Annual Review of Environment and Resources

The Concept of the Anthropocene

Yadvinder Malhi

Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford OX1 3QY, United Kingdom; email: yadvinder.malhi@ouce.ox.ac.uk

Annu. Rev. Environ. Resour. 2017. 42:77–104

First published online as a Review in Advance on September 11, 2017

The *Annual Review of Environment and Resources* is online at environ.annualreviews.org

https://doi.org/10.1146/annurev-environ-102016-060854

Keywords

Anthropocene, Earth system sciences, planetary boundaries, global change

Abstract

The Anthropocene, the concept that the Earth has moved into a novel geological epoch characterized by human domination of the planetary system, is an increasingly prevalent framework for debate both in academia and as a wider cultural and policy zeitgeist. This article reviews the proliferation of literature surrounding this concept. It explores the origins and history of the concept, as well as the arguments surrounding its geological formalization and starting date ranging from the Pleistocene to the twentieth century. It examines perspectives and critiques of the concept from the Earth system sciences, ecological and geological sciences, and social sciences and humanities, exploring its role as a cultural zeitgeist and ideological provocation. I conclude by offering a personal perspective on the concept of the Anthropocene and its utility.

Contents

INTRODUCTION 78
A HISTORY OF THE CONCEPT OF THE ANTHROPOCENE 79
Informal Adoption and Spread 80
THE USE OF THE ANTHROPOCENE CONCEPT 83
The Earth System Sciences Perspective 83
The Biosphere Perspective 84
The Geological Perspective 85
Critiques from the Natural Sciences 87
The Historical Perspective: The Case for an Early Anthropocene 88
Cultural and Philosophical Perspectives 92
Responding to the Anthropocene: Managerial, Optimistic, and Catastrophist Perspectives 94
Critiques from Political, Philosophical, and Cultural Perspectives 96
CONCLUSIONS AND PERSONAL PERSPECTIVE 97
Is the Anthropocene a Useful Concept? 97
When Did It Start? 98
Should It Be Formalized? 98
What Are the Implications for Formalization? 99
Where Next with the Anthropocene? 99

INTRODUCTION

A new epoch, the Anthropocene, is in the air. Climate scientists, geologists, archaeologists, historians, ecologists, social scientists, and philosophers are debating this concept, and it has been embraced by writers, activists, the arts, and poets. The deliberations of an obscure scientific working group and the conventions of geological stratification are the focus of media and public attention. Prestigious prizes have been awarded to books with titles such as *Adventures in the Anthropocene* (1) and *The Human Age* (2), while a plethora of other books or papers muse on, among other things, "freedom," "art," or "learning to die" in the Anthropocene. In 2011, *The Economist* declared "Welcome to the Anthropocene" on its front page, and in 2013 a well-received series of art exhibitions in Berlin explored "The Anthropocene Project." The moods around these discussions range from alarm and urgency, through wistful nostalgia or pragmatic management, to optimistic grasping of opportunity. The Anthropocene has become a scientific and cultural zeitgeist, a charismatic mega-category emerging from and encapsulating elements of the spirit of our age. It may be a passing cultural fad or end up as something more enduring; it is used in different ways by different users, but it is undoubtedly a core aspect of contemporary thinking about the environment. There are many versions of the Anthropocene implied by different usages of the term, but amid this melee several common themes do usually emerge. The core concept that the term is trying to capture is that human activity is having a dominating presence on multiple aspects of the natural world and the functioning of the Earth system, and that this has consequences for how we view and interact with the natural world—and perceive our place in it. Unlike previous terms that seek to embody human impacts on the environment, *Anthropocene* adopts the formal nomenclature of an epoch of the Geologic Time Scale, deriving from the Ancient Greek *anthropos* ("human") and -cene from *kainos* ("new" or "recent"). Adoption of this geological term serves to highlight that

contemporary environmental changes are planetary in scale and significant on the timescale of Earth history and thereby draws attention to the magnitude and all-encompassing nature of these changes. It is this geological framing—a source of much of the potency of the term—that offers a route to scientific formalization but also causes scientific and interdisciplinary friction. From its origins as a concept in the natural sciences, the term has spilled across disciplines into the social sciences and humanities and into the wider cultural and political discussions surrounding how to live on and respond to the challenges of a human-dominated planet. Much of the vigor of this term now comes from these wider cultural and philosophical debates.

Geoengineering: the deliberate large-scale manipulation of an environmental process that affects the earth's climate, in an attempt to counteract the effects of global warming

Other key features of the Anthropocene often include emphasis on (*a*) the global and pervasive nature of the change; (*b*) the multifaceted nature of global change beyond just climate change, including biodiversity decline and species mixing across continents, alteration of global biogeochemical cycles and large-scale resource extraction and waste production; (*c*) the two-way interactions between humans and the rest of the natural world, such that there can be feedbacks at a planetary scale such as climate change; and (*d*) a sense of a current or imminent fundamental shift in the functioning of our planet as a whole.

Understanding the debate about the concept of the Anthropocene requires delving across a range of disciplines including geology, climate science, Earth system sciences, archaeology, history, philosophy, political economy, and social theory, as well as a range of timescales from deep Earth history, human prehistory, the dawn of agriculture, the European conquest of the Americas, the Industrial Revolution, the modern era, and the near and far future. Much of the potency of the term results from its embracing and stimulating new thinking across so many intellectual disciplines and cultural spheres. This range of disciplines is a challenge but also makes it such a thought-provoking, exciting, and important topic to address, for in trying to define the Anthropocene we try to define the deeper meaning and context of the modern environmental challenge—and the relationship between the human and the natural. This review attempts to pull together and organize some of the key arguments in the voluminous recent literature on the Anthropocene, serving as one possible guide through this forest of disciplines and perspectives.

A HISTORY OF THE CONCEPT OF THE ANTHROPOCENE

The modern use of the term Anthropocene[1] began in 2000 with Crutzen & Stoermer's (3) paper in the *Global Change Newsletter*, simply entitled "The Anthropocene." This was followed in 2002 by Crutzen's (4) high-profile piece in *Nature* ("Geology of Mankind"), which gained much wider circulation and attention. This short perspective made the case for the Anthropocene in terms of the magnitude of human impacts on the Earth system, in particular climate change but also ranging through deforestation, energy use and air pollution, harvesting of fisheries, and climate change, and it concluded by arguing that there may be a need to employ large-scale geoengineering to "optimize" climate. Hence, the core of this initial proposition came from the relatively new discipline of Earth system science, which examines the Earth as an integrated system incorporating its physical, biological, chemical, and human social dimensions, and employs the macroscopic tools of in situ and satellite-based monitoring programs and computational models of the Earth system.

Many of the ideas embedded in the concept are not new; it is the framing of the ideas as a single word, and perhaps the timing of the promotion of the concept, that gave it so much currency. As pointed out in Crutzen's (4) original article, throughout the twentieth century there has been recognition of the concept of a recent human-dominated age that is materially different from

[1]Some Soviet scientists had been using the term in the 1960s in a different sense, to refer to the entire Quaternary.

its predecessors, most notably Teilhard de Chardin and Vernadsky's coinage in the 1920s of the term Noösphere (sphere of thought), which signifies the growing influence of human thought and action in shaping its own future and the planetary environment (5). Steffen et al. (6) and Lowenthal (7) review these and other antecedents. However, Hamilton & Grinevald (8) argue that these antecedents were limited in scope, often focused on terrestrial ecological impacts and in many cases heavily laden with sanguine assumptions of improvement and inevitable progress "rooted in evolution, stages of consciousness or limitless economic growth"; they argue that only in the late twentieth century did the modern scientific understanding of the whole Earth system enable the developing of an Anthropocene framework.

Informal Adoption and Spread

Following the Crutzen piece in *Nature*, there was an initially slow but gradual increase in use of the term in scientific literature, in particular in the environmental and Earth system sciences where it became an eye-catching but ill-defined term for human-dominated modernity. Crutzen partnered with climate scientist Will Steffen and environmental historian John McNeill to present a more detailed and analytic case for the Anthropocene in 2007 (9).

A pivotal event in terms of gaining wider scientific acceptance and adoption was the publication of a thematic issue of *Philosophical Transactions of the Royal Society* in 2011. This issue covered a range of perspectives, including conceptual and historical antecedents (6), biosphere transformation (10), sediment fluxes (11), and the geological case (12). The Anthropocene was now truly adopted in wider environmental scientific discourse, as witnessed by a surge in the numbers of scientific papers with the topic "Anthropocene" (**Figure 1**). In 2013 and 2014, three new scientific journals emerged, dedicated to this concept: *The Anthropocene* (Elsevier), *Elementa: Science of the Anthropocene* (University of California Press), and *The Anthropocene Review* (SAGE Publishing) (13). A periodical, *Anthropocene*, aimed at a more general audience, was launched in 2015.

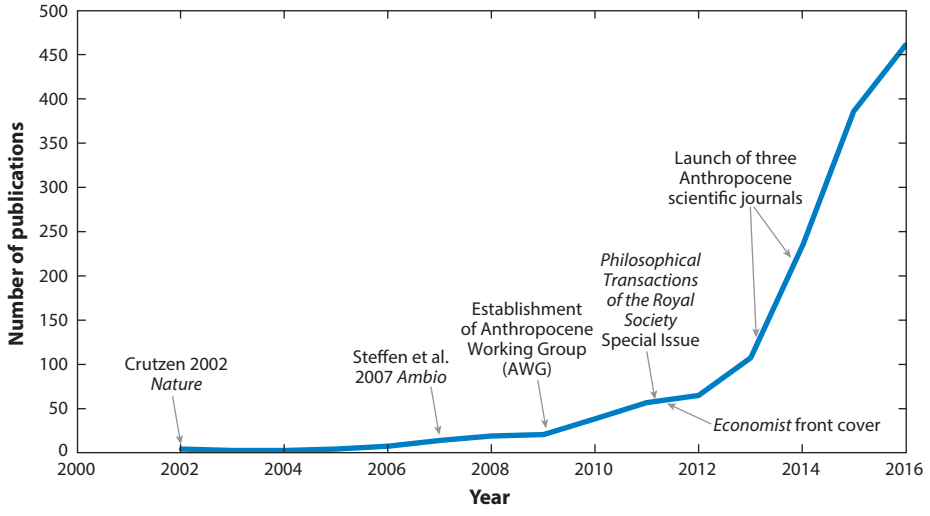

Figure 1

Timeline of the number of scientific journal publications per year on the topic "Anthropocene" (based on Web of Science) up until the end of 2016, with key events annotated.

The move toward a formal definition. Part of the chimeric nature of the term Anthropocene within the natural sciences comes from its intent and origins, as it is a concept deriving from the Earth system and environmental sciences, but it adopts the nomenclature conventions of geology. The increasing informal scientific and nonscientific usage of the Anthropocene soon gained attention within the geological sciences. On one hand, some geologists were unhappy that a concept dressed up as a geological term was being widely used in such a sloppy and imprecise way (14) and that the long timescales of the Geologic Time Scale were being adopted by and enmeshed in contemporary environmental advocacy and politics, which tend to be focused on much shorter timescales (15). On the other hand, some argued that a rigorous scientific case could be made for a new geological epoch, and this needed to be addressed formally.

WGA: Working Group on the Anthropocene

ICS: the International Commission on Stratigraphy

IUGS: the International Union of Geological Sciences

The prospect of geological formalization was raised in 2008 by Zalasiewicz et al. (16), who pondered whether a formal geological definition of the Anthropocene was justifiable, and if so, where and how its boundary might be placed. As a result, the Working Group on the Anthropocene (WGA) was established in 2009, with Zalasiewicz at its helm, to consider these questions and make recommendations to its parent body, the Subcommission on Quaternary Stratigraphy (SQS), one of 16 subcommissions of the International Commission on Stratigraphy (ICS) and its parent body, the International Union of Geological Sciences (IUGS). The IUGS is the major international scientific body for Earth scientists. The ICS is a major part of the IUGS, dedicated to defining the International Chronostratigraphic Chart, which sets out how the history of the Earth is formally partitioned.

After several years of deliberation and several scientific papers discussing key issues and proposed solutions (12, 17–20), in August 2016 the WGA announced to the meeting of the International Geological Society in Cape Town, South Africa, its vote in favor of formal adoption of the Anthropocene. The WGA made a provisional recommendation that the Anthropocene be established as a new geological epoch, with a start date in the mid-twentieth century, around the time of the Great Acceleration (see the section The Earth System Sciences Perspective, below). The exact start date would be defined by an as-yet unspecified stratigraphic marker, of which there are a multitude of candidates. That formal proposal will have to provide a detailed description of the stratigraphic content of the unit and show correlation of the stratigraphic record of the start of the Anthropocene to lake cores, ice cores, and other stratigraphic records from geographically widespread locations. A recommendation for a stratigraphic starting point (see the Stratigraphic Support for the Anthropocene section, below) will be submitted within a few years. Consideration of a proposal by the ICS Subcommission on Quaternary Stratigraphy and possibly then by the entire ICS will involve discussion among voting members. If the recommendation is approved by the ICS, the proposal to adopt the term would finally have to be ratified by the IUGS before its formal adoption as part of the Geologic Time Scale. Hence, despite much news coverage to the contrary, the Anthropocene has not yet been formally adopted as a geological epoch; any such adoption process will probably move at a relatively slow pace and is still likely to meet some resistance (see sidebar The Geologic Time Scale and the Anthropocene).

Spread as a cultural zeitgeist. Beyond the various scientific usages, whether formal or informal, the Anthropocene has spilled out of its Earth system sciences origins and has been adopted as a contemporary environmental and cultural icon. A key event in this cultural mainstreaming was the front page of *The Economist* in 2011, which declared "Welcome to the Anthropocene" (**Figure 1**). It is employed for several purposes, but at its broadest contemporary use it encompasses a notion that the relationship of humanity with the natural world has changed (although when exactly in the

THE GEOLOGIC TIME SCALE AND THE ANTHROPOCENE

In its nomenclature the Anthropocene is a geological term, so to understand its usage it is valuable to understand the Geologic Time Scale (21). In this scale, the history of the Earth has been divided up into a hierarchical set of eons, eras, periods, epochs, and ages. At the highest level are the four eons, the most recent of which is the Phanerozoic Eon (Greek: "revealed life"), which ranges from 541 million years ago (Mya) to the present, corresponding to the period in which hard-bodied complex multicellular organisms appear in the fossil record. The Phanerozoic is punctuated by occasional mass extinctions, and two particularly dramatic ones split it into three eras: the Paleozoic ("old life"; the time of trilobites and the first land plants and animals, the Mesozoic ("middle life"; the famous era of the dinosaurs), and the Cenozoic ("recent life"; the era of dominance by mammals and birds). These eras are further divided into periods, each typically approximately 50 million years long. The Cenozoic has three, the Paleogene ("old–recent"; 66–23.03 Mya), the Neogene ("new–recent"; 23.03–2.588 Mya), and the Quaternary (2.588 Mya–present). These periods are further divided into epochs: The epochs of the Cenozoic have typically lasted more than ten million years, but the last two are truncated by their proximity to our present (**Figure 2**). The penultimate formally accepted epoch is the Pleistocene Epoch (2.588 Mya–11.7 kya), the period of long ice ages punctuated by short interglacials that last 10–20,000 years. This is followed by the Holocene Epoch, which started 11,700 years ago (22). It is in many ways just another interglacial of the Pleistocene, but it is distinguished by the spread of agriculture and the rapid and highly unusual increase of one species of highly social and environment-transforming ape. Hence, the presence of agricultural human civilization is embedded into the concept of the Holocene (23). Proponents of the Anthropocene as a geological term usually make the case for it as a new epoch following the Holocene, although a plausible case can be made that the changes happening in the modern era can be considered the start of a new period (the Anthropogene) or even a new era (the Anthropozoic).

past this change may have happened is a subject of intense debate), that therefore all of "nature" is touched by the hand of humanity, and that realization of the implications of this change requires a new worldview. The phrase ". . .in the Anthropocene" in a title can entail a variety of meanings, ranging from "in a world that has been pushed away from a Holocene stable-state," through "in our modern, human-dominated times" or "throughout human history" to "in a complex world of human and natural entanglement." Many of these meanings have drifted some way from the original intent of signaling human domination of the Earth system. In all these various forms, the Anthropocene has become a device for re-examining and discussing the role of humanity in the natural world, on timescales from the deep past to the far future, and on scales from the intimately reflective and personal to the planetary and geological.

This notion has stimulated new thinking across the sciences and humanities, and it has been adopted in wider cultural debates (discussed below). It can be seen as a "charismatic mega-category" (24) or "boundary object" (25) that stimulates interaction and debate across a range of disciplines and perspectives. Beyond the academe, the Anthropocene has featured in numerous popular and specialist books, art exhibitions, a podcast series (*Generation Anthropocene*), a vibrant Twitter hashtag, and newspaper headlines and the covers of periodicals.

There are several reasons for its potency as a term. It acts as a useful interdisciplinary umbrella for considering the interactions between humans and the natural world, placing humanity in both a historical and Earth system context. On the one hand, the fact that it is a scientific term (albeit to date informal), using the nomenclature familiar to many from their school textbooks, perhaps adds some intellectual potency to political, philosophical, and cultural debates. On the other hand, it is still not that familiar a term to the wider public, which perhaps both limits its spread and also adds to a sense of newness and zeitgeist to those who employ it.

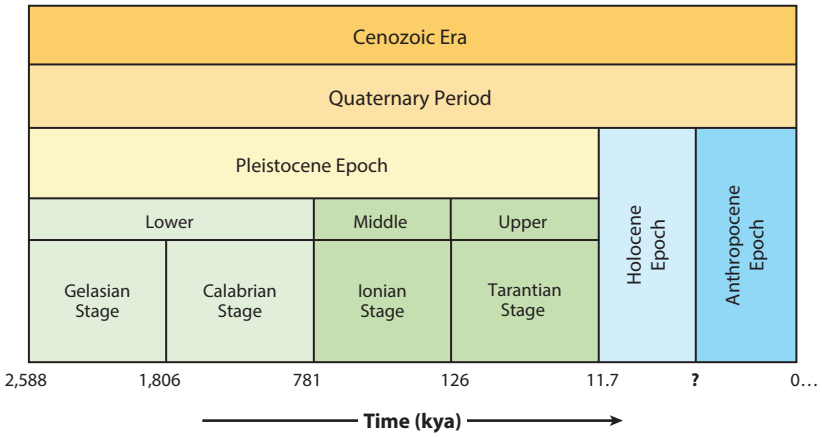

Figure 2

How the Anthropocene may fit as a formal geological epoch into the last 2.558 million years of the Geologic Time Scale. There are cases to be made (not formally, to date) to consider the new concept as a higher-order geological entity (period or era) and also to downgrade the Holocene to the final stage of the Pleistocene or the first stage of the Anthropocene.

THE USE OF THE ANTHROPOCENE CONCEPT

The next sections examine how different users have employed the Anthropocene and what they are seeking to capture in its usage. I start with the debates within the natural sciences before moving on to wider perspectives in academia and beyond.

The Earth System Sciences Perspective

Crutzen & Stoermer (3) originally based their argument for the Anthropocene from the perspective of the Earth system sciences. The core argument here is that the cumulative sum of human activity is disrupting many aspects of planetary functions, and moving them outside the modest range of variability that has defined the Holocene, and in a different, warming direction that is (or soon will be) outside of the range of the Pleistocene glacial-interglacial cycles. Most prominent of these disruptions is climate change, but other important disruptions of planetary biogeochemistry include ocean acidification and the greatly increased magnitude of the nitrogen and phosphorus cycles. Several approaches and metrics have tried to quantify this domination of natural biogeochemical cycles, including ecological footprints (26), planetary sociometabolism (27, 28), and human appropriation of net primary productivity (29). Others have tried to identify potential dangerous thresholds that should be avoided, including planetary tipping points (30) and planetary boundaries (33, 32). The planetary boundaries concept in particular has gained much traction as an attempt at quantifying the fundamental challenge of the expanding human footprint, and it can be regarded as "a particular version of the Anthropocene concept in all but name" (33, p. 441).

Planetary boundaries: thresholds in several Earth system processes, which if crossed as a result of human activity are likely to result in negative consequences for planetary function and human and nonhuman life on Earth

Crutzen (4) originally proposed the dawn of the industrial revolution in the mid-eighteenth century as a suitable start date, but industrialization was slow to spread from its western European origin, and there was little immediate and obvious disruption of the Earth system at that time. A much more convincing case for planetary impact can be made for the twentieth century, and in 2007, Steffen et al. (9) (including Crutzen) first outlined the case for a

mid-twentieth-century start to the Anthropocene, corresponding to the "Great Acceleration" in total human activity following the Second World War. This paper and a subsequent one in 2011 (6) presented time series of human alteration of variety of Earth system attributes, including biogeochemistry, species extinctions, and climate, as well as several human-associated drivers, including population, GDP, and transport. This type of figure, generally showing no or gradual increases in a variable prior to around 1950, and then a sharp upward turn, has become characteristic Anthropocene iconography. Steffen et al. (34) upgraded these original and highly influential Great Acceleration charts, by partitioning them into different classes of economic activity and nations, demonstrating how the drivers of contemporary change are unevenly partitioned across humanity. The Great Acceleration appears to be driven by a redirection of wartime industrial economies to mass production, together with a rapid spread of industrialization beyond its European–North American core (35). The deliberations of the WGA and broader scientific discussion since then have increasingly moved toward favoring such a mid-twentieth-century start to the Anthropocene.

From an Earth system sciences perspective, the key feature of the Anthropocene is that human domination has led to the emergence of feedback between human and nonhuman systems at a planetary scale, such that actions on energy use, land use, food consumption, and trade have consequences for the basic functioning of the planet and can potentially destabilize planetary function. Human societies have always been closely coupled to environmental conditions at local scales (36), but strong feedback at the planetary scale is a peculiar feature of the Anthropocene and a new challenge for policy and governance. From this perspective, it is this strong human imprint on planetary climate and biogeochemistry that is the hallmark of the Anthropocene.

The Biosphere Perspective

Another perspective on the nature of Anthropocene change has come from ecological sciences. This has considerable overlap with Earth system perspectives but offers some additional insights by highlighting fundamental changes in planetary biodiversity, independent of whether they have consequences for planetary function (which the Earth system sciences perspective emphasizes). Human activity is altering the diversity, distribution, abundance, and interactions of life on Earth through conversion of ecosystems into agricultural or urban "anthromes" (37), through direct harvesting or exclusion of species, through mixing of species between previously isolated regions, and through environmental change. This change in the patterns of biodiversity represents a fundamental change in the nature of life on Earth with legacies that will endure on timescales ranging from thousands of years to hundreds of millions of years or more (19). Although extensive species loss may well cause state shifts in planetary function (38), it is at least conceivable that there could be substantial biodiversity loss without changes in planetary function; however, something fundamental about the Earth would nonetheless have changed. A particular feature is the elevation in extinction rate and a prospective mass extinction event through a combination of habitat loss, overharvesting, invasion, and climate change. The frequent terming of this prospective mass extinction as the Sixth Extinction (39) emphasizes the magnitude and significance of contemporary changes in the biosphere on Earth system spatial scales and geological timescales.

Beyond actual extinction, many species and biomes have been greatly reduced in abundance and range to become almost negligible components of planetary ecosystem ecology. Williams et al. (19) summarize several distinctive features of the so-called Anthropocene biosphere that in combination distinguish it from all previous states of the biosphere. These include the following: (*a*) Global homogenization of flora and fauna through deliberate and accidental species transfer across

continents[2] is sometimes argued by ecologists as creating a "new Pangaea" through contemporary human activity (40, 41); (*b*) the total amount of biological activity in the biosphere has increased by ~20% to date, largely because of access to deep-time primary productivity (fossil fuels), a supply of energy that was previously unavailable to the biosphere (27); (*c*) a cluster of relatively large species (humans and associated animal domesticates) has been the main beneficiary of this extra energy and has commandeered ~25–40% of terrestrial primary productivity (29, 42); (*d*) humans are increasingly directing the evolution of other species; and (*e*) there is increasing interaction of the biosphere with the technosphere (43, 44). Many of these changes (especially extinction and biotic mixing) are resetting the evolutionary path of the biosphere and will have legacies that almost certainly persist for hundreds of millions of years. If humanity disappeared tomorrow, a hypothetical future paleontologist hundreds of millions of years hence would have little problem identifying that something extraordinary occurred, with a wave of extinction and movement of species, and introduction and homogenization of biota that had been previously separated by oceans and latitudes.

Technosphere: the global emergent system that includes humans and associated technological and social networks

The Geological Perspective

Although the concept of the Anthropocene emerged from the Earth system and environmental sciences, much of the formal scientific debate about the definition of the Anthropocene has focused on geological, and in particular stratigraphic, arguments for its definitions. This geological nomenclature immediately suggests placement of contemporary human-caused environmental changes in the context of Earth history (45), and this is where some of the potency of the term comes from (**Figure 2**).

The geological debate has tended to focus on whether there is a detectable stratigraphic signature of the Anthropocene (see the Stratigraphic Support for the Anthropocene section, below), which particular signature is the most appropriate, and how this ends up informing a decision on the start date for the Anthropocene. The aim of the geological approach is to examine the issue of whether contemporary change is detectable and significant on Earth history timescales. A somewhat science fiction thought experiment that is frequently employed is to imagine the mindset of a future geologist (human or alien) millions of years from now, trying to understand the geological record of our time (16). This approach makes defining the Anthropocene as a geological epoch analogous to the process of defining every other past geological period. There is a focus on stratigraphic markers, which tend to be hard bodied, and either marine or lacustrine sediments are particularly favored. There is a preference for dates that are worldwide and exact. A stratigraphic focus also has the advantage of disentangling the debate on definition from some of the political complexities and critiques (see the Critiques from the Social Sciences section, below). It does not seek to either uniformly homogenize or partition humanity in terms of culpability, but rather bases definition on the observed (or potentially observed) geological record (45).

Stratigraphic support for the Anthropocene. One of the key challenges in formal adoption of the Anthropocene as a scientific term has been meeting the stratigraphic criteria for a new geological epoch. The fact that the start of the Anthropocene is often argued to be a recent event within the historical record has resulted in demands for dating of its start to a precision that is rarely required or possible for most epochs.

[2] Such a state was last approximated around 400 million years ago, with the major land masses coalesced into the supercontinent of Pangaea, but life on land was at this time at a very early stage.

There are two ways in which the science of stratigraphy tends to define divisions in the Geologic Time Scale. The more favored route is a distinct stratigraphical signature, a particular point in a stratal section [a Global Boundary Stratotype Section and Point (GSSP) or "golden spike"], often in marine sediments where such signals are clearest or strongest. This is the approach now accepted for most periods and epochs of the Phanerozoic. Once a GSSP is set and agreed upon by the IUGS, it remains the boundary of that time period, even if the estimated age of that period changes. The alternative approach is to simply agree upon a specific time boundary without reference to a stratigraphic section [a Global Standard Stratigraphic Age (GSSA)], as is done for most pre-Phanerozoic geological divisions where clear stratigraphic sections are a challenge. A GSSA would be much more convenient for the Holocene-Anthropocene boundary and was initially favored by many in the WGA (18). However, perhaps in response to criticism from the ICS (15), the thinking of the WGA (as announced in 2016) has shifted toward a GSSP.

Global Boundary Stratotype Section and Point (GSSP): an internationally agreed upon reference point on a stratigraphic section that defines the lower boundary of a stage on the Geologic Time Scale

Global Standard Stratigraphic Age (GSSA): a chronological reference point in the geologic record used to define the boundaries between different geological periods, epochs, or ages in the Geologic Time Scale

Technofossils: Structures and artefacts created by human technology that are potentially preservable in the geological record

Adoption of a GSSP would better conform to the expectation of stratigraphic convention, and increase the likelihood of formal adoption. The identified golden spike does not need to be directly linked to the cause of the start of the new epoch, just a convenient marker of the period of change.

There is abundant evidence to support that current human activity is leaving a strong stratigraphic imprint (see below), but a key challenge is that if a recent start date for the Anthropocene is adopted, many of these relevant deposits will be only a few decades old and too often not clearly delineated, and will also have different timings in different regions (46). A recent book and paper by many members of the WGA (20) outline a range of possible stratigraphic indicators for the start of the Anthropocene (and particularly in favor of a mid-twentieth-century start date).

One set of indicators is new materials of purely anthropogenic origin [termed technofossils by Zalasiewicz et al. (47)]. These include the abundance of pure elemental aluminum (98% of all production of aluminum has been since 1950), concrete (which was invented by the Romans but only became a prime building material since World War 2; in the past 20 years the volume produced is equivalent to 1 kg m^{-2} of land surface), and plastics [which were developed around 1900, surged after 1950, and have a current annual production of 300 teragrams, equal to global human biomass; plastics are now common in marine sediments as both as macroscopic fragments and as ubiquitous microscopic particles (48)]. There are also other distinct organic geochemical signatures (e.g., polyaromatic hydrocarbons, polychlorinated biphenyls, and diverse pesticide residues) that show elevated concentrations since around 1950.

A second set of technofossils is not as new, but shows greatly increased abundance since the twentieth century. These include products of fossil fuel combustion (black carbon, inorganic ash spheres, and spherical carbonaceous particles). These leave a permanent marker in sediments and ice that is in many ways analogous to the global marker horizon apparent after the end-Cretaceous Chixculub bolide impact.

A third set of stratigraphic signals revolves around disruptions of global biogeochemical cycles, including changing rates of sedimentation (through vegetation loss and dam building); increases in the global nitrogen and phosphorus cycle because of extraction of nitrogen from the air and large-scale mining of phosphorus; the rapid increase in atmospheric carbon dioxide and methane concentrations (which associated changes in isotopic signatures), visible in Antarctic ice cores; and the increased global prevalence of previously rare elements such as cadmium, chromium, copper, mercury, nickel, lead, and zinc.

A fourth set of candidate markers is associated with the radioactive fallout from atmospheric nuclear weapons testing in the mid-twentieth century; these have a clear advantage of being unique and globally widespread. The first (fission-based) atmospheric detonation was the Trinity atomic device at 05:29:21 Mountain War Time (± 2 s) July sixteenth 1945 at Alamogordo, New Mexico, and that date has been suggested as a GSSA for the start of the Anthropocene (18). However, these

early fission-based explosions only left local fallout, and it was only since 1952 that fusion-based explosions left a clear and global signature. Two key geochemical signatures come from a peak in carbon 14, a naturally common carbon isotope with a half-life of 5,730 years, or in plutonium 239, which is naturally rare and has a half-life of 24,100 years. Both isotopes start rising around 1951 and peak around 1964, before declining after atmospheric testing fell out of favor. The plutonium 239 peak will be identifiable in sediments and ice for 100,000 years, and will decay to a distinct layer enriched in uranium 235 and, ultimately, stable lead 207, which will leave a long-term stratigraphic record. This radioactive fallout signature is currently a favored candidate for a golden spike (18). Atmospheric nuclear testing had little direct effect on the functioning or biodiversity of the Earth, but it is symptomatic of the period of technological expansion that marks the Great Acceleration.

A final set of markers is associated with changes in the flora and fauna, including both extinctions and intermingling of species between previously isolated continents and islands (49). Although the peak in extinction rates may be yet to come, this signature is the most time transgressive, with significant extinction and mixing events occurring throughout the late Pleistocene and Holocene, at different times in different locations. This makes it a poor candidate for an Anthropocene marker. However, the consequences of this mixing and extinction for the geological record will persist for hundreds of millions of years as local evolutionary pathways have been fundamentally reset to a degree that would be obvious to any future paleontologist. Changes in geological periods and epochs throughout the Phanerozoic are often recognized by abrupt changes in the fossil record of life. Such changes support the geological arguments for the Anthropocene epoch. Indeed, the magnitude and legacy of changes would support an argument for a higher level of stratigraphic classification, such as period (50) or possibly even era (the last change in era being the ecological "reset" that occurred after the extinction of the nonavian dinosaurs). This biotic signature may well be the most long-lived and obvious long-term stratigraphic signature of the Anthropocene.

Critiques from the Natural Sciences

The prospect of adoption of the Anthropocene has raised several critiques within the natural sciences, most prominently from some in the geological sciences. The most dismissive critiques label the Anthropocene as a mere item of "pop culture" (14, 51), subject to the vagaries and fashions of environmental politics. A more focused critique is that the Anthropocene, being a time we are immersed in, is a fundamentally different entity from previous chronostratigraphic units. In trying to formalize the Anthropocene, the knowledge practices and objectivity of geological convention are being stretched beyond their utility to answer what is a speculative and political question (52–54).

Finney & Edwards (15) summarize this critique. (Finney was Chair of the ICS and therefore a particularly influential voice in this discussion.) They argue that there is a fundamental difference between the Anthropocene and other chronostratigraphic units established by the ICS, and that in being encouraged to adopt the Anthropocene, the ICS is being asked to make a political statement, namely to raise awareness of contemporary human impacts on the Earth system, and thereby potentially encourage a planetary management mindset. Although all these may be laudable goals, they argue it is not the purpose of the ICS to make such a political statement. The Geologic Time Scale is not the appropriate arena for environmental and political arguments, and is of limited utility for debating modern environmental challenges (53).

Other features also draw critical attention to the Anthropocene. Its recent origin (in the most commonly expressed twentieth century start date) means that we are still immersed in what might just amount to the earliest phases of an Anthropocene transition. It is too soon to understand how

this will play out in the next few centuries and to identify what are the most important present or future features to define this period of time and its most appropriate start date. Indeed, the potential that a convincing argument could be made for a higher-level classification such as an Anthropogene period or Anthropozoic eon means that it might be premature, and of limited utility, to rush into defining an Anthropocene epoch (50).

Many recognize the potency and utility of the Anthropocene as an informal geological term but argue that formalization is unhelpful and unnecessary (15). Ruddiman et al. (55) suggest that an informal term would still have much utility and be less constrained by a single formal designation; for example, one could refer to an early agricultural anthropocene, or an industrial anthropocene (deliberately with a lower-case "a"). They argue that it would be neither appropriate nor useful to impose such a simplifying term on the rich complexity of human history. However, others argue that this fluidity of definition would simply create confusion (56).

There have also been several criticisms about the focus on Earth system science and in particular geological arguments for the definition of the Anthropocene, with perspectives from the humanities and social sciences receiving much less attention and having much less influence in the process. Ellis et al. (57) argue that the prevailing twentieth-century Great Acceleration focus reinforces "a Eurocentric, elite and technocratic narrative of human engagement with our environment that is out of sync with contemporary thought in the social sciences and the humanities."

They question the function and transparency of the WGA: a small and selected number of experts, predominantly natural scientists, drawn together by invitation only, reporting only to Earth scientists who vote on a final decision. Although such a structure is perfectly functional for the very technical working groups for preceding geological time periods, it appears ill suited for the Anthropocene, which has such wider social, political, and philosophical implications, and a wider, more inclusive approach may be needed. Several of these social and historical arguments (explored in the next section) argue for a more nuanced and earlier start to the Anthropocene.

The Historical Perspective: The Case for an Early Anthropocene

As outlined in the previous sections, the prevailing direction of discussions in the WGA and wider scientific opinion has been for a recent start to the Anthropocene, contemporary with the rapid industrialization of human societies. However, a persistent alternative narrative has argued for an earlier, sometimes much earlier, start, with timescales ranging from several thousand to even millions of years ago. What these arguments for an early Anthropocene seek to highlight and capture is a sense of long human alteration of the environment, a history and prehistory which is often under-recognized in the prevailing technocentric focus on industrial disruption and modernity (57).

It is useful to distinguish between three points along a spectrum of the degree of human influence of the environment, which underlie different ways of using the concept of the Anthropocene. At one extreme, the Anthropocene is defined to have started when there is any discernible human influence on the local environment, through modification of local ecosystems and shifts in local biodiversity (58). This can be viewed as the beginning of a long road that leads to modernity, planetary domination, and beyond. The emphasis is on detecting any human cause rather than large-scale environmental effect. Alternatively, the Anthropocene is deemed to start when there is any discernible human influence on the global environment, for example through changes in greenhouse gas concentrations or planetary albedo (59–61). Finally, at the other end of the spectrum, many argue the start of the Anthropocene requires an overwhelming or disruptive human domination of the global environment (62, 63). Advocates for an early Anthropocene tend to fall into the first two categories and those for a recent Anthropocene into the third category.

One consequence of adopting an early Anthropocene viewpoint is the recognition of the long history and prehistory of substantial human alteration of the environment. For example, the likely major human role in the extinction of most of the planet's large land mammals that accompanied human expansion out of Africa, and the ensuing alteration of many ecosystems through trophic cascades, is not always recognized (53, 54). Such viewpoints challenge the perception of an earlier, more sustainable and benign, human relationship with the natural world that modernity has disrupted. In the early Anthropocene narrative, alteration of the environment, whether intentional or accidental, seems embedded in being human, as is the case for other successful species from leaf-cutter ants to tree-killing elephants. Such arguments are a counterpoint to the human-nature dualism: By arguing that humans have always changed nature, there is no "after nature" or "end of nature" in the modern era.

The equal validity of these various viewpoints is contested. Hamilton (62, 64) argues vigorously that most arguments in favor of an early Anthropocene reduce the concept of the Anthropocene to a metaphor for all human interactions with the environment. Thereby the concept loses its potency and urgency and the sense of planetary rupture with the past that it was originally intended to capture (63). An emphasis on the long history of human alteration of the environment can risk normalization of global environmental change and a consequent failure to acknowledge how disruptive the magnitude and speed of contemporary change are. If humans have always been changing nature and we have been in the Anthropocene for centuries or even millennia, it may weaken arguments that contemporary environmental change needs particularly urgent political and societal attention.

A more practical issue surrounding adopting an early start for the Anthropocene, especially if it is adopted as a formal epoch, is what to do with the Holocene (or possibly even the late Pleistocene). The Holocene is defined as starting 11,700 years ago, and the main reason for distinguishing it from the numerous preceding interglacials is the presence of human agricultural societies and civilizations. If the Anthropocene is defined by the detectable presence of human alteration of the environment, the Holocene becomes redundant. It can be argued that there is a case for simply replacing the Holocene with the Anthropocene (58, 65), that the two constitute a single geological epoch marked by increasing human impact on the planet, initially moderate and spatially patchy but increasingly intense and ubiquitous. This epoch would be bounded by a distinct and geologically recognized climate event, the end of the last ice age, which made agriculture and human expansion possible.

Several compromise positions have been suggested that recognize the validity of some of the early Anthropocene arguments while also emphasizing planetary rupture of the recent Anthropocene case. Foley et al. (66) suggest adopting the informal term Paleoanthropocene to describe these early alterations of the environment, which form a spectrum of intensity building up to a recent start of the Anthropocene, but which are distinguishable by the lower magnitude and rate of human-caused change. Davies (45) suggests recognizing that we are in the midst of a long Holocene-Anthropocene transition event, which began around the fifteenth century and may culminate around the twenty-fifth century.

Many authors find the focus on start date for the Anthropocene an unnecessary distraction, especially if it is employed as an informal term. Finney & Edwards (15) use the concept of the Renaissance as an analogy. Key aspects of what made the Renaissance in fifteenth-century Europe are recognizable and it is certainly a useful term with which to discuss European history, but it is both difficult and unnecessary to define a formal start to the Renaissance. Because the timescales of the Anthropocene are so entangled with human history, any boundary to the Anthropocene is in fact a diffuse region, as it is with the Renaissance, with multiple slow antecedents and drawn-out consequences. The difficulty of agreeing on a start date is a strong argument against formal adoption of the Anthropocene (15).

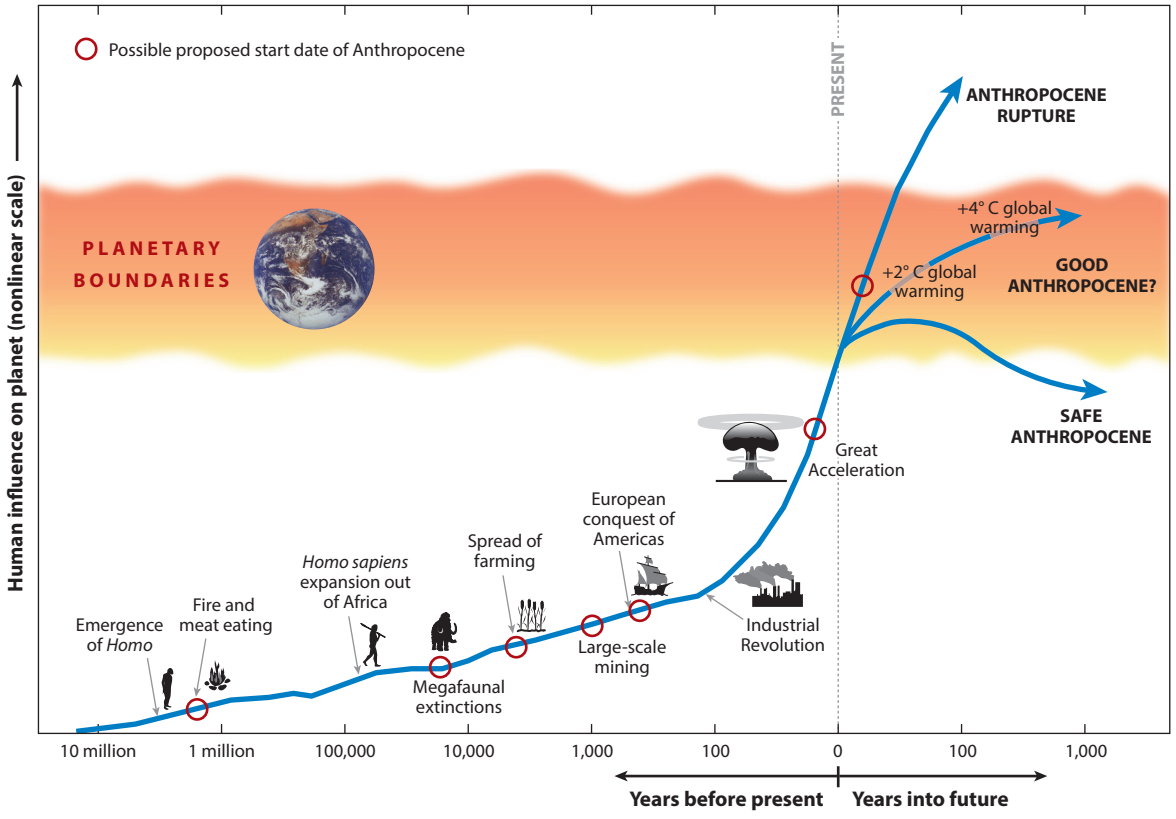

Figure 3

A timeline of increasing human influence on the Earth system, with some proposed start dates for a start date for the Anthropocene highlighted.

The earliest proposed start dates for the Anthropocene range back to the first evidence of human modification of local environments, possibly stretching back to the adoption of fire by *Homo erectus* 1–2 Mya, and our ancestors' switch to a meat-based diet of cooked food, that supported the expansion of energy-hungry brains (67; see also **Figure 3**). Several other subsequent prehistoric candidate dates are also possible as new tools were developed and *Homo* populations ranged across Africa and Eurasia and modified local ecosystems through fire manipulation and hunting. Proponents of these earliest Anthropocene start dates tend to focus on detectable human causes of local environmental change, rather than on regional or global impacts of such change (58). Critics such as Hamilton would argue that this invalidates the period as a plausible start date, as the core concept embedded in the term is human impacts on (or even domination of) the planetary system (63). Many other animals modify ecosystems at local scales, ranging from mound-building termites to trophic-web controlling top predators; modification of local ecosystems by a social ape is not a sufficient criterion to define a transformative event in Earth history.

The earliest proposed dates for human modification of Earth system functioning at regional and perhaps global scales are associated with the mass extinction of megafauna coincident with the late Pleistocene expansion of *Homo sapiens* out of Africa (~100 kya) and into Australia (~50 kya), the Americas (~14 kya), and ultimately numerous islands ranging in size from Madagascar and Japan downward. Overall, about 162 species of large mammal herbivore and 28 species of large

carnivore (about half of all large-bodied mammals) went extinct in this period, with the most severe extinctions being in the Americas (68). Only in Africa and southern Eurasia, where large animals perhaps had a longer history of adaptation to increasingly sophisticated *Homo* populations, did many large animal species survive. There has been much discussion about the relative influence of late Pleistocene climate change versus human hunting, especially in Europe where there was a drawn-out decline in climate, and in North America, where the climate change is closely coincident with first human arrival (69, 70). Taking a synoptic view across all world regions of first human arrival and megafaunal extinction times, however, the evidence for a significant human role appears very strong (71).

Large animals have a disproportionate role is shaping ecosystem functioning, and several studies have highlighted ways in which regional biosphere functioning may have been changed by megafaunal extinction. The expansion of dark, sun-absorbing forests into previously mammoth-maintained grasslands at high latitudes may have caused a regional warming of up to 1°C (61) and in other regions may also have resulted in shifting vegetation communities, biome boundaries, and increasing fire regime intensities (68, 72). Megafauna play a disproportionate role in moving nutrients across landscapes through their dung, and the postextinction reduction in lateral diffusion of nutrients may have had lasting consequences for planetary biogeochemistry (73, 74). Large herbivores are also major producers of methane, an important greenhouse gas, and there may have been a drop in atmospheric methane following megafaunal extinction (75).

Evidence of potential planetary impacts resulting from even pre-agricultural human activities has thought-provoking implications for conceptualization of human-nature relations and environmental sustainability, and for defining what natural ecosystems are. However, there are arguments against an adoption of such an early Anthropocene start date: (*a*) Although there may have been human modification of regional and global environments, such effects at large scales were still modest and are difficult to detect and attribute; and (*b*) the extinction event was diffuse and drawn out over 100,000 years, and therefore there is no single global date that could define the beginning of the Anthropocene.

A more frequently proposed candidate for the start of the Anthropocene is the onset of agriculture from ~10 kya. This was a global event, with multiple independent origins of farming in Africa, Eurasia, the Americas, and New Guinea, and it increased in spread and intensity throughout the subsequent 10,000 years, with bursts of intensification associated with the development of urban civilizations (76). Although most effects of farming were local, other effects may have had drawn-out regional and even global consequences through deforestation and modification of ecosystems. Ruddiman (59, 60) argues that the release of carbon dioxide from deforestation in Eurasia and release of methane associated with the spread of wet rice farming in Asia caused a sufficient greenhouse gas effect to prevent the onset of the next ice age. Such an effect would be sufficient to mark an anthropogenic alteration of planetary cycles, and could be a posited start date of the Anthropocene consistent with its Earth system terminology. It is still actively debated, however, whether the slow Holocene rise of carbon dioxide (77, 78) and variation of methane (79) during the Holocene is anthropogenic or a result of natural orbital variation, whether this greenhouse effect would be large enough to produce a substantial atmospheric effect, and when the next ice age would occur in its absence (80, 81). As with the Pleistocene extinctions, this is a drawn-out and spatially diffuse event where a formal start date is hard to define. Another challenge with adopting the onset of agriculture as the start of the Anthropocene is that it is closely coincident with the start of the Holocene, and it makes the Holocene epoch redundant (see above).

The impact and spread of human activities have increased throughout the Holocene, and other dates have been proposed as critical transitions that mark the start of the Anthropocene. One candidate is around 2,000 ya, marked by the occurrence of several well-organized societies (Roman

Europe, Han China, the middle kingdoms in India, Olmec Mexico, pre-Chavin Peru) substantially clearing and altering landscapes at regional scale and mining for heavy metals, thereby leaving a distinct stratigraphic record of altered anthropogenic soils (82). This also appears to be a period when increases in per capita energy use began to stall in much of Eurasia, possibly as demographic expansion began to cause limits to available land in local landscapes (27). A challenge with a 2,000 ya date is that these regional centers of human activity and environmental alteration were not connected or were only weakly connected, and collective human impact on the planetary system was still modest.

Another late Holocene date that has been proposed is around the sixteenth century, which marks the European invasion and colonization of the Americas, which had hitherto hosted an isolated and independent experiment in human civilization (23). The subsequent economic and cultural connection between Eurasia-Africa and the Americas heralded the beginning of a globalized economy, and the Columbian interchange: an exchange of domesticated plant and animals products between the regions (e.g., wheat, rice, cotton, cattle, and pigs from Eurasia; tomato, potato, cassava, tobacco, cacao from the Americas) that marks a key transition in the biosphere with clear stratigraphic legacies (83). The largely one-sided encounter caused a collapse in the populations of the Americas through disease, conflict, and slavery. It has been argued that this demographic shift led to an expansion of forests over abandoned agricultural lands (84), resulting in a drawdown of atmospheric CO_2 that can be seen as a drawdown of 7–10 ppm between 1570 and 1620 in high resolution Antarctic ice core records, which could serve as a golden spike (23).

A different argument for this start date comes from a political economic perspective. Moore (85–87) argues that this period corresponds to the formation of the capitalist world economic system (the Capitalocene), a "world ecology" of wealth, power, and nature that was intimately tied with the conquest and exploitation of the Americas and developed to exploit the flow of newly available American resources to Europe. This flow of organized resources and creation of Cheap Natures (labor, food, energy, and raw materials) facilitated the subsequent rise of Europe to geopolitical dominance, which ultimately facilitated the Industrial Revolution. Hence the sixteenth century could be argued to mark the beginning of the modern world. This period also marks an upward inflection in global sociometabolism, where the resource consumption per unit of human population increases as energy and materials use intensifies (28).

Critiques of this proposed start date point out that, although it is marked by a strong biological signal as species move across continents, is does not in itself mark a shift in the functioning of the Earth system and is therefore no more distinct a marker of the Anthropocene than any previous Holocene start date (62). In addition, the attribution of the Antarctic CO_2 dip to forest expansion is contested and there may be other similar fluctuations throughout the Holocene (89); therefore, it would be a controversial marker for the Anthropocene.

Finally, an alternative proposition is that the Anthropocene has not started yet, and would be deemed to start when and if the Earth system passes a critical transition such as the climate system being tipped into an alternative state (**Figure 3**), and/or the biosphere being degraded sufficiently to mark a mass extinction. This could potentially be in the mid-late twenty-first century. As such, the Anthropocene represents a planetary state to be avoided or steered away from, rather than one to be accepted and managed.

Cultural and Philosophical Perspectives

From its origins in the Earth system sciences, the Anthropocene has rapidly spilled out of the natural sciences discourse into wider academic literature, and perhaps uniquely for a geological term, it has attained a wider cultural and political significance. The single word provides a

multidisciplinary, multispatial scale and a multiple timescale framework for thinking about and discussing human relations to the environment and human responses to a changing world.

Philosophical and cultural responses to the Anthropocene tend to focus on two broad aspects embedded in the concept, which both lead to a range of perspectives, ranging from pessimistic, through resigned, pragmatically managerial, to optimistic. One thread of responses focuses on the challenges of responding to or managing the large-scale and multifaceted alteration of planetary functioning and the existential challenges this poses for the human story, for the idea of progress, and for the future of civilization. A second thread explores how to view, respond to, and value nature in a postnatural world where human influence is so pervasive—whether on modern or historical timescales—stimulating a re-evaluation of what is human and what is natural (90).

Within and between these threads, the concept is used for several purposes, and as a result there is a sometimes confusing melee of uses. Lorimer (54) offers an analytical framework for these multiple uses (or "Anthropo-scene") and identifies several ways that the concept of the Anthropocene has had an influence on cultural debates and movements, including as a cultural zeitgeist, as an ideological provocation, and as a new ontology.

The Anthropocene as a cultural zeitgeist. Outside of the formal scientific debates as to the definition and start date of the Anthropocene, the term has become a shorthand that captures concerns about the magnitude of contemporary human influence on the wider natural world. In much environmental literature, it has been enlisted as a new umbrella term and call to action to address environmental issues, by encompassing and connecting prevailing issues such as biodiversity, climate change, peak resource supply, and sustainability (although a quick inspection of the literature shows that these preceding terms are still more prevalent and are far from being replaced). The Anthropocene draws attention to a single fundamental cause and central organizing theme underlying these issues, namely the spread and increasing activity of humanity, and the multifaceted nature of human influence on the planet.

More broadly and less quantifiably, it is a label for a broad curiosity and concern about the state of the Earth, and about the well-being of both the immediate human and natural worlds in a context "after Nature" (90), where no aspect of the natural world is free from human influence [although the early Anthropocene debates have highlighted how such a concept of a natural world distinct from human influence until a recent date is a somewhat artificial construct (76)]. In this usage, the Anthropocene often becomes shorthand for "this modern world, where human fingerprints are everywhere and everything humans do has consequences for the natural world." It has emerged as a *leitmotif*, as the proliferation of titles "X in the Anthropocene" suggests. Examples of the large range of concepts recently examined under this leitmotif include "freedom in the Anthropocene" (91) (exploring the concept of freedom in the context of helplessness under global environmental change), "learning to die . . . " (92) (exploring responses to the potential mortality of civilization), socionatural relations (93), world politics (94), governing (95), theology (96), art (97), "listening to birds. . ." ("the anxious semiotics of sound in a human-dominated world") (98), through to defaunation (99), tropical forests (100), plant diversity (101) or soil (102). As such, it has become a platform for discussing the future of humanity and its relations with the Earth at scales from local and intimate to global and systems-oriented.

The Anthropocene as ideological provocation. Discussions about the causes and consequences of the Anthropocene have served to energize established debates about the implications (social, ecological, political and planetary) of concepts such as development, progress, capitalism, and modernity, from both critics and proponents of the concept. The debate about the start date serves as a means of interrogating the history of human-environment relations, on the one hand

challenging both idealizations and romantic visions of low premodern human impacts on the environment (37, 103), while on the other hand emphasizing the dramatic rupture of the contemporary global environmental change (63). The debate about which subsets of humanity are responsible for the Anthropocene pits visions of a systems view of collective human impact [through concepts such as sociometabolism (28) and planetary boundaries (31)] against a counter-perspective where critics argue that particular social and economic configurations are responsible for the arrival of the Anthropocene, in particular modern capitalism (85, 104), or that particular groups dominate the discussion of the concept. This has led to the geological designation "-cene" itself becoming a cultural meme as authors posit alternative names for the contemporary era, sometimes semi-serious but more often as mischievous points of ideological provocation. Examples include the Capitalocene (87), highlighting the dominant role of the capitalist economy; the Plantationocene (86), highlighting the important seminal role of colonialism capitalism, slavery, and the plantation economy; the Technocene (105), emphasizing the role of technological systems; the Anthrobscene (106) and Manthropocene (107), highlighting a male logic of resource exploitation and the largely male composition of expert panels deciding on the Anthropocene; the "Anthropo-not-seen" (108), highlighting indigenous perspectives and role of colonialism; and the Anglocene (109), noting the dominant role of the English-speaking world in producing the earliest industrial greenhouse gas emissions and also dominating the contemporary debate about the definition of the Anthropocene—i.e., "the *anthropos* . . . seems to have a very strong English accent," as Fressoz (110) contends. Most of these emphasize cultural or economic features that are relatively short-lived on the geological timescales that the adoption of the suffix "-cene" implies.

The Anthropocene as a new ontology. The debate about a new geological epoch has emerged from and stimulated a wave of new thinking about whether new worldviews—new understandings of the nature of being—are required that address the nature of life on a human-dominated planet where human activity is bounded within planetary constraints and the risk of nonlinear feedbacks (54). A defining feature of the Anthropocene is the recognition and approach of planetary boundaries, the transgression of which may lead to fundamental and potential shifts in the nature of life on Earth. The realization of planetary boundaries and dangerous feedbacks is something new in human history, and many of our modes of thinking, being, and behaving are challenged by it. These new geopolitics may well have been emerging independent of the conceptualization of the Anthropocene, but the term provides a succinct label or framework for these considerations.

Responding to the Anthropocene: Managerial, Optimistic, and Catastrophist Perspectives

Once the Anthropocene is recognized as a new phase of human-natural relationships, a range of societal and philosophical responses are possible. The prevailing and instinctive narrative response has tended toward one of scientifically informed management and planetary stewardship (94). This narrative tells a tale of how science is revealing the challenge of the Anthropocene planetary boundaries that human civilization is stumbling into. It implies that with informed consideration of these boundaries and development of new and evolving modes of governance, humanity can avoid potential planetary tipping points and steer the human-natural world into an undeniably altered but sustainable future. This viewpoint of dealing with the Anthropocene is implicit in many of the Earth system sciences writings (6).

The onset of the Anthropocene (assuming its mid-twentieth century start date) has been accompanied by a huge increase in human well-being in terms of longevity, child mortality, and global health statistics. A moderate Anthropocene pragmatism recognizes this ambiguous nature of the

Anthropocene and strives to maintain and improve these benefits for humanity, in particular for the large numbers still in poverty and deprivation, while staying within the planetary boundaries and avoiding dangerous tipping points of the Earth system (111). This perspective is well-encapsulated by Raworth's planetary "doughnut" (112), which describes a "safe and socially just operating space for humanity." In this framework, the aim of economic policy should be to lift people out of the inner (doughnut) hole of deprivation, while not breaching the planetary boundaries (outer doughnut ring) that are a defining feature of the Anthropocene. This narrative emphasizes the importance of stewardship, of gardening the Anthropocene, at scales from local to global.

To some, the Anthropocene blurring of the concept of a distinct and separate nature offers the possibility of new thinking and re-evaluation of how humans act as stewards of the biosphere. In conservation biology, the meaning of "wilderness" and natural areas has come under question in the context of a human-dominated planet (113, 114). As one example, this has supported cases for functional rewilding of ecosystems, where there is new emphasis on restoring ecosystem functions (nutrient cycle, trophic interactions and control by top predators and herbivores) rather than focusing only on prioritizing native species or static reserves (115). Some writers have suggested reconsidering the importance and value of many non-native species, a product of the global biotic exchange that is another key feature of the Anthropocene. They suggest putting higher value on total local diversity and functional diversity, which are often increasing because of the arrival of non-native species, rather than purely valuing local species uniqueness (114, 116).

A more strident, somewhat Promethean, response has been to actively embrace the Anthropocene, considering it inevitable and perhaps even a desirable epoch. Beyond simply trying to diminish human impacts on the planet, this philosophy argues for an enlightened anthropocentrism, where humanity should direct and manage its impact to deliver a "good Anthropocene" through planetary management. There are many different visions of what makes a good Anthropocene, but they have in common a viewpoint that optimism is needed to be able to engage successfully with the societal and political change needed in the Anthropocene. One particularly prominent vision, promoted by the California-based Breakthrough Institute, is embodied in the concept of ecomodernism (117), which proposes an embrace of high-technology solutions to tackle the challenge of the Anthropocene, such as nuclear power, genetically modified organisms, intensified agricultural production, and possibly geoengineering. This is coupled with actions that encourage "decoupling" of humanity from nature, including facilitating migration to cities and urbanization, and rewilding of abandoned agricultural regions. In contrast, another strand of ecomodernism also promotes the early Anthropocene narrative, which emphasizes the long history of human entanglement and alteration of the natural world and emphasizes humans' role as sustained and permanent stewards of the biosphere (103). There appears to be quite a philosophical chasm between technology-driven decoupling and traditional ecological stewardship, but both are argued to be part of the armory of ecomodernist enlightened anthropocentrism.

An alternative set of narratives, epitomized by the works of Hamilton (64), presents a deeply alarmed view of the near future. This eco-catastrophist narrative emerges from the call to emphasize the Anthropocene as a crisis and a rupture of the Earth system (63), marking a dangerous and unstable future trajectory of the Earth that ontologies focused on ecological or technological control fail to recognize. The prospect of such a rupture makes nonsense of the optimism and hubris of advocacy of new rounds of enlightened anthropocentrism. It highlights the difference between manageable risk (for example, a trade-off between calculable economic costs and amounts of damage associated with various levels of climate change) and unmanageable and potential catastrophic uncertainty around tipping points in the Earth system. It rails against the "good Anthropocene" narrative as a dangerously hubristic approach that diverts attention to the urgency and magnitude of the planetary environmental challenge.

Hence, the eco-catastrophist narrative emphasizes the Anthropocene as the epoch where modernity's aspirations of indefinite growth and progress have hit the boundaries of a finite planet, raising the high likelihood of tipping points and a planetary state shift. It suggests that the prevailing narrative of continuing social and economic progress needs to be transformed, that there is a real possibility of societal and planetary collapse that needs to be grappled with and brought into public awareness and political thinking (63), and this may require a fundamental re-evaluation of human values regarding progress and relations to the natural world beyond the strictly managerial.

Davies (45) highlights a neo-catastrophic view of Earth history, a recognition that the history of the planet is marked by extreme instability in its climate, something the brief relative stability of the Holocene has made humanity unaccustomed to. In this view, the Anthropocene marks a human-created return to the status quo of climatic instability that has been prevalent throughout the Pleistocene and before. Far from the Earth being a benign and abundant "mother" that fosters human and biological development, and that is a passive supplier of resources and repository for wastes that needs to be stewarded or gardened, there is a new appreciation of the Earth as an unpredictable and potentially hostile entity that needs to be treated with fear and trepidation. Lorimer (54) speaks of a "return of the repressed," where nature withdraws the fundamental grounds in which modern civilization came into existence. Hence Gaia is not the all-loving, all-nurturing Mother Earth of the Romantics, but the half-crazed, bloodthirsty and vindictive goddess of the original Greek tales (Bruno Latour, quoted in 118).

Critiques from Political, Philosophical, and Cultural Perspectives

The Anthropocene has been widely embraced beyond the natural sciences, and it has stimulated new frameworks for thinking and research in the social sciences and humanities (119). With this embrace, there have been several critiques of the concept of the Anthropocene. Many of these focus on what is lost or not captured by a single all-encompassing term. No single term can manage to capture the nuances of a complex and changing world, but a key argument made by some critics is that by missing or avoiding key points the usage of the term may do more harm than good (104).

Critics argue that the large-scale systems perspective of much natural sciences writing on the Anthropocene encourages a particular narrative that emerges from a western and technocentric cultural framing of the world. Almost all writing on the Anthropocene has emerged from Europe and North America, most of the committees deciding on the Anthropocene are made of representatives of this cultural mindset and as such, it tends to favor a technocratic, materialistic conceptualization of and response to the contemporary environmental challenge, particularly so in arguments for a recent start date for the Anthropocene (57, 109). This world view may also encourage macroscale systems views of managing the Anthropocene, such as planetary geoengineering guided by a global enlightened elite community of scientist-managers, rather than approaches that better recognize the complexity and heterogeneity of cultural and natural systems. Indeed, Crutzen's seminal paper did conclude by suggesting geoengineering as a necessary tool for managing the Anthropocene (4).

Malm & Hornborg (104) contend the following:

> The Anthropocene resembles an attempt to conceptually traverse the gap between the natural and the social . . . through the construction of a bridge from one side only, leading the traffic, as it were, in a direction opposite to the actual process: in climate change, social relations determine natural conditions; in Anthropocene thinking, natural scientists extend their world-views to society.

Such a systems view and grand narrative of the Anthropocene may also encourage a sense of historical inevitability and grand destiny, that the surge in environmental degradation is an inevitable consequence of general human progress, rather than a particular consequence of specific economic structures and power dynamics (87, 104). A related criticism is that it is a universalist term that merges all of humanity into a single amorphous *anthropos* without recognizing the substantial inequities in cause and impact, as well as huge cultural differences of perspective (85). The Anthropocene as caused and experienced by a Western urbanite is very different from that experienced by an African subsistence farmer, for example; however, much Anthropocene writing tends to refer to humanity as a collective "we" that ignores and occludes huge disparities in power, impact, and the corresponding issues surrounding justice and equity. Social relations of power are key to how the Anthropocene is being shaped, and yet they are ignored and occluded in the invocation of a universal *anthropos* that has emerged from history by some "natural" process (120).

Others argue that it is possible to distentangle issues surrounding equity and power from the overarching issues of the Anthropocene and that the term still has utility and potency. Chakrabarty (121) argues that a much more equitable world, with more equal distribution of resources among humanity and millions raised out of poverty, would face equal or perhaps even greater challenges related to the human footprint on the Earth system. Hamilton (64) points out that even if the early stages of the Anthropocene disruption were predominantly Western, in the early twenty-first century the disruption is an increasingly Asian phenomenon, and moreover one created by conscious Asian aspiration rather than by economic or political colonialism.

It is also argued that an Anthropocene worldview can further encourage a human domination of the natural world, one which views nature increasingly as an object of management and gardening, rather than a focus of reverence and spirituality and respect. Davies (45) counters these accusations of dualism, arguing the objective stratigraphic concept of the Anthropocene is not about humans alone, but also all the interactions with other species and Earth systems processes (i.e., all of nature) that coincide with this period of human influence. Hence, humans are a prominent and key driving feature of the Anthropocene, but the Anthropocene is not about a human mastery of a separate nature.

CONCLUSIONS AND PERSONAL PERSPECTIVE

This review has attempted to examine the concept of the Anthropocene from a variety of perspectives. The concept has proliferated across disciplines ranging from the geological sciences to the humanities, which makes it worthy of a review but also makes such an exercise challenging, and any such review could have taken different pathways and chosen different foci. The concept is both potent and contentious, and I conclude by offering a personal perspective on some of the key debates.

Is the Anthropocene a Useful Concept?

At its core, the Anthropocene is an encapsulation of the concept that modern human activity is large relative to the basic processes of planetary functioning, and therefore that human social, economic, and political decisions have become entangled in a web of planetary feedbacks. This global planetary entanglement is something new in human history and Earth history, something that encompasses a range of processes including climate, biodiversity, and biogeochemistry, and therefore something that warrants a name that includes all these terms. The Anthropocene seems a good candidate for that name. In the scientific realm, it seems to be emblematic of a new systems thinking that incorporates human activities and human histories into planetary functioning. It

also adds a deep time perspective to contemporary environmental change, demonstrating how contemporary change is significant on the deepest timescales of Earth history.

The wide variety of new literature on the Anthropocene suggests that it has been useful in catalyzing new thinking. It seems to be stimulating environmental thinking in and across a variety of disciplines, from a re-examination of historic and prehistoric human impacts on the natural world to new perspectives on what is natural, and whether we live in a postnatural world.

There are valid arguments that in some way the concept is harmful because of what it ends up neglecting, by encouraging a view of humanity as a uniform *anthropos* at the expense of awareness of cultural, political, and economic disparities and injustices within the *anthropos*. There is a need to incorporate social science viewpoints into the debate on definition. These arguments themselves illustrate the potency of the term as a point of cultural debate, but in the end it is hard to envision any single term that could accommodate all these needs.

When Did It Start?

The debate about the early Anthropocene has been very useful in prompting a re-examination and wider awareness of the long history of human-environmental relations. It would be unfortunate to prematurely shut down this debate and many perspectives it opens up. However, much of the value of the Anthropocene comes from its ability to capture something new in human history: the rapid recent increase in the magnitude of human influence of planetary functioning, which results in an entanglement of human history and Earth history that did not exist before, and which, as a side product, leads to a tangible stratigraphic signature that allows potential formal chronostratification. This seems to be the core concept that should be retained in any discussion of start dates, namely when human influence on planetary function becomes large and potentially overwhelming.

As the directions of debate in the WGA indicate, the industrial period, and in particular the mid-twentieth century, makes a convenient point that retains this original sense. It is useful and insightful to recognize the long precursors to the Anthropocene, perhaps as an informal Paleoanthropocene. The concept of a roughly 1,000-year-long Holocene-Anthropocene transition event (45) of which we are currently in the midst also seems to better capture the reality of important precursors to the mid-twentieth-century Great Acceleration, although when and how it could be decided this transition would end would remain highly uncertain.

Should It Be Formalized?

In many ways geological formalization is irrelevant. The Anthropocene has become a leitmotif far beyond the natural sciences, and many of the most interesting debates would continue irrespective of formalization. Neither the urgency of contemporary environmental challenges nor the philosophical and existential questions they raise will disappear if the concept is not formalized. There are valid arguments that the Geologic Time Scale is not well-suited for this political and cultural concept, and the formal structures of the geological sciences seem to be struggling under the intense public interest and spotlight to which they are not accustomed. In its original and most useful form, the term is trying to capture the concept of human planetary domination: The stratigraphic signal that is at the core of the geological debate is an indicator of this period of Earth system alteration, but should not be the overwhelming focus about what the term is about and trying to capture. The geological attention arises because of the geological nomenclature that has been adopted; some of the power and the umbrella-like nature of the term come from this connection with a deeper Earth history. What perhaps makes the terminology of the Anthropocene

so powerful is this marriage between description of planetary crisis and the dispassionate rigor of chronostratigraphy.

Although there are reasonable objections to an excessive geological focus that fails to capture many of the other aspects of the power of the concept, the adoption of a geological nomenclature makes this focus warranted. Objectively, using only the considerations of geological significance, the evidence of a major stratigraphic signal associated with the Anthropocene seems overwhelming, although the recent nature of the sediments does present some practical challenges. Therefore, by the most objective geological standards the case for a new epoch is strong (see the Stratigraphic Support for the Anthropocene section, above). Therefore, it would seem odd not to mark this substantial shift in the Earth's long-term sedimentary record with a formal geological term, although it could be argued from purely geological considerations that there should be no hurry to do so. The hurry comes from its wider cultural power and significance, and from any assistance the term can give in conceptualizing, understanding, and dealing with contemporary environmental challenges.

What Are the Implications for Formalization?

Much of the vigorous contemporary debate could proceed in the absence of formalization, with the Anthropocene remaining a widely used but informal term. But formalization does bring at least three consequences, whether positive or negative. Firstly, it would represent a scientific seal of approval, which would further facilitate its wider acceptance and increase its potency in capturing an important feature of the modern world. Secondly, formal adoption of a starting date would enable the multiple uses and discussions of starting dates (which have in themselves been a stimulating part of the power of the concept) to converge on an agreed common definition, and enable the debate to move on to focus more on responses to the Anthropocene. Thirdly, formalization within the Geologic Time Scale would likely result in a durability of the concept that is less available to other environmental concepts, even powerful ones such as climate change or biodiversity. The "accident" of adopting a geological nomenclature increases its likelihood of transition from passing zeitgeist to a long-lived mindset with which we view our planetary history. It is possible to envisage literature a century from now and beyond (if the Anthropocene rupture permits such a century) referring to the concept. It may still have cultural saliency, in the way the nineteenth-century geological term "Jurassic," originally based on the Jura mountains, still carries Hollywood blockbusters in the twenty-first century.

Where Next with the Anthropocene?

Ultimately, the concept of the Anthropocene can be judged in its utility. It presents a new and potent framing for thinking about the unique challenges facing a burgeoning humanity on a finite planet. Framings matter in academic and political discussion by organizing thought and facilitating new forms of identity and conduct (120). The Anthropocene is certainly stimulating new thinking across disciplines, and this article has shown how Anthropocene thinking brings a diverse interaction of research frameworks, worldviews, and political dispositions, sometimes in fruitful interaction and at other times in uncomfortable but potentially creative tension. Its embrace in the wider cultural sphere has stimulated wider awareness of new perspectives on human history and planetary change. It captures the spirit of an age and the planetary-scale challenges that we face. As such, it may make a contribution to a civilizational mindset that enables humanity to live with and on a human-dominated planet.

SUMMARY POINTS

1. The term Anthropocene emerged in 2000 to encapsulate the concept of a time period during which human activity has come to have a major effect on the natural functioning of the planet.
2. The concept acts as an umbrella term, incorporating a range of human influences on the planet including climate change, biodiversity loss and mixing, resource limitation, and waste production.
3. The geological nomenclature has led to an ongoing process of formal adoption of the Anthropocene as a geological epoch. There is controversy as to whether formalization is necessary or desirable.
4. The slow and geographically diffuse timeline of increasing human influence on the planet has led to vigorous debates about the most appropriate start date.
5. The prevailing narrative is converging on a start date for the Anthropocene in the mid-twentieth century, concurrent with the Great Acceleration of human alteration of the planet.
6. Irrespective of the process of formalization, the Anthropocene has spilled out of its natural sciences origins to become a cultural zeitgeist, a catalyst for numerous cultural, philosophical, and political debates about how to understand and respond to human domination of the Earth.

DISCLOSURE STATEMENT

The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

1. Vince G. 2016. *Adventures in the Anthropocene: A Journey to the Heart of the Planet We Made*. London: Penguin
2. Ackerman D. 2014. *The Human Age: The World Shaped by Us*. New York: Norton
3. Crutzen PJ, Stoermer EF. 2000. The Anthropocene. *Glob. Chang. Newsl.* 41:17–18
4. **Crutzen PJ. 2002. Geology of mankind. *Nature* 415(January):23**
5. Vernadsky W. 1945. The Biosphere and the Noösphere. *Am. Sci.* 33(1):1–12
6. Steffen W, Grinevald J, Crutzen P, McNeill J. 2011. The Anthropocene: conceptual and historical perspectives. *Philos. Trans. A. Math. Phys. Eng. Sci.* 369(1938):842–67
7. Lowenthal D. 2016. Origins of Anthropocene awareness. *Anthr. Rev.* 3(1):52–63
8. Hamilton C, Grinevald J. 2015. Was the Anthropocene anticipated? *Anthr. Rev.* 2(1):59–72
9. Steffen W, Crutzen J, McNeill JR. 2007. The Anthropocene: Are humans now overwhelming the great forces of Nature? *Ambio*. 36(8):614–21
10. Ellis EC. 2011. Anthropogenic transformation of the terrestrial biosphere. *Philos. Trans. R. Soc. A* 369:1010–35
11. Syvitski JPM, Kettner A. 2011. Sediment flux and the Anthropocene. *Philos. Trans. R. Soc. A.* 369:957–75
12. Zalasiewicz J, Williams M, Fortey R, Smith A, Barry TL, et al. 2011. Stratigraphy of the Anthropocene. *Philos. Trans. R. Soc. A* 3691938:1036–55
13. Oldfield F, Barnosky AD, Dearing J, Fischer-Kowalski M, McNeill J, et al. 2013. The *Anthropocene Review:* its significance, implications and the rationale for a new transdisciplinary journal. *Anthr. Rev.* 1(1):3–7

4. The seminal short piece that introduced the Anthropocene to a wide scientific audience.

14. Autin WJ, Holbrook JM. 2012. Is the Anthropocene an issue of stratigraphy or pop culture? *GSA Today* 22(7):60–61
15. Finney SC, Edwards LE. 2016. The "Anthropocene" epoch: scientific decision or political statement? *GSA Today* 26(3):4–10
16. Zalasiewicz J, Williams M, Smith A, Barry TL, Coe AL, et al. 2008. Are we now living in the Anthropocene? *GSA Today* 18(2):4–8
17. Zalasiewicz J, Williams M, Haywood A, Ellis M. 2011. The Anthropocene: a new epoch of geological time? *Philos. Trans. A. Math. Phys. Eng. Sci.* 369(1938):835–41
18. Zalasiewicz J, Waters CN, Williams M, Barnosky AD, Cearreta A, et al. 2015. When did the Anthropocene begin? A mid-twentieth century boundary level is stratigraphically optimal. *Quat. Int.* 383:196–203
19. Williams M, Zalasiewicz J, Haff P, Schwägerl C, Barnosky AD, Ellis EC. 2015. The Anthropocene biosphere. *Anthr. Rev.* 2(3):196–219
20. Waters CN, Zalasiewicz J, Summerhayes C, Barnosky AD, Poirier C, et al. 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351(6269):137–48
21. Gradstein FM, Ogg JG, Schmitz M, Ogg G. 2012. *The Geologic Time Scale 2012*. Amsterdam: Elsevier
22. Walker M, Johnsen S, Rasmussen SO, Popp T, Steffensen J-P, et al. 2009. Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records. *J. Qt. Sci.* 24(1):3–17
23. Lewis SL, Maslin MA. 2015. Defining the Anthropocene. *Nature* 519(7542):171–80
24. Reddy E. 2014. What does it mean to do anthropology in the Anthropocene? *Castac*, Apr. 8. **http://blog.castac.org/2014/04/what-does-it-mean-to-do-anthropology-in-the-anthropocene/**
25. Leigh Star S. 2010. This is not a boundary object: reflections on the origin of a concept. *Sci. Technol. Hum. Val.* 35(5):601–17
26. Wackernagel M, Schulz NB, Deumling D, Linares AC, Jenkins M, et al. 2002. Tracking the ecological overshoot of the human economy. *PNAS* 99(14):9266–71
27. Malhi Y. 2014. The metabolism of a human-dominated planet. In *Is the Planet Full?*, ed I Goldin, p. 272. Oxford: Oxford Univ. Press
28. Fischer-Kowalski M, Krausmann F, Pallua I. 2014. A sociometabolic reading of the Anthropocene: modes of subsistence, population size and human impact on Earth. *Anthr. Rev.* 1(1):8–33
29. Haberl H, Erb K-H, Krausmann F. 2014. Human appropriation of net primary production: patterns, trends, and planetary boundaries. *Annu. Rev. Environ. Resour.* 39(1):363–91
30. Lenton TM. 2013. Environmental tipping points, *Annu. Rev. Environ. Resour.* 38:1–29
31. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, et al. 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.* 14(2):32
32. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, et al. 2009. A safe operating space for humanity. *Nature* 461(7263):472–75
33. Castree N. 2014. The Anthropocene and geography I: the back story. *Geogr. Compass* 8(7):436–49
34. Steffen W, Richardson K, Rockström J, Cornell S, Fetzer I, et al. 2015. Planetary boundaries: guiding human development on a changing planet. *Science* 348(6240):1217
35. McNeill JR, Engelke P. 2014. *The Great Acceleration: An Environmental History of the Anthropocene Since 1945*. Cambridge, MA: Harvard Univ. Press
36. Thornton TF, Malhi Y. 2016. The trickster in the Anthropocene. *Anthr. Rev.* 3(3):201–4
37. Ellis EC. 2011. Anthropogenic transformation of the terrestrial biosphere. *Philos. Trans. R. Soc. A* 369:1010–35
38. Barnosky AD, Hadly EA, Bascompte J, Berlow EL, Brown JH, et al. 2012. Approaching a state shift in Earth's biosphere. *Nature* 486(7401):52–58
39. Kolbert E. 2014. *The Sixth Extinction: An Unnatural History*. New York: Henry Holt & Co.
40. McKinney ML, Lockwood JL. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends Ecol. Evol.* 14:450–53
41. Baiser B, Olden JD, Record S, Lockwood JL, McKinney ML. 2012. Pattern and process of biotic homogenization in the New Pangaea. *Proc. R. Soc. Lond. B Biol. Sci.* 279:4772–77

18. The paper that outlines the geological case from the Anthropocene Working Group for the mid-twentieth-century start to the Anthropocene.

20. A paper from the Anthropocene Working Group that summarizes the stratigraphic case for a distinct new geological epoch.

42. Smil V. 2011. Harvesting the biosphere: the human impact. *Popul. Dev. Rev.* 37(4):613–36
43. Haff P. 2014. Humans and technology in the Anthropocene: six rules. *Anthr. Rev.* 1(2):126–36
44. Zalasiewicz J, Williams M, Waters CN, Barnosky AD, Palmesino J, et al. 2016. Scale and diversity of the physical technosphere: a geological perspective. *Anthr. Rev.* 4:9–22
45. Davies J. 2016. *The Birth of the Anthropocene*. Oakland, CA: Univ. Calif. Press
46. Edgeworth M, Richter DD, Waters C, Haff P, Neal C, Price SJ. 2015. Diachronous beginnings of the Anthropocene: the lower bounding surface of anthropogenic deposits. *Anthr. Rev*. 2:33–58
47. Zalasiewicz J, Williams M, Waters CN, Barnosky AD, Haff P. 2014. The technofossil record of humans. *Anthr. Rev*. 1:34–43
48. Worm B, Lotze HK, Jubinville I, Wilcox C, Jambeck J. 2017. Plastic as a persistent marine pollutant. *Annu. Rev. Environ. Resour.* 42:1–26
49. Barnosky AD. 2014. Palaeontological evidence for defining the Anthropocene. *Geol. Soc. Lond. Spec. Publ.* 395(1):149–65
50. Bacon KL, Swindles GT. 2016. Could a potential Anthropocene mass extinction define a new geological period? *Anthr. Rev.* 3:208–17
51. Zalasiewicz J, Cearreta A, Crutzen PJ, Erle E, Ellis MA, et al. 2012. Response to Autin and Holbrook on "Is the anthropocene an issue of stratigraphy or pop culture?" *GSA Today* 22(7):e21–e22
52. Finney SC. 2014. The "Anthropocene" as a ratified unit in the ICS International Chronostratigraphic Chart: fundamental issues that must be addressed by the Task Group. *Geol. Soc. Lond. Spec. Publ.* 395(1):23–28
53. Gale SJ, Hoare PG. 2012. The stratigraphic status of the Anthropocene. *Holocene* 22:1491–94
54. Lorimer J. 2016. The Anthropo-scene: a guide for the perplexed. *Soc. Stud. Sci.* 47:117–4
55. Ruddiman WF, Ellis EC, Kaplan JO, Fuller DQ. 2015. Geology. Defining the epoch we live in. *Science* 348(6230):38–39
56. Lewis SL, Maslin MA. 2015. A transparent framework for defining the Anthropocene Epoch. *Anthr. Rev.* 2(2):128–46
57. Ellis E, Maslin M, Boivin N, Bauer A. 2016. Involve social scientists in defining the Anthropocene. *Nature* 540(7632):192–93
58. Smith BD, Zeder MA. 2013. The onset of the Anthropocene. *Anthropocene* 4:8–13
59. Ruddiman WF. 2013. The Anthropocene. *Annu. Rev. Earth Planet. Sci.* 41(1):45–68
60. Ruddiman WF. 2003. The Anthropogenic Greenhouse Era began thousands of years ago. *Clim. Change* 61(3):261–93
61. Doughty CE, Wolf A, Field CB. 2010. Biophysical feedbacks between the Pleistocene megafauna extinction and climate: The first human-induced global warming? *Geophys. Res. Lett.* 37(15):1–5
62. Hamilton C. 2015. Getting the Anthropocene so wrong. *Anthr. Rev.* 2(2):102–7
63. Hamilton C. 2016. The Anthropocene as rupture. *Anthr. Rev.* 3:1–14
64. Hamilton C. 2017. *Defiant Earth. The Fate of Humans in the Anthropocene.* Crows Nest, Austr.: Allen & Unwin
65. Certini G, Scalenghe R 2015. Holocene as Anthropocene. *Science* 349(6245):246
66. Foley SF, Gronenborn D, Andreae MO, Kadereit JW, Esper J, et al. 2013. The Palaeoanthropocene—the beginnings of anthropogenic environmental change. *Anthropocene* 3:8–88
67. Glikson A. 2013. Fire and human evolution: the deep-time blueprints of the Anthropocene. *Anthropocene* 3:89–92
68. Malhi Y, Doughty CE, Galetti M, Smith FA, Svenning J-C, Terborgh JW. 2016. Megafauna and ecosystem function from the Pleistocene to the Anthropocene. *PNAS* 113(4):838–46
69. Barnosky AD, Koch PL, Feranec RS, Wing SL, Shabel AB. 2004. Assessing the causes of late Pleistocene extinctions on the continents. *Science* 306(5693):70–75
70. Koch PL, Barnosky AD. 2006. Late Quaternary extinctions: state of the debate. *Annu. Rev. Ecol. Evol. Syst.* 37(1):215–50
71. Sandom C, Faurby S, Sandel B, Svenning J-C. 2014. Global late Quaternary megafauna extinctions linked to humans, not climate change. *Proc. Biol. Sci.* 281(1787):20133254
72. Rule S, Brook BW, Haberle SG, Turney CSM, Kershaw AP, Johnson CN. 2012. The aftermath of megafaunal extinction: ecosystem transformation in Pleistocene Australia. *Science* 335(6075):1483–86

54. A concise overview of the range of thinking and debate on the Anthropocene, especially within the humanities.

73. Doughty CE, Wolf A, Malhi Y. 2013. The legacy of the Pleistocene megafauna extinctions on nutrient availability in Amazonia. *Nat. Geosci.* 6(9):761–64
74. Doughty CE, Roman J, Faurby S, Wolf A, Haque A, et al. 2016. Global nutrient transport in a world of giants. *PNAS* 113(4):868–73
75. Smith FA, Hammond JI, Balk MA, Elliott SM, Lyons SK, et al. 2016. Exploring the influence of ancient and historic megaherbivore extirpations on the global methane budget. *PNAS* 113(4):874–79
76. Ellis EC, Kaplan JO, Fuller DQ, Vavrus S, Goldewijk KK, et al. 2013. Used planet: a global history. *PNAS* 118(20):7978–85
77. Stocker BD, Strassmann K, Joos F. 2011. Sensitivity of Holocene atmospheric CO_2 and the modern carbon budget to early human land use: analyses with a process-based model. *Biogeosciences* 8(1):69–88
78. Kaplan JO, Krumhardt KM, Ellis EC, Ruddiman WF, Lemmen C, Goldewijk KK. 2011. Holocene carbon emissions as a result of anthropogenic land cover change. *Holocene* 21(5):775–91
79. Singarayer JS, Valdes PJ, Friedlingstein P, Nelson S, Beerling DJ. 2011. Late Holocene methane rise caused by orbitally controlled increase in tropical sources. *Nature* 470(7332):82–85
80. Doughty CE. 2013. Preindustrial human impacts on global and regional environment. *Annu. Rev. Environ. Resour.* 38:503–27
81. Fuller DQ, van Etten J, Manning K, Castillo C, Kingwell-Banham E, et al. 2011. The contribution of rice agriculture and livestock pastoralism to prehistoric methane levels: an archaeological assessment. *Holocene* 21(5):743–59
82. Certini G, Scalenghe R. 2011. Anthropogenic soils are the golden spikes for the Anthropocene. *Holocene* 21(8):1269–74
83. Mann CC. 2011. *1493: How Europe's Discovery of the Americas Revolutionized Trade, Ecology and Life on Earth*. London: Granta Books
84. Dull RA, Nevle RJ, Woods WI, Bird DK, Avnery S, Denevan WM. 2010. The Columbian encounter and the Little Ice Age: abrupt land use change, fire, and greenhouse forcing. *Ann. Assoc. Am. Geogr.* 100(4):755–71
85. Moore JW. 2015. *Capitalism in the Web of Life: Ecology and the Accumulation of Capital*. Brooklyn, NY: Verso
86. Haraway D. 2015. Anthropocene, Capitalocene, Plantationocene, Chthulucene: making kin. *Environ. Humanit.* 6:159–65
87. Moore JW. 2016. *Anthropocene or Capitalocene? Nature, History, and the Crisis of Capitalism*. Oakland, CA: PM Press
88. Deleted in proof
89. Zalasiewicz J, Waters CN, Barnosky AD, Cearreta A, Edgeworth M, et al. 2015. Colonization of the Americas, "Little Ice Age" climate, and bomb-produced carbon: their role in defining the Anthropocene. *Anthr. Rev.* 2:117–27
90. Purdy J. 2015. *After Nature: A Politics for the Anthropocene*. Cambridge, MA; Harvard Univ. Press
91. Stoner AM, Melathopoulos A. 2015. *Freedom in the Anthropocene: Twentieth-Century Helplessness in the Face of Climate Change*. Basingstoke, UK: Palgrave Macmillan
92. Scranton R. 2015. *Learning to Die in the Anthropocene: Reflections on the End of a Civilization*. San Francisco: City Lights Books
93. Arias-Maldonado M. 2015. *Environment and Society: Socionatural Relations in the Anthropocene*. Cham, Switz.: Springer
94. Biermann F. 2014. *Earth System Governance: World Politics in the Anthropocene*. Cambridge, MA: MIT Press
95. Delanty G, Mota A. 2017. Governing the Anthropocene. *Eur. J. Soc. Theory* 20(1):9–38
96. Simmons EL. 2014. Theology in the Anthropocene. *Dialog* 53(4):271–73
97. Davis H, Turpin E. 2015. *Art in the Anthropocene: Encounters Among Aesthetics, Politics, Environments and Epistemologies*. London: Open Humanities Press
98. Whitehouse A. 2015. Listening to birds in the Anthropocene: the anxious semiotics of sound in a human-dominated world. *Environ. Humanit.* 6(1):53–71
99. Dirzo R, Young HS, Galetti M, Ceballos G, Isaac NJB, Collen B. 2014. Defaunation in the Anthropocene. *Science* 345(6195):401–6

100. Malhi Y, Gardner TA, Goldsmith GR, Silman MR, Zelazowski P. 2014. Tropical forests in the Anthropocene. *Annu. Rev. Environ. Resour.* 39(1):125–59
101. Ellis EC, Antill EC, Kreft H. 2012. All is not loss: plant biodiversity in the Anthropocene. *PLOS ONE* 7(1):e30535
102. Richter DD, Bacon AR, Brecheisen Z, Mobley ML. 2015. Soil in the Anthropocene. *IOP Conf. Ser. Earth Environ. Sci.* 25(1):12010
103. Ellis EC, Fuller DQ, Kaplan JO, Lutters WG. 2013. Dating the Anthropocene: towards an empirical global history of human transformation of the terrestrial biosphere. *Elem. Sci. Anthr.* 1:1–6
104. Malm A, Hornborg A. 2014. The geology of mankind? A critique of the Anthropocene narrative. *Anthr. Rev.* 1(1):62–69
105. Hornborg A. 2015. The political ecology of the Technocene: uncovering ecologically unequal exchange in the world-system. See Ref. 118, pp. 57–69
106. Parikka J. 2014. *The Anthrobscene*. Minneapolis, MN: Univ. Minn. Press
107. Raworth K. 2014. Must the Anthropocene be a Manthropocene? *The Guardian*, Oct. 20. **https://www.theguardian.com/commentisfree/2014/oct/20/anthropocene-working-group-science-gender-bias**
108. De la Cadena M. 2015. Uncommoning Nature. *e-flux* 56. **http://supercommunity.e-flux.com/texts/uncommoning-nature/**
109. Bonneuil C, Fressoz J-B. 2016. *The Shock of the Anthropocene: The Earth, History, and Us*. Brooklyn, NY: Verso
110. Fressoz J-B. 2015. Losing the Earth knowingly. Six environmental grammars around 1800. See Ref. 118, pp. 70–83
111. Raworth K. 2012. *A safe and just space for humanity: Can we live within the doughnut*? Oxfam Discuss. Pap., Febr.
112. Raworth K. 2017. *Doughnut Economics, Seven Ways to Think Like a 21st-Century Economist*. New York: Random House
113. Corlett RT. 2015. The Anthropocene concept in ecology and conservation. *Trends Ecol. Evol.* 30:36–41. **http://dx.doi.org/10.1016/j.tree.2014.10.007**
114. Marris E. 2011. *Rambunctious Garden: Saving Nature in a Post-wild World*. London: Bloomsbury
115. Svenning J, Pedersen PBM, Donlan CJ, Ejrnaes R, Faurby S, et al. 2015. Science for a wilder Anthropocene—synthesis and directions for rewilding research. *PNAS* 113:898–906
116. Thomas CD. 2017. *Inheritors of the Earth*. London: Penguin
117. Asafu-Adjaye J, Blomqvist L, Brand S, Brook B, Defries R, et al. 2015. *An Ecomodernist Manifesto*. **http://www.ecomodernism.org/**
118. Hamilton C, Bonneuil C, Gemenne F, eds. 2015. *The Anthropocene and the Global Environmental Crisis: Rethinking Modernity in a New Epoch*. Abingdon: Routledge
119. Brondizio ES, O'Brien K, Bai X, Biermann F, Steffen W, et al. 2016. Re-conceptualizing the Anthropocene: a call for collaboration. *Glob. Environ. Chang.* 39:318–27
120. Dalby S. 2016. Framing the Anthropocene: the good, the bad and the ugly. *Anthr. Rev.* 3(1):33–51
121. Chakrabarty D. 2015. The Anthropocene and the convergence of histories. See Ref. 118, pp. 44–56

104. A key critique of the concept of the Anthropocene from a social science perspective.

RELATED RESOURCES

Anthropocene: Innovation in the Human Age (**http://www.anthropocenemagazine.org/**) is an online magazine with stimulating journalism and comment pieces and also a useful daily science roundup of Anthropocene-related content.

The Smithsonian Anthropocene webpage (**http://www.smithsonianmag.com/science-nature/age-humans-living-anthropocene-180952866/**) hosts a range of media resources exploring the concept of the Anthropocene.

Generation Anthropocene (**http://anthropocene.stanford.edu/**) is an excellent podcast series run out of Stanford University that explores many of the scientific, political, and philosophical issues surrounding the Anthropocene.

Annual Review of Environment and Resources

Volume 42, 2017

Contents

I. Integrative Themes and Emerging Concerns

Plastic as a Persistent Marine Pollutant
Boris Worm, Heike K. Lotze, Isabelle Jubinville, Chris Wilcox, and Jenna Jambeck 1

African Environmental Change from the Pleistocene to the Anthropocene
Colin Hoag and Jens-Christian Svenning 27

The Intergovernmental Panel on Climate Change: Challenges and Opportunities
Mark Vardy, Michael Oppenheimer, Navroz K. Dubash, Jessica O'Reilly, and Dale Jamieson 55

The Concept of the Anthropocene
Yadvinder Malhi 77

Marked for Life: Epigenetic Effects of Endocrine Disrupting Chemicals
Miriam N. Jacobs, Emma L. Marczylo, Carlos Guerrero-Bosagna, and Joëlle Rüegg 105

II. Earth's Life Support Systems

Degradation and Recovery in Changing Forest Landscapes: A Multiscale Conceptual Framework
Jaboury Ghazoul and Robin Chazdon 161

III. Human Use of the Environment and Resources

Drivers of Human Stress on the Environment in the Twenty-First Century
Thomas Dietz 189

Linking Urbanization and the Environment: Conceptual and Empirical Advances
Xuemei Bai, Timon McPhearson, Helen Cleugh, Harini Nagendra, Xin Tong, Tong Zhu, and Yong-Guan Zhu 215

Debating Unconventional Energy: Social, Political, and Economic Implications
Kate J. Neville, Jennifer Baka, Shanti Gamper-Rabindran, Karen Bakker, Stefan Andreasson, Avner Vengosh, Alvin Lin, Jewellord Nem Singh, and Erika Weinthal 241

Emerging Technologies for Higher Fuel Economy Automobile Standards
Timothy E. Lipman 267

The Future of Low-Carbon Electricity
Jeffery B. Greenblatt, Nicholas R. Brown, Rachel Slaybaugh, Theresa Wilks, Emma Stewart, and Sean T. McCoy 289

Organic and Conventional Agriculture: A Useful Framing?
Carol Shennan, Timothy J. Krupnik, Graeme Baird, Hamutahl Cohen, Kelsey Forbush, Robin J. Lovell, and Elissa M. Olimpi 317

Smallholder Agriculture and Climate Change
Avery S. Cohn, Peter Newton, Juliana D.B. Gil, Laura Kuhl, Leah Samberg, Vincent Ricciardi, Jessica R. Manly, and Sarah Northrop 347

The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda
Benjamin K. Sovacool, Jonn Axsen, and Willett Kempton 377

Technology and Engineering of the Water-Energy Nexus
Prakash Rao, Robert Kostecki, Larry Dale, and Ashok Gadgil 407

IV. Management and Governance of Resources and Environment

Landscape Approaches: A State-of-the-Art Review
Bas Arts, Marleen Buizer, Lumina Horlings, Verina Ingram, Cora van Oosten, and Paul Opdam 439

Foreign Direct Investment and the Environment
Matthew A. Cole, Robert J.R. Elliott, and Liyun Zhang 465

Land Tenure Transitions in the Global South: Trends, Drivers, and Policy Implications
Thomas K. Rudel and Monica Hernandez 489

Ecosystem Services from Transborder Migratory Species: Implications for Conservation Governance
Laura López-Hoffman, Charles C. Chester, Darius J. Semmens, Wayne E. Thogmartin, M. Sofia Rodríguez-McGoffin, Robert Merideth, and Jay E. Diffendorfer 509

V. Methods and Indicators

Legacies of Historical Human Activities in Arctic Woody Plant Dynamics
Signe Normand, Toke T. Høye, Bruce C. Forbes, Joseph J. Bowden, Althea L. Davies, Bent V. Odgaard, Felix Riede, Jens-Christian Svenning, Urs A. Treier, Rane Willerslev, and Juliane Wischnewski 541

Toward the Next Generation of Assessment
Katharine J. Mach and Christopher B. Field 569

Sustainability Transitions Research: Transforming Science and Practice for Societal Change
Derk Loorbach, Niki Frantzeskaki, and Flor Avelino 599

Attribution of Weather and Climate Events
Friederike E.L. Otto 627

Material Flow Accounting: Measuring Global Material Use for Sustainable Development
Fridolin Krausmann, Heinz Schandl, Nina Eisenmenger, Stefan Giljum, and Tim Jackson 647

The Impact of Systematic Conservation Planning
Emma J. McIntosh, Robert L. Pressey, Samuel Lloyd, Robert J. Smith, and Richard Grenyer 677

Indexes

Cumulative Index of Contributing Authors, Volumes 33–42 699

Cumulative Index of Article Titles, Volumes 33–42 705

Errata

An online log of corrections to *Annual Review of Environment and Resources* articles may be found at http://www.annualreviews.org/errata/environ