult to ascertain.

It is also worth noting that field collections saw a drastic increase in the 1900s. Thus, the most robust and well-documented extinction rates are from the 20th century with an average rate of 3.6 species per year, which doubles the rate for the 1,500–1,800 period. If these rates are maintained, a 75% biodiversity loss would be attained in "only" 400,000 years for the known species and 1.8 million years for Earth's estimated biodiversity. This falls within the range of a mass extinction, as defined paleontologically. If so, we might actually face the beginning of the sixth mass extinction caused by humans (Leakey & Lewin, 1995).

It is interesting to compare the extinction rates documented by the IUCN Red List with the estimated background extinction even though such a comparison cannot be generalized due to the lack of reliable background E/MSY values for some groups. In the case of vertebrates—mammals, birds, fish, reptiles, and amphibians—for which the average background extinction has been estimated at 1.8 E/MSY, we would expect nine species to go extinct during the 20th century (Ceballos *et al*, 2015). In reality, 390 vertebrate species disappeared since 1,900, which is more than 40 times the background extinction rate for this group of animals.

Future projections

It is not possible to anticipate whether *Homo sapiens* will continue to behave in the same way for millions of years—we have been here for barely 200,000 years—or if we will go extinct ourselves. Thus, most future projections are inevitably based on present-day standards. For example, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) concluded that "…at least a million animal and plant species – more than one in eight – already face extinction" based on nearly 15,000 studies. This assessment is based on the idea of extinction debt (Hanski & Ovaskainen, 2002), that presumes that IUCN species listed as vulnerable, endangered, and critically endangered—accounting for 28% of the total species evaluated—will eventually disappear along a similar percentage of the total biodiversity.

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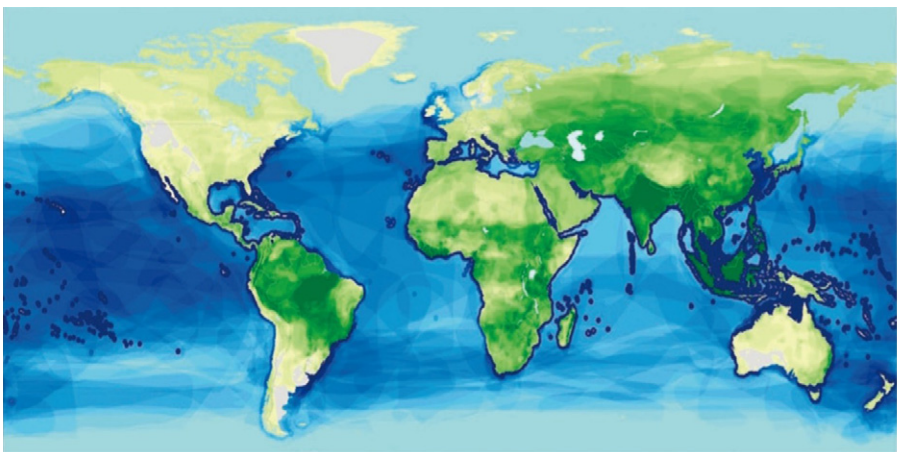

Figure 3. Map of currently threatened species.
World map of threatened species (vulnerable, endangered and critically endangered). Terrestrial species are in green, and marine species are in blue. The intensity of the colors is proportional to the number of endangered species. Modified from IPBES (2019).

Notably, most of these endangered species live in the tropics, especially in the Indomalayan region, whereas North America and Australasia show smaller values (Fig 3). According to the IPBES report, in which more than 130 countries participated, many of these extinctions may occur within the next decades because current extinction rates are "...at least tens to hundreds of times higher than the average over the past 10 million years." The main direct anthropogenic threats to biodiversity are (by order of importance) land/sea use change, direct exploitation, pollution, invasive alien species, and climate change (IPBES, 2019). Although these are imprecise estimates based on assumptions and extrapolations, the need for urgent and radical economic, social and political changes is undeniable. Otherwise, major biodiversity losses will continue until and beyond 2,050.

Conservation

To conclude, the current human-driven biodiversity crisis still does not qualify for a mass extinction in terms of the percentage of extinct species yet, but the current rates of biodiversity loss actually fit within the range of the five major mass extinctions during the Phanerozoic. This should not be a criterion for deciding whether biodiversity conservation is a necessity—this is indisputable—but it is an urgent warning sign that conservation actions should be taken now.

To discuss conservation strategies in detail is beyond the scope of this essay, but a brief comment on targets seems pertinent. The magnitude and the high extinction rates of the current biodiversity crisis seem to have led to an obsession for conserving every living species. This not the idea. Species listed on the IUCN Red List as endangered should have priority, but conservation actions to prevent other species from entering this category are equally important. What is nonsense is trying to conserve every living species, which is contrary to the natural evolutionary process. If we were hypothetically able to preserve every single species living on the planet, we would prevent background extinction, stop natural selection and, as a consequence, evolution. The living world is what it is thanks to the speciation/extinction balance, which is fundamental for evolutionary diversification. 99% of all species that have ever lived on Earth, approximately 4×10^9 species, have gone extinct over time (Barnosky *et al*, 2011), most of them without human mediation. Stopping extinction is nonsensical in evolutionary terms and is as unnatural as accelerating it.

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