PHILOSOPHICAL TRANSACTIONS B

royalsocietypublishing.org/journal/rstb

Review

Cite this article: Williams M, Zalasiewicz JA, Waters CN, Petrovskii S, Whitehead H, Wong Hearing TW. 2026 Stories and science: two roles for palaeontology in the Anthropocene. *Phil. Trans. R. Soc. B* **381**: 20240433.
https://doi.org/10.1098/rstb.2024.0433

Received: 26 March 2025
Accepted: 29 July 2025

One contribution of 18 to the theme issue 'The biosphere in the Anthropocene'.

Subject Areas:
palaeontology

Keywords:
Anthropocene, biosphere, palaeontology, contemporary change, storytelling, science

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THE ROYAL SOCIETY
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Stories and science: two roles for palaeontology in the Anthropocene

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People have observed and collected fossils for thousands of years, sometimes using these to tell stories about mythical beasts or events. In more recent times, fossils have been fundamental to the development of a deep understanding of Earth's dynamic processes, including its evolving biosphere, with notable contributions to the development of this science from Western, Middle Eastern and Asian traditions. Thus, fossils have been used both through technical studies in scholarly research and for telling stories about our broader relationships with the biosphere. Here, we examine the fossil records of two aspects of anthropogenic impact on the biosphere, those of extinction and of non-native species. We discuss how a scientific understanding of the fossil record grounds our projections of future environmental change, while storytelling is an essential art that helps people understand and forge a more sustainable relationship with a biosphere that has maintained life for billions of years.

This article is part of the theme issue 'The biosphere in the Anthropocene'.

1. Introduction

At present, the Earth is in a protracted episode of major change to its biosphere [1] (figure 1), resulting from ecosystem loss and fragmentation, pollution, over-exploitation, climate change, the rapid translocation of thousands of non-native species and other environmental factors. These changes include extinction, which may within a few centuries become a mass extinction comparable to those of deep time, like that at the end of the Cretaceous period 66 Ma [9–11]. Other authors have noted that regional biodiversity has sometimes been enhanced by non-native species even as global biodiversity is diminishing [12] and that the effects of present biodiversity change are part of the adjustment of the biosphere to human interactions [13,14]. In the context of this dynamic change to the biosphere, palaeontology has taken on a significant role in enabling comparisons with deep-time biological change, and so providing clues to possible trajectories of future change [15,16].

In this articler, we summarize how people have related to the fossil record in different contexts. We argue that storytelling is a powerful approach to affect public perception of fossils, of the corresponding extinctions of the past and the environmental changes that caused them. We ask what kinds of fossils are recording anthropogenic impacts on the biosphere. We attempt to draw some simple comparisons between current change and those of the past. And, drawing on the breadth of different cultural experiences of palaeontology, we discuss how fossils can be employed as a kind of universal language to help reflect on current biotic change and some of its possible outcomes.

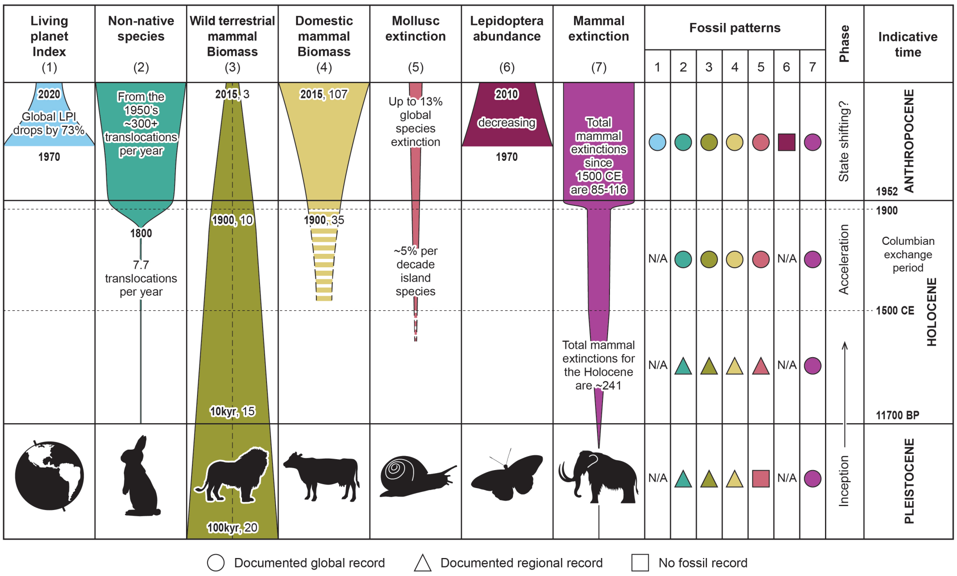

Figure 1. Schematic image of some key changes to the biosphere resulting from anthropogenic activity, columns (1)–(7). Graphs are approximated from the following data sources. (1) The Living Planet Index, https://livingplanetindex.org/lpi, fig. 1. The global LPI had dropped by 73% in 2020 compared with 1970, based on an assessment of 34 836 populations of more than 5495 vertebrate species. (2) Non-native species translocations based on Seebens *et al.* [2], who record an average of 7.7 translocations annually between 1500 and 1800 CE, reaching over 300 per year from the late 1950s (their fig. 2). (3) Wild mammal biomass based on Ritchie [3] and references therein; numbers adjacent to the dates indicate millions of tonnes of carbon. (4) Domestic mammal biomass taken from Ritchie [3]; figures adjacent to the dates denote millions of tonnes of carbon. (5) Mollusc extinctions summarized from information in Cowie *et al.* [4], with an estimated up to 13% loss of total biodiversity, i.e. possibly 260 000 species extinct since 1500 CE. For mollusc extinctions prior to 1500 CE, see Régnier *et al.* [5]. (6) Lepidoptera abundance based on Dirzo *et al.* [6] (fig. 1 therein): we note that the same figure shows a much steeper decline in the overall abundance of invertebrates. (7) Vertebrate extinctions are pronounced through the late Pleistocene and Holocene and include the loss of 177 large mammal species between 132 ka and 1000 years BP [7] and estimates of an overall approximately 241 mammal species lost during the Holocene [8]. Total vertebrate losses (including fish, birds, reptiles, amphibians and mammals) since 1500 CE are between 429 and 866 species extinct or extinct in the wild, where the ‘possibly extinct’ category is included in the latter figure. Of these, between 85 and 116 mammal species are extinct or extinct in the wild (IUCN Red List, summary table 3, https://www.iucnredlist.org/statistics, accessed March 2025). The numbers for fossil patterns (1–7) relate to the numbers in the columns for non-native species, domestic mammal biomass, etc.

2. Palaeontology: a historical perspective

People have been observing and collecting fossils long before Leonardo da Vinci’s famous observations in the Codex Leicester (folio 8v, *ca* 1508–1510 CE) that fossils were buried in ordered sedimentary layers [17]. Two millennia earlier, the Greek philosopher Xenophanes (*ca* 570–478 BCE) had noted the imprints of various animals in rocks and considered these to be evidence of a world that existed in two states—one dry and one wet—with ‘fossils’ being the remnants of life in a past cycle when the land had receded into the sea, and the Earth was covered by mud and water ([18, pp. 269—270], [19, p. 3]). In his observations, Xenophanes had noted the weathering of sediment on land and its return to the sea, and thus had an early understanding of the rock cycle later developed by Ibn Sina, Charles Lyell and others. Xenophanes thought that life emerged in a new cycle when the Earth began to dry out again [19]. His work is an early attempt at using fossils to understand past environments. Several other early Greek philosophers commented on the occurrence of shells far from the sea as indicating past changes in sea level [20].

Islamic scholars recorded fossils and drew similar conclusions to those of the Greeks, and they also greatly expanded our understanding of how ecosystems work, especially through the work of Al Jahiz (776–868 CE), who, in his *Book of Animals*, described both food chains and the struggle for existence [21]. Another of these Islamic scholars, Ibn Sina (980–1037 CE), developed an understanding of mountain building and of landscape erosion about eight centuries before Lyell’s nineteenth-century book *The Principles of Geology* (Draper 1876, cited *in* [22, p. 1468]). Some 1500 years after Xenophanes, the Chinese polymath Shen Kuo (1031–1095 CE) observed petrified ‘bamboo shoots’ (now known to be fossils of the late Palaeozoic *Neocalamites*) at Yan-shui-guan, Shaanxi province [23], and surmised that they represented a more humid and warmer climate in the past. He thus made one of the earliest observations that Earth’s climate changes. Fossils are now widely used by palaeontologists for both environmental and climate analysis in deep (i.e. geological) time, for the subdivision of the geological succession through successive evolutionary assemblages, and for detecting major macroevolutionary events such as extinctions and radiations of life [24].

If classical scholars observed fossils as a basis for understanding a dynamic and ancient Earth, there is also a significant and ancient record of a non-scientific palaeontology from every inhabited continent, beginning in Africa tens to hundreds of thousands of years ago [25]. In Africa and globally, people have been collecting fossils for symbolic and utilitarian reasons, including fragments of vertebrates, molluscs and trilobites [26], probably for as long as there have been people [25]. Relationships between fossil footprints and rock art suggest that pre-colonial and ancient cultures in Africa used fossils to invoke a sense of mythological periods before their existence [26, p. 554], which is a common thread across human societal interactions with fossils up to the present day. Fossils have been widely used as ornaments [27], as cures for ailments [27,28], and in folklore

[29,30]. Mayor [31] convincingly showed how in Greek and Roman times, the bones of dinosaurs were viewed as relics of giants, ogres and mythical creatures such as the griffin. Younger geological deposits with fossilized vertebrate bones may also have formed the basis of mythologies of giants in cultures from Europe to the Americas, including the potential misinterpretation of dwarf elephant skulls for the heads of the giant Cyclopes [32]. At the dawn of western science-based studies into Earth's history, the Comte de Buffon's 1778 *Les Époques de la Nature*, a popular science book of its day, showed a recognition that fossils represented animals and plants that lived in earlier times but that subsequently died out [33]. Alongside and within these early European studies, fossils were also considered in a mythical context, e.g. in William Buckland's 1823 *Reliquiae Diluvianae*, which interpreted fossils from cave deposits as representing the remains of living animal communities later covered by sediment he ascribed to the Biblical 'Great Flood' (subsequently, he recognized that there was no evidence of the Biblical flood and added his support to the then-new concept of former major glaciation). Throughout the twentieth and twenty-first centuries, alongside the development of the science of palaeontology, fossils have continued to serve as inspiration across diverse media, spanning books, music, film, television and games [34,35]. Across human societies past and present, fossils therefore possess a dual function, both as objects of scientific enquiry and as inspiration for imagination and storytelling [29].

In the following two sections, we look at the interconnected questions of which types of current biotic change leave a fossil record, which might be useful for comparison with deep-time changes, and how these changes can be elaborated beyond the confines of science by storytelling.

3. How do fossils express recent and current changes to the biosphere?

Most species that ever lived have gone extinct, but only a tiny proportion of these have left any trace of a fossil record. Here, we examine the recent and contemporary fossil records of three different animal groups, all of which show dramatic changes to abundance and diversity (figure 1): arthropods and molluscs are the two most species-rich groups of invertebrates, and mammals have the most precise assessments of biodiversity change. We examine two aspects of their recent fossil record: extinction and the spread of non-native species.

(a) Extinction

Arthropods are the most biodiverse animal group, with an estimated approximately 7 million terrestrial species of which approximately 5 million are insects, including perhaps 80% that have not yet been described [36]. Marine diversity is less well-quantified, but over 50 000 arthropod species are documented [37,38]. Arthropods are abundant as fossils [39,40] and were already the most species-diverse animal group in the early Cambrian, though at that time entirely marine [41]. Nevertheless, fossil species represent a tiny fraction of the actual living species, evident from the observation that just approximately 46 000 fossil insect species have been described from the strata of the past approximately 400 million years, versus approximately 5 million living species [42].

There is no systematically documented fossil record of the current global loss of arthropod taxonomic diversity, and records of extinction in many contexts remain sparse, especially so in marine settings [43]. The IUCN Red List ([44], https://www.iucnredlist.org/resources/summary-statistics, table 1a) has assessed 12 474 insect species (from approx. 1 million described species), of which about 19% (2423) are considered threatened. Some 3213 crustaceans have also been assessed, of which about 23% (748) are considered threatened. However, these records only assess extinctions since 1500 CE and do not incorporate evidence of earlier extinctions linked to human activity [45,46]. Nevertheless, if arthropod habitats continue to be threatened globally, the extinction debt will rise (i.e. the number of species likely to go extinct as a result of environmental change, e.g. [47,48]), and would likely leave a fossil signature, just as deep-time arthropod extinctions have [42,49,50]. Given that only a tiny proportion of insect species left a fossil record prior to the last 2.6 million years of the Quaternary, many living species will leave no trace. However, if abundance drops on the scale of the 'insect Armageddon' invoked by studies such as Wagner *et al.* and Hallman *et al.* [47,51] continue, whole taxonomic families of insects might disappear [42], a scale of loss likely to leave a distinctive future fossil record. The higher preservation potential of organisms that live in water means that aquatic arthropods like marine decapod crustaceans will undoubtedly show significant biodiversity loss in the future fossil record as the ongoing demise of coral reef systems [52] restricts their environmental range (see [50] for a deep-time comparison in the Jurassic).

Molluscs are a biodiverse group of approximately 2 million species [4], second only to arthropods in terms of their biodiversity. Like arthropods, they are also a group with a very extensive fossil record extending back to the early Cambrian (e.g. [41]), and their study is often important to the analysis of past extinction events (e.g. [53,54]). The IUCN Red List has examined some 9127 mollusc species and records 2456 (27%) of these as threatened [44]. But a more holistic assessment of terrestrial molluscs and extrapolation to marine molluscs suggests that as many as 150 000–260 000 species may have gone extinct since 1500 CE, representing some 7.5–13% of species diversity and constituting a significant extinction event [4]. Anthropogenic extinction stress on molluscs is associated with a fossil record, especially in ocean island settings [55–57] where extinctions have been severe [4].

IUCN [44] assessments of vertebrate biodiversity encompass some 84% of described species (estimated at 75 923). Of those 63 761 evaluated, 4017 (over 6%) are assessed as threatened. Severe environmental impacts on global vertebrate populations are referred to as a 'biological annihilation' by some authors (e.g. [58,59]). Over 400 vertebrate species have gone extinct since the early twentieth century, which is up to approximately 100 times faster than would be expected [11], with monitored populations of vertebrates losing some 73% of their abundance between 1970 and 2020 [60] (see also figure 1). While a mass extinction of species has not yet occurred, a mass depletion of individuals within those species is underway, likely storing up substantial extinction debt for the near future [61]. We note that for some vertebrate groups, only a tiny percentage of extinctions will register in the fossil record; e.g. only 3.3% of threatened birds in the IUCN Red List have a fossil record [62].

Mammals have far lower species diversity than arthropods but (and perhaps in part because of this) show the most easily recognized extinctions. Some 6753 species are recognized in the 'ASM Mammal Diversity Database' (v. 1.13, released 13 July 2024, accessed March 2025). Although the vast majority of mammal species are wild, with only 17 domestic species, 98% of terrestrial mammalian biomass is concentrated in domestic species together with humans [63]. Some 113 mammal species are recorded as recently extinct (i.e. since 1500 CE). Mammals have an extensive deep-time fossil record, which is punctuated by extinctions, including at the end of the Cretaceous period, with geographical range and abundance exerting strong controls on which species survive (e.g. [64]). Anthropogenic impacts on mammal biodiversity are evident over several tens of millennia, most obviously as megafaunal extinctions (e.g. [7,65]), extinction of island species [66] and more recently of marine species. Megafaunal extinctions have produced an approximately 50% loss of the world's large mammal species and an approximately 4% loss of mammal species in general [67].

Some 5991 mammal species have been assessed in the IUCN Red List [44], of which 1354 (22.6%) are considered threatened. An earlier analysis of this dataset (when it comprised 5515 species) suggested that only 8.8% of the species considered at risk of extinction have a fossil record, whereas of those species classified as lower concern, 19.7% have a fossil record [62]. Plotnick *et al*. [62] concluded that mammals with larger body size have a better chance of preservation as fossils and that species with a wider geographical range have a lower chance of extinction. Ceballos *et al.* [58] examined a subset of the IUCN Red List comprising 177 species and estimated that approximately 58 000 populations of these mammal species were lost between 1900 and 2015 CE, associated with markedly reduced geographical ranges, indicating that extinction debt is increasing. For example, in Madagascar, some 30 mammal species have gone extinct over the past approximately 2500 years, with anthropogenic impacts invoked for at least half of these [66]. If the 56 Madagascan species currently classified as threatened in the IUCN Red List go extinct, it may take millions to tens of millions of years for the island's biodiversity to recover [66]. These population loss data, and those of a broader analysis of vertebrate losses (Living Planet Index reports, e.g. [60]), strongly suggest the present time as representing the precipice of a mass extinction [58,59], and one that is likely to leave a distinctive if incomplete fossil record of regional and global biodiversity loss.

(b) Non-native species

Recent extinctions are closely associated with a fossil record of the spread of non-native species, including those of many domesticated species extending over centuries, but becoming increasingly apparent from the nineteenth century [68] and involving many invertebrate species [69]. It is these species translocations that provide a globally widespread signal of current biotic change, especially from the twentieth century [70].

Many arthropods show rapid range extensions as non-native species. A study of 16 926 established non-native species, including 5867 arthropods [2], noted increasing dispersal over the past 200 years. While 87% of the arthropods in this study are insects, with a very low fossilization potential, they also include some 480 crustacean taxa. This has already left a fossil record, e.g. of ostracod crustaceans in the San Francisco Estuary [71]. There, the non-native ostracod taxa *Bicornucythere bisanensis* and *Spinileberis quadriaculeata* can be found in strata accumulating since the 1970s. These ostracods appeared in the San Francisco Estuary about a century after the extinction of the indigenous mollusc *Diala exilis* [43], and thus potentially there will be a record of local extinction followed at a stratigraphically higher level by the local first occurrence of non-native species.

While global mollusc populations have suffered marked biodiversity loss [4], some molluscs have become highly successful non-native species. These include Asian clams (*Corbicula fluminea*) and zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena rostriformis bugensis*, respectively) in European and North American waterways during the nineteenth and twentieth centuries [72,73] (figure 2), which have left a fossil record—for example in the River Thames; invasive golden apple snails (*Pomacea canaliculata*) through East and Southeast Asia since 1980 [74], and their recent spread into East Africa [75] facilitated through human-modified aquatic ecologies such as rice paddies; and the introduction of species such as the cannibal snail (*Euglandea rosea*) and giant African snail (*Achatina fulica*), to places like the Pacific Islands, where they have supplanted the indigenous snails, leaving a fossil record of extirpation closely coincident with the introduction of these non-native species [56]. These terrestrial mollusc species are joined by the many coastal marine species, like the Amur River clam (*Potamocorbula amurensis*) that is known from the recent sedimentary record of the San Francisco Estuary [71], and the Pacific oyster (*Magallana gigas*) that is now effectively global in its marine distribution [70,76].

Patterns of change in terrestrial mammal populations, including extinction and the arrival of domesticated animals, have already been used to denote North American Land Mammal Ages (NALMAs). Thus, the Santarosean NALMA begins at approximately 14 ka and is characterized by early evidence of humans in North America and by domesticated dogs [77]. An early and late Santarosean NALMA can be differentiated, the latter associated with the loss of megafauna by 10 ka, which includes native horses [77]. A Saintaugustinean NALMA is recognized beginning at 1540 CE, associated with the arrival of domesticated horses in North America, which can be morphologically differentiated from the native and extinct horse; and by imported goats, sheep, domesticated cats and cows, which have left an archaeological record. This interval is associated with a number of extinctions of indigenous mammals [77].

Many of the non-native species changes we document above have occurred quite recently, especially in the twentieth century [69]. These non-native species will leave a significant biostratigraphical marker of their arrival in new geographical regions (e.g. [70,71,73]), closely coupled to the extinction of native species, as in the stratal record of Hawaii [56]. Given that biodiversity loss may be as high as 13% of mollusc species since 1500 CE [4], this episode of extinction, coincident with and often followed by

Figure 2. Invasive quagga mussels (*Dreissena rostriformis bugensis*) at Grafham Water, UK. Accumulations of non-native species like these have a good chance of forming a permanent fossil record of anthropogenic impacts on the biosphere.

global translocation of mollusc species in its latter stages during the twentieth century, marks a significant change in the species composition of ecosystems globally.

4. Palaeontology and the Anthropocene

If changes to the biosphere are observable in recently accumulating strata, it is also clear that people have been observing and collecting fossils for many millennia and, in many cultures, they have in some way or other demonstrated the deep geological roots of the biosphere. Fossils therefore play an important role in how humanity visualizes its increasing impacts on the biosphere. Here, we review this from scientific and non-scientific viewpoints that include comparisons between contemporary and deep-time change, and the potential of fossils to tell stories about our wider relationship with the Earth.

(a) Deep-time comparisons and contemporary change

The Anthropocene is a proposed new epoch of geological time with its start point in the mid-twentieth century [78–80]. Although it remains an informal designation of geological time, compelling evidence has been collected to show that this interval equates to a rapid increase in the number and intensity of human impacts on the planet [1,80–84] with transformative effects including on the biosphere [69,70]. Our brief review of some of the Anthropocene impacts on the biosphere in §3 indicates that the observable change and its fossil record do not yet bear comparison with, as regards species loss, the greatest mass extinction records in deep time [9]. For instance, we have not yet lost 70% of species biodiversity [85]. However, patterns that are now emerging may soon emulate geologically recognizable mass extinctions (figure 1), driven by habitat reduction and fragmentation, competitive replacement by non-native species, global and regional effects of climate change, anthropogenic pollution and other factors. Thus, certain past extinction events and the geographical interchange of non-native species may be particularly useful comparators for what is happening now and what may be in store [16].

The Anthropocene follows a period of significant changes to the biosphere caused by humans over tens of millennia, including megafauna extinctions and landscape domestication, which have left a widespread fossil record ([69] and references therein). In the latest stages of these anthropogenic modifications, there is widespread and rapid translocation of non-native species, strongly enhanced through international transport networks such as shipping [86]. The rapid global spread of non-native species to some extent resembles certain deep-time events, e.g. those of the early and middle Palaeozoic detailed by Stigall [15]. These are the Late Ordovician, Richmondian Invasion (approx. 446 Ma) and the Late Devonian Biodiversity Crisis (approx. 375 Ma). Both are associated with the influx of non-native marine species into the palaeocontinent of Laurentia (modern North America and Greenland) [15]. In these deep-time examples, many of the non-native species appear to have been widespread generalists that readily adapted to their new geographic ranges. Widespread endemic and non-native species preferentially survived in the Richmondian Invasion. The biodiversity crisis of the Late Devonian, which may have lasted millions of years, shows markedly reduced rates of speciation, attributed to the lack of opportunity for allopatric speciation, with endemic species much more likely to go extinct than widespread forms [15]. Similar geographic patterns are evident in the recent replacement of ocean island mollusc faunas by non-native taxa [4], and in the influx of non-native species into inland waterways [87,88]. In these contexts, the stratigraphical occurrence of non-native species such as zebra mussels may be closely associated with the last occurrences of indigenous species such as unionid mussels [87]. The Anthropocene invasions differ from the deep-time examples in that species have been transferred between every continent and every ocean by ship, motor vehicle and aeroplane, rendering geographic barriers nugatory [70,89].

Pimiento & Antonelli [16] identified the Great American Biotic Interchange (GABI) as another potential (if continental, rather than global-scale) comparison with the Anthropocene. The GABI peaked from about 2.5 Ma as the Isthmus of Panama formed a land bridge between North and South America and allowed terrestrial species to migrate between the two previously separated continents. The GABI shows a differential response of North American and South American land animals to the migration of non-native species. There was increased extinction in South American mammals, possibly resulting from competitive replacement or susceptibility to predation by North American placental carnivores, which reduced the diversity of native taxa that migrated northwards. This asymmetry in the success of North American versus South American mammals during the interchange may highlight the complex responses of many terrestrial ecologies to the arrival of non-native species in the Anthropocene [90]. Macroevolutionary aspects, particularly the pre-exchange context, become important in this respect. Thus, South America had been largely isolated over millions of years preceding the GABI, in contrast to North America, which had connections to Eurasia throughout much of the Paleogene and Neogene, and the South American reservoir and diversity of genera were considerably smaller than those of North America [91]. In recent history, similar evolutionary aspects explain detrimental effects that non-native (and invasive) species often have on ecological communities in isolated areas such as islands [92].

When proposing a formal definition of the Anthropocene, much emphasis has been placed upon geochemical signals suitable for pinpointing the base of this potential new epoch because they can show global changes resolved to decadal and even annual resolution [79,80]. Global changes to the biology of the planet through extinction or the distribution of non-native species can appear to occur at a slower tempo by comparison, but when viewed in a deep-time perspective, these palaeontological changes are extremely rapid and can be important for providing markers allowing local to regional correlation of successions [69]. The results of current rapid anthropogenic warming will persist for many millennia [84] and are likely to have a significant impact on global biotic distribution [93]. Deep-time events that show very rapid warming, such as the early Toarcian (approx. 183 Ma) of the Jurassic Period, suggest a trajectory of near-future change that may involve extinction [94]. Therefore, as the story of the Anthropocene progresses into the future, it is likely that the most persistent evidence of global change that will justify the Anthropocene as being demonstrably different to precursor epochs will be a fundamental and irreversible change to the palaeontological record [69,70], one which may ultimately warrant the Anthropocene to be considered at higher rank than epoch, as proposed by Bacon & Swindles [95], to be consistent with the chronostratigraphic expression of earlier major extinctions.

However, the geological record also shows intervals of major evolutionary innovation that have led to sustained, step-change increases in planetary habitability. These include the evolution of oxygenic photosynthesis deep in the Precambrian at approximately 2.4 Ga, the evolution of green algae in the late Proterozoic, and of land plants (approx. 480 Ma) that increased the primary production of the biosphere and its biomass [96]. The evolution of symbioses between plants and fungi has been instrumental in the terrestrialization of the biosphere, which transformed Earth’s land surface from the preserve of microbial organisms into a suite of habitats that can sustain complex life [97]. These and other evolutionary innovations have augmented biomass, taxonomic and functional diversity, and the wider spatial distribution of life on Earth. These intervals provide important clues for how humanity must manage its relationship with the biosphere for the near future, if the current trajectory of negative biosphere impacts documented above is to be avoided. This speaks to themes of behavioural change that nurture relationships between humans and non-humans [98].

Palaeontology therefore has much to say about the potential direction of near-future change to the biosphere, including about extinction, the effects of widespread non-native species and the fast rate of environmental change that may lead to elevated extinction [99] as rates of species adaptive evolution struggle to keep pace with changes in the environment [100]. It also has something to say about how we might live more harmoniously with the other species we share this planet with.

(b) Storytelling and the biosphere

While the technical description of fossil assemblages can clearly contribute to a deeper understanding of contemporary biotic change, storytelling has the capacity to greatly expand viable and meaningful engagement with the problems of rapid environmental change, given that '*most people deal in stories and anecdotes, not graphs and statistics*' [101, p. 9]. However, the tone, style and narrative by which the information is related can be at least as important as the information itself. Although sensational and horrifying representations of environmental change may capture people's attention, they can also lead to despair, apathy and even denialism; ultimately, '*fear won't do it*'. [102]. Instead, a greater sense of personal engagement with the issues can be stimulated through narrative approaches that take account of audience '*values, attitudes, beliefs, local environment and experiences*' [102, p. 375]. Audiences engage more positively with constructive, emotionally charged stories meaningfully embedded in their local environments, often using vivid visual imagery that may then act as representations in miniature of the wider environmental crisis [103].

Fossils have clearly invoked a sense of awe in many cultural traditions throughout human history and have become a significant part of storytelling, folklore and mythology that includes everything from mammal bones to sea urchins [25,34,35,104]. Fossils have significant power in conveying messages about environmental change, past, present and future.

Mayor [30] observed how the presence of fossils is sometimes reflected in place names in many regions of the world, often imbued with the geomythology of indigenous peoples. For example, Mediterranean sites of the classical world with fossil remains of vertebrates were sometimes associated with mythical battlegrounds between gods and titans or gods and Amazonians. In China, dinosaur bones were associated with dragons and were ground down for medicine [30], a practice that extended to invertebrate fossils like 'stone swallows', the remains of Palaeozoic spiriferid brachiopods [27,28]. In the Americas, recent names from the colonial era evoke a continuing sense of awe, like 'Big Bone Lick' and 'Big Bone Cave' [30]. In the Americas too is Otam kawi, 'Skeleton Mountain', a site of special importance to the indigenous Yaqui of Sonora, NW Mexico that is associated with a 'mythical' giant predatory bird [30]. Skeleton Mountain and the associated Rio Yaqui valley preserve extensive vertebrate fossil deposits of Pliocene-Pleistocene age transported downslope from the Sierra Madre, which the Yaqui interpreted as the bones of the victims of the giant bird [30].

In China, there are stories of 'stone swallows' (those fossil brachiopods mentioned above) taking off and flying during thunderstorms, though later this movement was realized to be from more mundane downslope creep (Du Wan in his book '*yun lin shi pu*' [105], *fide* [28]). Nevertheless, stone swallows have been a part of Chinese medicine for centuries, where, dissolved in vinegar, they were used to treat various skin ailments and other conditions [104]. In Europe, other fossils were used for protection and medicine, such as echinoderms (fossil sea urchins), used to stop milk souring, to protect against lightning strikes, and even as antidotes for snake venom, whereas belemnites were used as a cure for rheumatism [104]. Ammonite fossils have also been prominent in folklore. The Early Jurassic ammonite genus *Hildoceras* was named after St Hilda (*ca* 614–680 CE [106, p. 99]). According to legend, St Hilda prayed to rid the town of Whitby of a plague of snakes that were turned to stone and cast from the clifftops to lie scattered on the beach below where they were found by locals who then carved snake heads onto the fossils, creating 'snakestones' [107]. The myth of St Hilda invokes a narrative of human-driven local extinction to explain the ammonite fossils, which fossils themselves embody past extinctions.

A sense of awe, or perhaps even of the supernatural, may have pervaded many sites with fossil footprints that are often associated with cave art in Africa, the Americas and Europe [26,29]. Mayor & Sarjeant [29, p. 161] noted how both '*storytelling*' and '*scientific curiosity*' have been used to understand fossils, and how fossil footprints were used to '*visualise the corporeal substance and daily activities of creatures that once walked the earth but will never be seen alive*'. In contemporary settings such as tours of building materials in cities or museum exhibits, storytelling continues to play a central role in connecting people with their geological heritage, embedding a deep understanding of fossils and the evolution of the biosphere, and of the dynamism of tectonic plates and past geographies on a changing Earth [108,109]. Moreover, connecting the great extinctions of the past to ongoing environmental change and embedding these ideas more generally in society—as may be done by collaborations between artists and scientists (e.g. [110]), via narratives of biodiversity research [111] or even via science-fiction-like narratives set in the far future [112]—may help to change human behaviour and hence decelerate environmental change by creating an indirect feedback loop to the climate [113].

For palaeontologists working in the Anthropocene, many of the organisms around us are threatened with extinction and may '*never be seen alive again*' (to reuse the quote of [29]), and new patterns of non-native species are arising as a distinctive feature of this change, visible both on the land and in the sea. The message from non-native species like the Amur River clams in San Francisco Estuary speaks to 'scientific curiosity', the traditional practices of palaeontology documenting the biosphere in deep time, being critically important to understanding the trajectory of near-future change [9,10]. The second message is in the storytelling of the 'stone swallows', dinosaur footprints or fossilized 'bamboo shoots', that animals and plants that are no longer living can tell a story of geological change. This is a story of the successes and failures of the biosphere, including its history of extinction, in which we come to understand both our broader place within and the legacy of our impacts on a biosphere that has sustained life for approximately 3.7 billion years of Earth's evolution.

5. Conclusions

Fossils convey a diversity of messages about life on Earth, of its impermanence at the individual species level and its permanence at the level of the biosphere. Ideas about a changing biosphere have deep roots in human cultures across the globe (e.g. [25]), long before Renaissance ideas became a spark that, later, formalized palaeontology as a science. Fossils also convey messages across cultures that sometimes include mystical beliefs about their protective or medicinal properties. Here, we have discussed the value of both scientific and storytelling approaches to palaeontology and their utility for connecting people to the long story of Earth at a time of unprecedented human impacts on all its lifeforms.

Ethics. This work did not require ethical approval from a human subject or animal welfare committee.

Data accessibility. This article has no additional data.

Declaration of AI use. We have not used AI-assisted technologies in creating this article.

Authors' contributions. M.W.: conceptualization, writing—original draft, writing—review and editing; J.A.Z.: writing—original draft, writing—review and editing; C.N.W.: writing—original draft, writing—review and editing; S.P.: writing—original draft, writing—review and editing; H.W.: writing—original draft, writing—review and editing; T.W.W.H.: writing—original draft, writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

Funding. No funding has been received for this article.

Acknowledgements. We thank Lisa Barber for drafting figure 1 and David Aldridge (University of Cambridge) for the image of figure 2. We are grateful for the constructive comments of two anonymous reviewers.

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