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Physical geography in the Anthropocene

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Abstract
Even as it remains an informal term defining the emergence of humans as a force transforming Earth as a system, the Anthropocene is stimulating novel research and discussion across the academy and well beyond. While geography has always been deeply connected with the coupled human–environment paradigm, physical geographer's embrace of the Anthropocene still appears lukewarm at best. While there are good reasons to hesitate, including the fact that the Anthropocene is not yet, and might never be, formalized in the Geologic Time Scale, physical geographers have much to gain by embracing what is rapidly becoming the most influential scholarly discussion on human–environmental relations in a generation. This editorial was commissioned for the author's debut as Contributing Editor of *Progress in Physical Geography*.

Keywords
Anthropogenic global environmental change, climatology, biogeography, geomorphology, hydrology, pedagogy

I Introduction

The call to recognize the Anthropocene as a new epoch of geologic time is spreading rapidly across the scholarly world and beyond. Whether or not the Anthropocene is ultimately formalized within the Geologic Time Scale, its widespread popularity embodies a paradigm shift now well underway. The Anthropocene marks our time as one in which Earth's form and functioning have become inextricably entangled with the workings of human societies (Steffen et al., 2004, 2016; Waters et al., 2016). It is no longer possible to understand, forecast, or manage Earth's dynamic environments using only the conventional tools of the natural sciences. In the Anthropocene, geophysics, geochemistry, and biogeography are simply not enough.

The Anthropocene demands that we go beyond the classic spheres of the Earth system, toward an integrated understanding of the form, functioning, and dynamics of the anthroposphere and its interlinkages and interactions across the spheres (Figure 1) (Ellis and Haff, 2009; Lucht, 2010; Schellnhuber, 1999). In the words of Hans Joachim Schellnhuber, the Anthropocene paradigm forms the roots of a "Second Copernican Revolution" (Schellnhuber, 1999).

The Anthropocene has already stimulated an explosion of publications on human–environmental change across the scientific disciplines and the humanities (Figure 2). At the end of July

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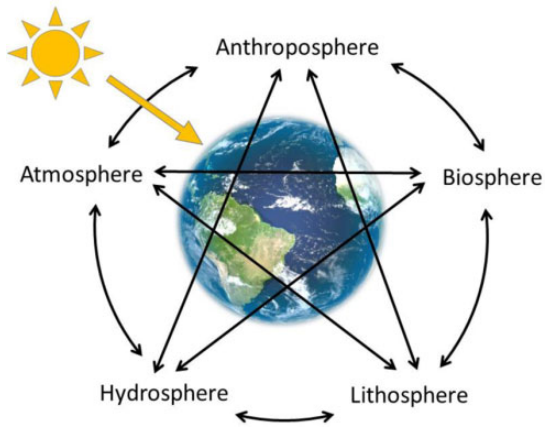

Figure 1. The spheres of the Earth system, including the anthroposphere.

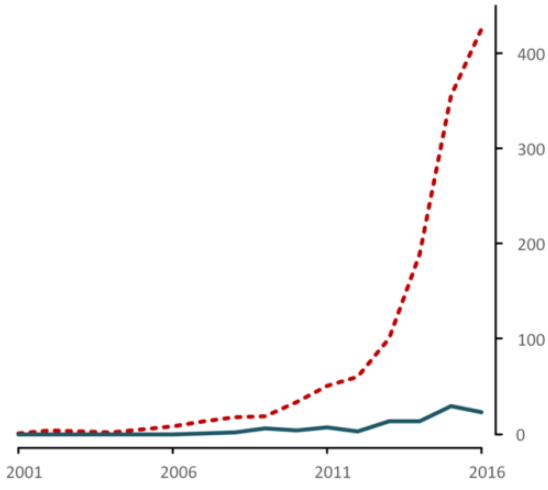

Figure 2. Publications in Web of Science with the topic "Anthropocene" from 2000 to 2016 (dashed line); publications in the Physical Geography research area are represented by a solid line.

2017, Google Scholar included more than 42,800 sources containing the word Anthropocene, with more than 3000 including it in their title. Web of Knowledge recorded 1573 sources with 16,307 citations on this topic. Yet only 119 of these sources (<8%) and 1806 citations (~11%) were in the Physical Geography research area, while "Environmental Sciences Ecology" included 435 sources, and Geology 237, respectively. *Progress in Physical Geography* published only five of these articles, while *Progress in Human Geography* published nine; *Science*, *Nature*, and *PNAS* together published 57. Physical geographers, or at least the physical geography journals, have clearly not been major contributors to the Anthropocene literature.

The relatively low contribution of physical geography is puzzling. Despite the novelty of "Anthropocene" as a term, the paradigm it represents might even be said to have originated among geographers (Cook et al., 2015). In 1865, George Perkins Marsh published "Man and Nature: or, Physical Geography as Modified by Human Action". Like "Man and Nature", even the titles of numerous subsequent geographic classics say it all, including Thomas (1956) and Turner et al. (1990). Yet, it is equally clear that the current proposal to formally recognize an "age of humans" emerged almost entirely outside geography as a discipline, coined by ecologist Eugene Stoermer, published by atmospheric chemist Paul Crutzen, and established through the work of Earth system scientist Will Steffen, geologist Jan Zalasiewicz and many others with only marginal linkages with geography (Steffen et al., 2011; Zalasiewicz et al., 2017b). The work of Castree (2014) and Lewis and Maslin (2015) are among the rare exceptions that prove the rule.

Should physical geographers be doing more to embrace the Anthropocene? As the term has come to embody the global-scale coupling of human and environmental change, it seems awkward that a discipline with such deep paradigmatic connections with this is not clearly associated with it. Why is geography not waving its flag at the head of the Anthropocene movement?

II Not ready to rock?

Despite the Anthropocene's popularity, and perhaps because of it, there are good reasons for geographers to hold back. Much scholarly work

on the Anthropocene, including publications by prominent geologists, argues against its establishment as a formal period of geologic time (Finney and Edwards, 2016; Ruddiman et al., 2015; Zalasiewicz et al., 2017b). For many geographers, the Anthropocene represents a problematic misnomer; a "species narrative" embodying a profound misunderstanding of the socially differentiated, historically contingent, and deeply heterogeneous and unequal nature of human–environmental change – one that might produce more problems than solutions (Castree, 2014; LeCain, 2015; Malm and Hornborg, 2014; Moore, 2016). It is not "humans" who are causing Earth to change – but rather, differentiated groups of humans, engaging in different social–environmental processes at different times with different consequences. These and other such criticisms are only likely to increase if and when the Anthropocene is formalized within the Geologic Time scale.

As an informal term, the "anthropocene" merely represents Earth's transition to a time of profound human influence on its functioning as a system (Ruddiman et al., 2015). As such, there is little controversy in the scholarly world. A formal Anthropocene epoch will likely be quite different. A formal Anthropocene epoch will require the insertion of a discrete break, or lower boundary, into the scientific calendar of Earth's history, marking the precise start of its one and only "human" epoch, most likely at some point in the middle of the 20th century (Waters et al., 2016). Even with the appropriate caveats from geologists about the limited meanings of the Anthropocene's lower boundary (Zalasiewicz et al., 2017a), and even were its boundary set to a much earlier time, at the start of the Industrial Revolution (circa 1800 CE), the Columbian exchange (circa 1610 CE), or the rise of anthropogenic methane from rice and livestock production (circa 5000 BP (Lewis and Maslin, 2015), the act of defining a discrete and precisely dated start for an age of humans will be seen by many as obfuscating, or at least clashing with, the continuous, gradual, heterogeneous, and diachronous model of human–environmental change that has long been and likely will remain the dominant paradigm of geographers and other environmental and social scientists (Bauer and Ellis, 2018; Brown et al., 2017; Edgeworth et al., 2015; Ellis et al., 2016).

There are other issues for geographers considering the Anthropocene. The Anthropocene's paradigm of a global coupling of human and environmental change has more or less been the mainstream view of geographers since the inception of the discipline. Aside from its problematic demand for a discrete boundary in time, it is not clear how the Anthropocene adds substantially to the existing human–environment frameworks of geography. Moreover, the Anthropocene is already showing signs of becoming an academic fad – a bubbling up of scholarly interest that might ultimately fade into noise as its interpretations become too varied and intermingled for it to mean anything specific (Cook et al., 2015). Perhaps geographers would be wise to simply wait for the whole Anthropocene thing to blow over.

III Engage the Anthropocene

In my view, this would be a major mistake. To continue waiting on the sidelines while the Anthropocene reshapes scholarly discussion on human–environment relations across the academy will merely leave geography out in the cold. Geographers, with such a deep historic and processual understanding of the complex realities of human–environmental change, are ideally placed to lead in shaping the future of Anthropocene scholarship. Given that the Anthropocene is attracting interest to some of the most important core areas of geographic expertise, areas where geography can make major impacts across the academy and beyond, the Anthropocene is just too important to leave to others.

Geography has long prided itself as one of the most interdisciplinary departments at the

university, the home of both natural and social scientists, scholars of the humanities, experts in geospatial computing, and many working closely at their interface. Largely for this reason, geographers have long led the call to integrate scholarship and pedagogy across disciplines. Yet, the first question that geographers tend to ask each other is "physical or human?" Although sometimes the answer is "both" (for the many working on human–environment interactions), disciplinary divides within geography have generally remained strong and deep (Malanson et al., 2014; Tadaki et al., 2012).

The Anthropocene calls on geographers to bridge the two-cultures divide and to fulfill their long-stated purpose of being the most integrative scholars of the academy (Harden et al., 2014). It urges physical geographers to return to their roots – to think more deeply in time and more broadly in scale – to bridge the disciplinary (and sometimes pragmatic) separation of Earth system science and the sciences of Earth surface processes at local, regional, and global scales (Clifford and Richards, 2005; Davis, 1899; Richards and Clifford, 2008; Summerfield, 2005). The Anthropocene is a call to action for geographers to do what they do best. Not to do so would be a missed opportunity of epochal proportions.

IV Physical geography *of* the Anthropocene

Physical geographers have already contributed substantially to scientific efforts to understand the emergence of globally significant human–environmental change: an essential part of defining the Anthropocene. For example, the top cited Anthropocene paper in the physical geography research area of Web of Science presents a "spatially explicit database of human induced global land use change over the past 12,000 years (Klein Goldewijk et al., 2011). This and related work has been fundamental to investigating and modeling long-term anthropogenic changes in global climate and the biosphere (e.g. Ellis, 2011; He et al., 2014; Kaplan et al., 2011; Ostberg et al., 2015; Ruddiman et al., 2016; Verburg et al., 2016). Geographers, especially Billie Turner, helped to lead the integrative efforts of natural and social scientists, including those across the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP) that synthesized key evidence characterizing Earth's transition to the Anthropocene (Steffen et al., 2004; Turner et al., 1990). These are just a few among the many critical contributions already made by geography and geographers to the science of the Anthropocene; a thorough review would easily find hundreds more. To continue their essential and pervasive contribution to "Anthropocene studies", geographers need only continue their work on human–environmental change, while identifying it as relevant to the Anthropocene with a keyword or other use of the term.

V Physical geography *in* the Anthropocene

The Anthropocene paradigm irreversibly interlocks the natural and social sciences and the humanities. Conditions remain under which the human and natural worlds still operate independently, as they have for most of Earth's history. Nevertheless, in the Anthropocene – and especially in the anthropocene – this independence must be treated as an hypothesis to be tested, not as an operational assumption. The hydrologic flow dynamics of a river might be fully explained without any need to consider the direct human manipulations of this flow or the structural forms of its watershed hydraulics. Yet, the opposite might also be true: the degree of human influence must always be tested. As with hydrology, so also with geomorphology, climatology, biogeography, and the other subdisciplines of physical geography in the Anthropocene.

Humans and human societies are an evolved product of the natural world. There is nothing unnatural about us. Yet, there are profound ways in which human societies and their interacting world systems, or "human systems", have brought unquestionably novel processes and new forms of social–environmental interactions to the Earth system. On one level, human systems simply interfere with pre-existing Earth system processes, as when the frequency of forest fires are increased or suppressed, together with their greenhouse gas and aerosol emissions to the atmosphere and their interactions with global climate. Yet, some anthropogenic processes are entirely novel, like the mass combustion of fossilized biomass, the mass production of non-biodegradable plastic materials, the direct harvest of energy from nuclear fission, and the widespread tillage of soils. Human systems represent far more than a mere disturbance or impact on the functioning of the Earth system. In the Anthropocene, human systems have emerged as Earth subsystems, as integral and defining to the functioning of Earth as a planet as are its classic geophysical, geochemical, and biogeographic processes. As with the rise of life and photosynthesis, the emergence of human systems with the capacity to transform the functioning of Earth as a system has moved our planet onto a new and uncharted path.

VI Human systems are part of physical geography

It has long been common for physical geographers and other natural scientists to consider only the consequences or impacts of human systems, but not their causes. In the Anthropocene, such limited scientific understanding of Earth and environmental processes is no longer adequate. Environmental change is now coupled in both directions with human social change. To engage in Earth and environmental science in the Anthropocene, physical geographers and other natural scientists must expand their causal understanding of human systems and their dynamics to levels similar to those at which they already understand the natural systems outside their closest specialty. Biogeographers have always studied geophysics and biogeochemistry. Climatologists and biogeochemists study biogeography. Now, we must all study human systems and the anthroposphere.

Such study is no small investment. It requires sustained dedication to learning across disciplines. Yet, the returns are absolutely worth it. I can personally attest to this, and my efforts have likely been harder than most; I am a plant physiologist by training. As is commonly stated, the real breakthroughs in research do indeed come at the interface among disciplines. Along with these breakthroughs come both broader recognition and important advances in our thinking – both inside and outside the scholarly world.

Such efforts are already paying off. The classic subdisciplines of physical geography – climatology, biogeography, geomorphology, and hydrology – are now linking human systems more deeply into their research and pedagogy. Striking examples of what might become subdisciplines in themselves include anthroclimatology (Peterson and Broad, 2016; Ruddiman et al., 2016), anthrobiogeography (Ellis, 2015; Young, 2015), and anthrogeomorphology (or anthropogeomorphology; Brown et al., 2017; Goudie, 2017; Goudie and Viles, 2016; Tarolli, 2016).

VII Human systems are not physical, chemical, or biological

Perhaps the most important step down the path of engaging with human systems is developing a deep appreciation of their distinctiveness from physical, chemical, and biological systems. Humans are only one of many primate species living in the physical, chemical, and biological world. However, human systems are much more than this. Human systems are social systems

that emerge from the interactions of large numbers of individual decision-making agents structured by social roles, social institutions, social networks, and ultimately by social learning across generational time (cultural inheritances), all of which respond to both current and historical contexts and conditions on many different levels simultaneously (Chase-Dunn and Lerro, 2013; Ellis, 2015; Giddens, 1984). As a result, human systems bring entirely new dimensions of complexity and surprise to the functioning of Earth systems.

It is wise to be humble when confronted with the many ways that human systems have overcome what might appear to be hard physical, chemical, and biological limits (Defries, 2014; Ellis, 2015). For example, such limits cannot explain in a useful way how many people can live on Earth (Cohen, 1995; Franck et al., 2011; Marchetti, 1979; Sayre, 2008). The same square kilometer of land that once could sustain no more than a dozen individuals engaged in hunting and foraging might now sustain thousands of city dwellers around the world through intensive agricultural production distributed through global supply chains. In less than 10,000 years – the blink of an eye in Earth history – human societies have increased in scale from a few dozen individuals to hundreds of millions to billions.

From the first use of biomass to cook food (substituting for human biological energy in digestion) to the use of fossil fuels and nonbiological energy from the sun, wind, and nuclear, humans have harnessed huge amounts of nonhuman energy to do their work. No other species has these capacities, nor the ability to move materials, energy, biota, and information across an entire planet and beyond. Most importantly, humans have no unique biological capacity to do these things. All of these capacities are socially learned and can evolve far faster than any capacity produced by biological evolution.

It should surprise no one that just one single species in all of Earth's history has inspired its own geologic time period, or that human social capacities to transform Earth now threaten the future of both nonhuman species and contemporary societies.

VIII Physical geography *for* the Anthropocene

In response to a rapidly changing climate, acidifying oceans, mass extinction, and the wide array of other harmful anthropogenic environmental changes, physical geographers have an important role to play (DeFries et al., 2012). In efforts to address the challenges of the Anthropocene, it is critical to keep in mind that understanding the causes of environmental problems is not the same as understanding or seeking solutions (Oreskes, 2015). Solving environmental problems is ultimately a social enterprise and usually far removed from the scholarly world. There is no cockpit on planet Earth. If we want our science to change things for the better, it is not enough to make our measurements more accurate or to broadcast these to the media or to policymakers (Glynn et al., 2017). To shift human systems toward better outcomes, we must find ways to work in partnership with the people, social institutions, and processes that create and sustain our societies, even when our professional or personal belief systems might not agree with them.

IX Concluding thoughts

As Earth moves deeper into the Anthropocene, the inseparability of the human and natural worlds is increasingly evident to all. This awareness is galvanizing a broad movement to rethink the role of humans on Earth – not only as environment exploiters and destroyers, but also as engineers, gardeners, permanent stewards, and just bystanders on a planet rapidly and permanently reshaped by our societies. To make *Progress in Physical Geography*, it is time to engage with the Anthropocene as an intellectual

tool that might ultimately help guide societies toward better outcomes in the ongoing human transformation of Earth.

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