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The prospect of global environmental relativities after an Anthropocene tipping point

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ABSTRACT

While there is vigorous debate on whether the Anthropocene epoch began in 1800, as originally proposed, less attention has been paid to the transition from Stage 2 of the existing three stage chronology, in which carbon dioxide emissions accelerated after 1945, to Stage 3, in which after 2015 acceleration is expected to reach criticality, and the Earth System is predicted to pass through an irreversible "tipping point" to a warmer state, unless this is averted by a new planetary stewardship. This paper critically evaluates this chronology and finds (a) that there is insufficient evidence for an imminent irreversible tipping point, and (b) that the international community established a new planetary stewardship in 1992 when it agreed on new conventions on climate change and biodiversity in response to three decades of warnings about global environmental problems. The paper proposes an alternative framework for conceptualizing the transition between Stages 2 and 3 of the Anthropocene. This generates the hypothesis that after the actual carbon dioxide concentration of the atmosphere has exceeded a critical threshold level, some biophysical processes will change at rates proportional to the difference between the carbon dioxide concentration of the atmosphere and the threshold level, and to the rate of climate change. Evidence is presented which suggests that this new reversible tipping point could have been passed before 1980, when enhanced forest growth was first observed in mature forests in Amazonia. Modelling simulations suggest that this temporal relativity effect could soon be joined by a spatio-temporal relativity effect, as species become committed to extinction and/or form new species assemblages in the 21st Century when climate zones shift. Since this new tipping point is reversible there is still time for planetary stewardship to become more effective and minimize the harmful effects of climate change.

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1. Introduction

Increasing human modification of the global environment led Crutzen and Stoemer (2000) to propose that we should "emphasize the central role of mankind in geology and ecology" by recognizing that since the end of the 18th Century we have lived in a new geological epoch, called the "Anthropocene". They chose to start the epoch at the beginning of the Industrial Revolution, whose dependence on fossil fuel combustion initiated the rise in carbon dioxide emissions that is now changing global climate, by enhancing the natural warming mechanism of the 'greenhouse effect' (Arrhenius, 1896).

This paper aims to assess, and enhance, the relevance of the Anthropocene to forest research. While welcoming the fact that geology is now incorporating phenomena which they have studied for decades, forest researchers would also be quite justified in thinking that the Anthropocene concept is unlikely to benefit them. Indeed, only a few forest studies have been framed by it so far (e.g. Paquette and Messier, 2010; Malhi et al., 2014; Allen et al., 2015; Lugo, 2015). One crucial difficulty is that *time* means different things to different scientific disciplines, and the periods of time over which geologists detect significant changes far exceed those to which scientists in other disciplines are accustomed. Forest science is proud of taking a long-term view, supporting the sustainable management of forests on rotations of typically 50 years or more in temperate countries. Yet it is dwarfed by geology, which measures time in units of millions of years. The 216 years since the Anthropocene epoch began may seem to have passed like the blink of an eye to geologists, but they encompass the entire history of forest science: the founding of the first schools of forestry in Europe around 1800 coincided with the start of the Anthropocene, and much knowledge has been gained since then. So if the new term is to be used properly, "Forestry in the Anthropocene" should not refer to a new type of forestry that responds to *current* conditions in "the last several decades" (Lugo, 2015), but to the whole history of forestry over the last 216 years! Other studies with 'Anthropocene' in their titles fall into this trap too.

Those promoting recognition of the Anthropocene as a new epoch in the taxonomy of geological time are engaged in two main lines of research. First, determining when the *start* of the epoch will be best measured in rocks by future geologists (e.g. Zalasiewicz et al., 2011, 2015). Second, viewing the Anthropocene as a *process* which is evolving in distinct stages. In one chronology, the first stage began in 1800. A second,

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"Great Acceleration", stage followed in 1945, after which there was a dramatic rise in the human imprint on the planet, as measured by such indicators as carbon dioxide emissions from fossil fuel consumption and tropical deforestation. A third stage would begin after 2015, as the human imprint accelerated toward "criticality". If business proceeds as usual, and the human imprint is not controlled by a "new planetary stewardship", the planet could pass through a "tipping point" to a permanently warmer state, with serious consequences for all life on Earth (Steffen et al., 2007, 2011a).

After reviewing the Anthropocene literature, this paper draws three conclusions. First, the process approach is of most relevance to forest researchers, since it can provide a tangible focus for *contemporary* studies. Second, forest research will derive most benefit if the process at the core of Anthropocene research is the enhanced greenhouse effect, as originally proposed by Crutzen and Stoemer (2000), complemented by biodiversity change, which is also highlighted by Steffen et al. (2007, 2011a) and is studied by both contemporary ecologists and palaeoecologists (Barnosky et al., 2011). Third, greater clarity is needed about the transition between Stages 2 and 3 of the three stage chronology, and about the timing of the concepts of "criticality", "new planetary stewardship" and "tipping point" and the mechanisms that link them.

To fill this gap, and respond to an invitation to all scientists to collaborate in "re-conceptualizing the Anthropocene" (Brondizio et al., 2016), this paper proposes a new conceptual framework for explaining the transition between Stages 2 and 3. This framework generates the hypothesis that above a threshold level of carbon dioxide in the atmosphere the planet will pass through a *reversible tipping point* and move from the special condition of relative "*stationarity*" in climate, which has prevailed since at least the start of the Anthropocene (Wolkovich et al., 2014), to a *non-stationarity* condition common in pre-human times, when climate zones and ecosystem types were more mobile on the Earth's surface. Under non-stationarity, we further hypothesize that new *global environmental relativities* will emerge in which key biophysical processes start to change at rates that are directly proportional - though not necessarily in a linear way - to the difference between the carbon dioxide concentration of the atmosphere and this threshold level, and to the rate at which climate changes. In this more uncertain non-stationary world, ecosystem properties can no longer be predicted by using past environmental measurements, but will change in ways that are related to changes in environmental variables linked to the enhanced greenhouse effect. Empirical data are vital for timing the transition to Stage 3, and the paper presents evidence that the new tipping point could have been passed before 1980. Since conventions on biodiversity and climate change were agreed at the United Nations Conference on Environment and Development in 1992, the shift to a "new planetary stewardship" may have already taken place too. There is still time to avoid passing through the later irreversible tipping point predicted by Steffen et al. (2007, 2011a).

The rest of the paper is in four parts. Part one critically evaluates the Anthropocene literature and the three stage chronology and suggests how to refine the latter. Part two outlines a new conceptual framework for explaining the transition between Stages 2 and 3, and generates from this hypotheses linked to a reversible tipping point. Part three examines the currently available evidence for testing these hypotheses. Part four discusses the research, economic and policy implications of this new approach.

2. Literature review

2.1. The core Anthropocene literature

One conceptual advance made by the originators of the Anthropocene concept (Crutzen and Stoemer, 2000) was to identify humanity as a "major geological force" on a *global scale* (Crutzen, 2002). Another was to connect anthropogenic global environmental change and geological time. Geologists divide the 4550 million (M) years of the Earth's existence into ten eras, most of which are divided in turn into periods and then epochs (Table 1). We are now in the Cenozoic era, which began 66 M years ago (Mya), and in its Quaternary period, which began 2.6 Mya. The first epoch of the Quaternary, the Pleistocene, was characterized by various glaciations and non-glacial intervals. Almost 12,000 years ago it was followed by the Holocene epoch, which is the latest to be officially recognized by the International Commission on Stratigraphy (ICS) of the International Union of Geological Sciences (Cohen et al., 2013). In the "accommodating" and "resilient" environment of the Holocene (Steffen et al., 2011a), human beings have played an increasingly important role (Roberts, 1989). This taxonomy of geological time will be modified to insert an Anthropocene epoch after the Holocene epoch if representations by advocates of the Anthropocene succeed.

Since the year 2000 the Anthropocene concept, and its justification, have been refined by a collaboration between one of its originators, an environmental scientist (Crutzen), and scientists from other disciplines, especially geology, who are also members of the ICS Anthropocene Working Group (http://quaternary.stratigraphy.org/workinggroups/anthropocene/). These *core Anthropocene scholars*, as they will be referred to here, have made two further fundamental contributions.

First, they have examined various options for reaching international agreement on timing the start of the new epoch in the *geological record* (see below) and have provided four justifications for the epoch (Zalasiewicz et al., 2010):

1. It is necessary to distinguish a new interval of time which is "dominated by human activity" that has had environmental impacts at *global* scale, from the Holocene in which humans had more limited (and localized) impacts.
2. Human impacts have led to "an order of magnitude increase in the long-term rate of erosion and sedimentation" which is geologically important.
3. Humanity has also had a global impact by greatly increasing the atmospheric concentrations of trace gases, such as *carbon dioxide* and *methane*. This is expected to raise the mean average temperature of the planet by 2–5 °C during the 21st Century.
4. Global climate change is expected to combine with habitat change and other human impacts to greatly increase the current rate of *species extinction*.

Second, by developing a *process-based approach*, and using quantitative indicators of environmental and socio-economic changes, they have proposed that the Anthropocene can be divided into three stages (Table 2) (Steffen et al., 2007, 2011a):

1. Stage 1 began around 1800, at the same time as the Industrial Revolution, which increased fossil fuel combustion and had other major impacts on the planet.

Table 1
The geological time scale since the Cambrian period.
Source: Cohen et al. (2013).

Era	Period	Epoch	Millions of years ago
Cenozoic	Quaternary	Holocene	0.01
		Pleistocene	2.6
	Tertiary	Pliocene	5.3
		Miocene	23.0
		Oligocene	33.9
		Eocene	56.0
		Palaeocene	66.0
Mesozoic	Cretaceous		145.0
	Jurassic		201.3
	Triassic		252.1
Palaeozoic	Permian		298.9
	Carboniferous		358.9
	Devonian		419.2
	Silurian		443.4
	Ordovician		485.4
	Cambrian		541.0

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