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Could a potential Anthropocene mass extinction define a new geological period?

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Abstract

A key aspect of the current debate about the Anthropocene focuses on defining a new geological epoch. Features of the Anthropocene include a biodiversity crisis with the potential to reach "mass extinction" status alongside increasing global CO_2 and temperature. Previous geological boundaries associated with mass extinctions, rises in atmospheric CO_2 and rises in global temperature are more usually associated with transitions between geological periods. The current rapid increase in species extinctions suggest that a new mass extinction event is most likely imminent in the near-term future. Although CO_2 levels are currently low in comparison to the rest of the Phanerozoic, they are rising rapidly along with global temperatures. This suggests that defining the Anthropocene as a new geological period, rather than a new epoch, may be more consistent with previous geological boundaries in the Phanerozoic.

Interest in the Anthropocene concept has increased exponentially across science, social science and the humanities in recent years (Oldfield et al., 2013). However, formalising the Anthropocene within standard stratigraphic terms is extremely difficult as it must rely on what is observed in the stratigraphic record while being intrinsically a present- and future-facing issue. There has already been much debate over whether a new epoch should be defined (e.g. Zalasiewicz et al., 2008; Autin & Holbrook, 2012; Devries Klein, 2015; Finney & Edwards, 2016; Waters et al., 2016), the timing of the potential Holocene–Anthropocene boundary (Zalasiewicz et al., 2015a), and appropriate stratigraphic markers that may be used to demarcate its onset (Zalasiewicz et al., 2014; Swindles et al., 2015), if indeed it is accepted by the International Stratigraphic Commission (ICS). Some of the times that have been proposed for the beginning of the Anthropocene have been based on ambiguous or regionally-variable stratigraphic markers (see Zalasiewicz et al., 2015b). For the purposes of continuity within the International Chronostratigraphic Chart, unambiguous, globally-widespread markers in the geological record are needed to define the Anthropocene; such as the appearance/disappearance of indicator fossils, chemical signatures or abiotic markers. Two stratigraphic markers – spheroidal carbonaceous particles (SCPs) (Rose, 2015; Swindles et al., 2015) and radionuclides from nuclear weapons testing (Zalasiewicz et al., 2015a) may be well placed to provide a globally-synchronous marker for a mid-twentieth century date, as they can be found in sediment successions across the globe. This corresponds with the onset of the Great Acceleration which is a period defined by rapidly increasing impact of human activities on the Earth system since the 1950s (Steffan et al., 2007). Data detailing the rapid increase in human impact (e.g. CO_2, nitrous oxide, ocean acidification, human population increase, and fertilizer consumption) on the Earth system since the 1950s were first published in 2004 and recently updated to reflect changes up to 2010 by Steffen et al., (2015). If the Anthropocene is formalised by the ICS, then the transition from the Holocene to the Anthropocene must be supported by the identification of a clear signal in the geological record, and given that human activity is the driver of the Anthropocene, such a signal should ideally reflect the impact of human activity on the Earth system (Hamilton, 2015).

Williams et al. (2015) have suggested that the Anthropocene may potentially mark a third stage in the evolution of the biosphere, characterised by the dominant impact of humans across planet Earth. Williams et al. (2015) discuss potential trajectories for human influence on the biosphere, both with a potential collapse of the human-dominated Anthropocene leaving only a minor trace in the geological record at one extreme and a potential major increase in human influence that leaves a much more significant mark in the geological record at the other. The authors suggest that, with the latter potential trajectory, the Anthropocene may come to mark the beginning of a third phase in the development of the biosphere. This possibility far exceeds the definition of a new geological epoch. The formalisation of the Anthropocene as an *epoch* may be premature as the Earth system is still in transition, and future trajectories are currently unclear. However, without significant action, the scale of humanity's impact on the Earth system is more likely to at least match transitions between *periods* in the geological timescale.

A key feature of this transition is a major decline in the number of species across the planet that may reach levels similar to previous mass extinction events. This potential mass extinction has been coined 'the sixth mass extinction' in the literature (e.g. Barnosky et al., 2011; Ceballos et al., 2015). The International Union for Conservation of Nature (IUCN) reports over 800 confirmed extinctions in the last 500 years, and global extinction rate is increasing at an unprecedented pace (e.g. Ceballos et al., 2015; De Vos et al., 2014; Urban, 2015; Waters et al., 2016). The current extinction rate has already far exceeded the one extinction per million species years (E/MSY) "background" geological level (Pimm et al., 1995) and will continue to increase in the near future (Pimm et al. 2014; De Vos et al., 2014). True background extinction rates are difficult to estimate with wide variation between studies. For example, the value of 1 E/MSY rate was proposed based on terrestrial vertebrate fossil record (Pimm et al., 1995), but even higher rates have been suggested for mammals. For example, Barnosky et al., (2011) suggest 1.8 E/MSY whereas Ceballos et al., (2015) assessed mammal extinctions based on a 2 E/MSY background level and found that rates of extinction in the last 500 years were over 100 times this level. De Vos et al (2014) suggested even greater current extinction rates approximately

1,000 times higher than natural background levels of 0.1 E/MSY based on phylogenetic analysis and diversification rates. Regardless, current extinction rates exceed all of these projections of "background" extinction (Pimm et al., 2014), which strongly suggests that a major extinction event is beginning or about to begin.

The previous five mass extinctions, three of which occur over several tens to hundreds of thousands of years or more towards the end of geological periods, are characterised by a decline of at least 75% of species (Sepkoski 1996; Jablonski & Chaloner, 1994; Barnosky et al. 2011; Table 1). The fossil record is clearly imperfect, with certain plants and animals more likely to become fossils than others due to their abundance, habitat, life form and chemical composition as well as how they were actually preserved (e.g. Spicer, 1989; Greenwood, 1991; Benton et al., 2000; Gastaldo, 2001; Kidwell, 2001; Benton and Harper, 2009; McNamara et al., 2012; Bacon et al., 2015). Shallow marine invertebrates, for example, have a much more complete fossil record (Jablonski, 1991; Alroy et al., 2008) than small mammals such as bats and rodents (Plotnick et al., 2016). Different organisms also have different sensitivities to mass extinction events. For example, plants do not show globally severe responses to most previous mass extinctions with the exception of the end-Permian (Cascales-Miňana et al., 2015; McElwain & Punyasena, 2007). These differences are reflected in the fossil record by an often much clearer signal of mass extinction in the marine compared with the terrestrial realm (Jablonski, 1991; McElwain & Punyasena, 2007), and the "Big 5" mass extinction events were first identified in the marine invertebrate record (Raup and Sepkoski, 1982; Sepkoski, 1996).

The disparities between marine and terrestrial fossil records and between modern ecological and palaeobiological data make comparing modern extinction likelihoods to past mass extinctions problematic. Plotnick et al., (2016) compared IUCN mammal data to palaeoecological data and found that many of the currently at risk species do not have a fossil record. They suggest that, for mammals, greater than 75% species decline is required to generate an extinction event that would leave a fossil record similar to one of the "Big 5" mass extinction events. Although modern extinctions are severe, they have not yet reached a level comparable with previous mass extinctions (Bamback, 2006). Although the 75% species decline is somewhat arbitrary and may over-estimate the likelihood of a mass extinction event, it remains a useful starting point to investigate current threat levels.

The IUCN assesses species of plant, animal and fungi to determine their extinction risk. Currently, just under 5% (4.6%) of species within these groups have been assessed (IUCN, 2015). Within classes, this ranges from 100% of species assessed (e.g. Aves) to under 1% of species assessed (e.g. Anthocerotopsida (Hornworts) and Insecta). interpretation of IUCN data must be considered with the caveat that only a small fraction of most classes have been assessed for their conservation status and extinction risk. This is particularly the case for several classes of invertebrate and plant. However, the assessments provide an interesting sample of species current extinction risk across groups. In order for a mass extinction to be considered in progress, a minimum of 75% observed extinctions would be needed in at least two classes (Bamback, 2006).

An examination of IUCN extinction status for the species currently assessed, shows that, with the exception of Turbellaria (flatworms), for which only one species has been assessed, no class of assessed plant or animal has experienced known extinction rate at or exceeding 18% (Figure 1(a)). When data are included for species highly likely to be extinct, but not confirmed to be extinct (classified informally by the IUCN as critical, probably extinct and critical, probably extinct in the wild) (Figure 1(b)), no class of plant or animal has confirmed or likely extinct numbers at or above 35%. These percentage species extinctions across classes are far below the required 75% species extinction level needed to define a mass-extinction event. Figure 1(c) combines known extinctions, likely extinctions and species classified as ‘threatened’ by the IUCN. The inclusion of the threatened species categories highlights groups that are at greatest risk of reaching the 75% threshold in the near-term future. When these threatened species are considered, 14 classes reach or exceed 75% of species either extinct or at risk of extinction. Similar to previous studies (Barnosky et al., 2011; 2012), these data suggest that although not all these species are condemned to extinction, this is a clear warning that the mass extinction may be almost imminent.

Observations of increasing CO_2 (130ppm rise since ~1880; IPCC, 2013), temperature (1°C higher than the pre-industrial level; IPCC, 2013), and changes to ecosystem structure (urbanisation, agriculture, deforestation, acidification of freshwater and marine environments), although not directly comparable to events in the geological record, are not dissimilar to the early onset stages of previous mass extinction events (Wagner et al., 2006; McElwain et al., 2009; Roopnarine & Angielczyk, 2015). In comparison to the three most recent mass extinctions that are all associated with changes to the global carbon cycle, these current rises are quite modest. For example, the end-Permian mass extinction was characterised by an increase in CO_2 of ~2,000ppm (Payne et al., 2010; Clarkson et al., 2015; van de Schootbrugge & Wignall, 2015; see Table 1) and a rise in global average temperature of ~8°C (Payne et al., 2010; Retallack, 2013; van de Schootbrugge & Wignall, 2015; see Table 1). Similarly, the end-Triassic mass extinction was characterised by an increase in CO_2 by ~1,500ppm (McElwain et al., 2007; Steinthorsdottir et al., 2011; Schaller et al., 2011; van de Schootbrugge & Wignall, 2015; see Table 1) and in global average temperatures by ~4°C (McElwain et al., 2007; Schaller et al., 2011; Retallack, 2013; van de Schootbrugge & Wignall, 2015); see table 1). Therefore, while these modern increases are highly concerning, once again they are not at the level associated with a major environmental change linked to mass extinction events.

The current increases in extinction rate, temperature and CO_2 are characteristic features of the Anthropocene. These environmental variables have been linked with mass extinction events, many of which occur towards the end of geological periods in the Phanerozoic. However, extinction is not yet at a level that can be clearly identifiable in the geological record across the globe (Plotnick et al., 2016). Currently, increases in global temperature and CO_2 concentrations are in transition and have yet to reach their peak levels (IPCC, 2013). However, these variables are on track to match or exceed the levels seen across the most severe mass extinction events in Earth history (Barnosky et al., 2012;

Ceballos et al., 2015). Modern extinction levels, alongside increases in temperature and CO_2 are driven by human activity. Therefore, depending on the near-future trajectories of these environmental variables which remain uncertain (Williams et al., 2015; IPCC, 2013), proposing the Anthropocene as an epoch may be in haste. Although the more conservative definition of the Anthropocene as an epoch may be approved by the ICS in the short-term, it is perhaps useful to be mindful of geological and biological signals that may support the definition of a new geological period in the medium-term (next 100–200 years). Perhaps debates over the timing of the Anthropocene boundary would be better focussed on considering the likelihood of a new period in the next century rather than a new epoch in the 20th Century to define the age of human dominance on the Earth system. In the mid-term future, a new period boundary may completely overwrite the proposed epoch boundary for the Anthropocene.

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Figure caption:

Figure 1: Percentages of species within classes that are listed as (a) extinct (b) extinct and likely extinct, and (c) extinct and threatened by the IUCN red lists of threatened species (red line indicates 75% species extinction level). Relevant IUCN categories of species risk are: extinct – EX (known extinct species) plus EXW (known extinct in the wild species); likely extinct – CR(EX) critically endangered species thought to be extinct plus CR(EXW) critically endangered species thought to be extinct in the wild [these are not formal categories in the IUCN red list but are part useful indicators of likely extinct species]; threatened species – CR (critically endangered), EN (endangered) plus VU (Vulnerable) species. These figures include all species and classes of animal, fungi, and plant assessed by the IUCN as of November 2015 (other than Turbellaria, which is not included because it obscures the scale and

represents one group described as 100% assessed extinction by the IUCN). Data available from tables 3, 4, and 9 on the IUCN website (www.iucnredlists.org). Data downloaded December 2nd 2015.