Review

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The Anthropocene concept in ecology and conservation

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The term 'Anthropocene' was first used in the year 2000 to refer to the current time period in which human impacts are at least as important as natural processes. It is currently being considered as a potential geological epoch, following on from the Holocene. While most environmental scientists accept that many key environmental parameters are now outside their Holocene ranges, there is no agreement on when the Anthropocene started, with plausible dates ranging from the Late Pleistocene megafaunal extinctions to the recent globalization of industrial impacts. In ecology, the Anthropocene concept has focused attention on human-dominated habitats and novel ecosystems, while in conservation biology it has sparked a divisive debate on the continued relevance of the traditional biocentric aims.

Origins of the Anthropocene concept

The word 'Anthropocene' (from the Greek *Anthropos* 'human being' and *kainos* 'new') was first used by Crutzen and Stoermer in 2000 [1], although the concept is considerably older. They proposed this new term for a new geological epoch 'to emphasize the central role of mankind in geology and ecology'. Various similar definitions have been suggested subsequently, but the basic concept is that humans are now a major geological and environmental force, as important as, or more important than, natural forces. Although the start of the period it refers to has not yet been agreed, the term has been increasingly widely adopted in the earth and environmental science literature, as well as in the environmental social sciences, and has had increasing media coverage.

The Anthropocene Working Group (AWG) of the International Commission on Stratigraphy's Subcommission on Quaternary Stratigraphy is currently considering whether the Anthropocene should be formalized within the geological timescale [2]. Other disciplines are likely to accept the authority of any decision they make. Most members of the AWG are from geology and related disciplines, but the working group also includes an ecologist, a soil scientist, a climate scientist, two archaeologists, an environmental historian, a lawyer, and a journalist. Proponents of formalization have dominated the literature, but there is considerable opposition to this within the earth science community, largely because of the difficulties of finding a globally identifiable marker that reflects the point at which human impacts started to overtake natural processes [3]. Moreover, the use of the '-cene' ending raised the stakes by suggesting that the Anthropocene should have the same 'epoch' status as the Holocene, which would thus end, rather than the more easily arguable case for a subdivision of a continuing Holocene. Thus, ratification of the formalization proposal by the voting members of the International Commission on Stratigraphy is by no means certain.

A formal definition of the Anthropocene with a definite start date would probably put an end to the current highly varied and informal use of the term in ecology and conservation biology, as well as in other fields. A decision not to formalize might also affect usage in these fields, because it would highlight the problems with the term and the concept it is applied to. Therefore, here I look at the following major questions. Are we in the Anthropocene? When did it start? How is the concept currently being used in ecology and conservation biology? Would standardization of the concept be useful in these fields?

Are we in the Anthropocene?

The pervasiveness, magnitude, and variety of human impacts leave little doubt that we are currently in a distinct time period from an environmental viewpoint. It can be argued that the geological impacts so far are shallow and could be obliterated by 'another extended interval of voluminous flood basalts or another large asteroid impact' [2], but this must have been true at the beginning of other geological periods. While geologists might be concerned with the detectability of the Anthropocene when looking back from the distant future, this is not a consideration that should influence our use of the term today in ecology.

Justification for viewing the Anthropocene as a geological epoch distinct from the Holocene depends on showing that key environmental parameters are now outside their Holocene ranges. This is clearly true for many critical elements of our biophysical environment, including greenhouse gas concentrations [4], ocean acidity [5], river systems [6], global and regional nitrogen (N) cycles [7], the creation of novel minerals [8], the transport of materials from place to place [9], human appropriation of net primary production [10], extinction rates [11], invasion rates [12], biotic homogenization [13], and the spread of novel ecosystems (Box 1). It will be true for others within a few decades, including global climates [14] and glacial extent [15]. These

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Box 1. Novel ecosystems and the Anthropocene

A novel ecosystem in the broadest sense is one that differs from 'historical' ecosystems as a result of human agency. In this sense, most of the land surface of the Earth is covered in novel ecosystems [58]. Most authors restrict the term by requiring that novel ecosystems do not need continued human intervention to persist, thus excluding areas that are actively managed [59]. Some also exclude novel species assemblages arising from indirect anthropogenic stresses, such as climate change, N deposition, and ocean acidification, and require that novel ecosystems have 'crossed an ecological threshold' that makes the changes difficult or impossible to reverse [60]. However, evidence for such irreversible ecological thresholds is generally lacking [61]. Indeed, the increasingly voluminous literature provides surprisingly little information on how novel ecosystems work. If, as some have argued [62], the biogeographical origin of a species has little bearing on its impact, then alien-dominated novel ecosystems are just ecosystems. Evidence from invasion biology suggests that at least some nonnative species are more disruptive than expanding native species [63], but it is not clear how general this is.

Although the novel ecosystem concept can be used in a value-neutral way, several authors have suggested that 'embracing novelty' is a sensible response to the advent of the Anthropocene [59]. Moreover, novel ecosystems that result from self-assembly and persist without human intervention can reasonably be considered wild and are often beautiful [45]. In response to these positive views, criticism of the concept has centered on the fear that it legitimizes negative human impacts that could be avoided or mitigated [61,64]. However, most ecologists favor a middle way, where novel ecosystems that cannot practicably be prevented or returned to nearer their original state are managed for most of the same values that we want from historical ecosystems [65,66].

global impacts on terrestrial, freshwater, and marine ecosystems, in turn, reflect a smaller number of major drivers, particularly human population growth, economic growth, and increasing international travel and transport.

When did it start?

The major practical problem with the Anthropocene concept is choosing an agreed start date. The environmental parameters listed above did not move out of their Holocene ranges at the same time. Ecologists have had little problem with a diachronous start (i.e., starting at different times in different places), depending on the date at which human impacts became regionally significant: for example, 'New Zealand . . .represents the last place on earth to enter the Anthropocene, with the first human colonists. . . arriving only c. 740 yr ago' [16]. However, geological periods must have globally synchronous start dates.

Crutzen and Stoermer suggested that the late 18th century would be an appropriate starting date for their proposed new epoch [1], to reflect the start of the industrial revolution in northern Europe, and dates between 1712 (the invention of the steam engine) and 1850 (when atmospheric signals of industry first become clear) have received the most support in the literature. However, the industrial revolution was strongly diachronous and did not reach large parts of the surface of the Earth until more recently. Another date that has received considerable support is the 'great acceleration' of 1945–1955, when economic activity and human impacts increased exponentially on a global scale [17]. The year 2000, when the concept was first proposed [1], is another possibility. Alternatively, a case can be made that the Anthropocene will start in the future, perhaps later this century as global climate moves outside its Holocene range or at some unforeseeable future date.

By contrast, other authors have pointed out that widespread human impacts on the natural environment started long before the industrial revolution, and much earlier suggested starting dates include the first human use of fire to modify ecosystems (up to 1.8 m years ago [18]), the late Pleistocene megafaunal extinctions (14 000–15 000 years ago [19]), the arrival of modern humans on all continents except Antarctica (c. 10 000 years ago [20]), and the rise of agriculture (c. 7000 years ago [21]). One possibility would be to merge the Holocene and Anthropocene, because the major claim for the Holocene to be distinct from previous interglacial periods is the near-global presence of modern humans [20]. Alternatively, the Holocene could be abolished or demoted, and the Pleistocene extended up to an industrial-era start of the Anthropocene [22]. The term 'Paleoanthropocene' (or Pre-Anthropocene) could then be used in a nongeological sense for regional signs of preindustrial anthropogenic change [23].

Others have suggested that the complexities of human history mean that the term 'Anthropocene' is best used informally, as it is now, and that formalization would be a distraction [2,21,24]. However, given the wide range of different human impacts and time periods that the term is currently applied to, it is hard to see how this 'informality' aids communication. Moreover, many authors who use the term are referring to a particular period, so the collective informality reflects the sum of different, individual attempts at formalization. In any case, the geological word ending implies, even to the layman, a definite, global period, so leaving it undefined is confusing.

Procedures developed during the late 1960s by the International Commission on Stratigraphy require that the lower boundary of each stratigraphic unit is defined by a Global Stratotype Section and Point (a GSSP or 'golden spike'). If this procedure was to be followed for the Anthropocene, possible markers include anthropogenic deposits and landforms [25], novel minerals [8], nondegradable plastic debris [26], subsurface changes [27], or bomb-test radioisotopes [28], with the latter having the advantage that they are a global signal. A possible future marker would be the expected decline in high-magnesium carbonate on tropical and subtropical continental shelves between 2040 and 2080 as a result of ocean acidification [29]. Alternatively, a date in human history could be chosen as the lower boundary (a Global Standard Stratigraphic Age; GSSA), although this raises the question of why this is an issue for geologists rather than environmental historians. Previous geological boundaries also separate distinct biological assemblages, but although extinction is a potential marker for local and regional Anthropocene impacts [30], both Late Pleistocene and recent extinctions have been highly diachronous.

The Anthropocene in ecology

The recent literature shows that both ecologists and conservation biologists increasingly recognize that we are in the Anthropocene. Most usage is informal, but the implied

start date is usually within the past few decades, rather than the earlier dates favored by many in the earth sciences. Responses to this recognition vary widely. On the one hand, the use of the term often has a purely negative connotation, as shorthand for all that is wrong with the world (e.g., [31]). On the other hand, some have found it liberating [32]. However, the most common response is to recognize that the world has changed: it is no longer 'business as usual' and so our approaches to both research and practice will also have to change.

With the world changing rapidly, globally, and directionally, the steady-state assumptions that previously underpinned ecology will need to be abandoned or heavily modified [33]. The idea that the statistical properties of stochastic processes cannot be assumed to be constant ('temporal non-stationarity') is not new in ecology, but nonstationary environments are a hallmark of the Anthropocene, with consequences for the ways in which we approach both ecology and conservation [34]. Exactly what will replace these assumptions is less clear, but a focus on interactions, feedbacks, and thresholds has been suggested [33,35]. Many authors have also recommended increased attention on relatively neglected research areas, including novel ecosystems (Box 1), and human-dominated agricultural [36] and urban [37] areas. In island biogeography, Anthropocene models need to include economic isolation because it influences invasion rates [38]. On a larger scale, the recognition that some key environmental parameters are now outside their Holocene ranges has given rise to the concept of 'planetary boundaries' (Box 2), beyond which it is not safe to transgress. The need for interdisciplinarity, synthesis, and theory building are common, crosscutting themes. Finally, some have called for a more proactive approach, where ecologists not only observe and try to understand change, but are also involved in shaping change towards sustainable outcomes [33].

The Anthropocene in conservation

The conservation community has also emphasized 'planetary stewardship', as well as the need for conservation to recognize and deal with the pervasiveness and irreversibility of Anthropocene impacts. The most important changes in the ways that conservation biologists think and act have come from two parallel realizations: that conservation can no longer focus only on preserving and restoring ecosystems of the past, because this will be impossible in many places, and that we can no longer treat natural systems as separate from human systems [39,40]. While some authors see these changed perceptions as a threat, fearing that they will 'cultivate hopelessness in those dedicated to conservation' and 'undermine both conservation and restoration objectives' [41], most seem prepared to accept the reality and focus on the inevitably novel future rather than the irretrievably lost past. The often acrimonious debate on how this 'new conservation' should be done (Box 3) hides a great deal of agreement among conservationists in the field that saving species from extinction and maintaining resilient, functioning ecosystems are still worthwhile goals on a human-dominated planet.

Box 2. Planetary boundaries in the Anthropocene

Planetary boundaries are envisaged as limits beyond which it is not safe to push key global environmental variables [67,68]. Together, they define a safe operating space (the 'planetary playing field') for humanity. They can be seen as an attempt to stay within the Holocene-like state of the Earth system, because this is the only state that we know will support human civilization [69]. Originally, nine boundaries were described, seven with quantitative estimates, relating to climate change (CO_2 <350 ppm or 1 W m^{-2} increase in radiative forcing), ocean acidification (mean surface sea-water saturation state with respect to aragonite ≥80% pre-industrial), stratospheric ozone (<5% reduction from pre-industrial levels), the biogeochemical N cycle (agricultural and industrial N fixation <35 Tg N yr^{-1}), the phosphorous cycle (phosphorous inflow to oceans <10× natural background rate), global freshwater use (<4000 km^3 yr^{-1}), and the rate of biodiversity loss (<10 extinctions per million species per year), and two without initial estimates, chemical pollution and atmospheric aerosol loading [67]. The proposed quantifications were considered as 'rough, first estimates only, surrounded by large uncertainties and knowledge gaps'. At least three boundaries (climate change, N cycle, and biodiversity loss) were considered to have already been crossed. Note that some are unambiguously global problems, such as climate change and ocean acidification, while others, such as the N and phosphorous cycles, are global only in aggregate [70]. Moreover, planetary boundaries may or may not be tipping points, where there is a rapid shift to an alternative state [71]. Indeed, the heterogeneity of ecosystem responses to major drivers of environmental change is likely to result in relatively smooth changes at the global scale [72]. Subsequent studies have refined the initial estimates [73] and suggested additional boundaries (e.g., global net primary productivity [74]). In practice, most environmental governance takes place at regional scales or below, so there have also been attempts to 'downscale' the concept for practical application [75]. The planetary boundaries hypothesis has also been criticized as negative and nostalgic, portraying the Anthropocene as a crisis rather than an opportunity, when human societies have been expanding beyond apparent biophysical limits for millennia [76].

The idea that conservation must happen in human-altered landscapes is by no means new, particularly in Europe, where almost all landscapes were altered centuries ago, but it is a radical concept in parts of the world where conservation has traditionally focused on protecting 'pristine' landscapes from humans. One aspect of this concerns the future of restoration ecology. If restoring historical reference ecosystems is not a practical target in a time of rapid environmental change, then multiple goals are possible, including a greater emphasis on ecosystem services and other aspects of human well being [42,43]. Active intervention, adaptive management, and experimentation seem likely to become increasingly standard practices in conservation management [44]. The Anthropocene concept has also been used to advocate such nontraditional conservation strategies as assisted migration and rewilding [45], and has sparked more radical suggestions for actively creating new ecosystems with desirable properties for biodiversity conservation and ecosystem services, rather than simply protecting historical remnants and managing spontaneous novel systems [46].

While some have seen opportunities in the recognition that humans have irreversibly changed the Earth ('It is no longer Mother Nature who will care for us, but us who must care for her' [47]), there has also been an increasing backlash among conservationists against the idea of a human-managed Anthropocene, encapsulated in the title

Box 3. The new conservation

The so-called 'new conservation' can be seen as a direct consequence of the recognition of the Anthropocene. If humans are now the dominant ecological force on the planet, then it is impossible to separate 'humans' and 'nature' in the way that conservation has traditionally tried to do. However, even for those who agree with this statement, there are multiple potential ways forward for conservation. As with previous debates in conservation (wise use versus preservation, parks versus humans [77]), these can be assigned to positions on a continuum from the extreme anthropocentric view that only humans matter, to the extreme biocentric view that humans are just another species [78]. The label 'new conservation' has been applied to the anthropocentric side of the current debate, while the 'old' conservationists are presumed to be more biocentric.

Although all participants in the recent debate claim similar overall objectives, including protecting nature and preventing extinction, they differ in emphasis and methods. The biggest theoretical and practical difference has been the greater emphasis that new conservation gives to the benefits of conservation for humans ('conservation for people rather than from people' [79]), echoing the earlier debates mentioned above. In the writings of the major proponents of new conservation, this emphasis sits rather uneasily with a willingness to work more closely with large corporations than has been usual in conservation biology [79].

To an outsider, much of the recent debate appears to involve the creation and knocking down of 'straw men', which exaggerate or misrepresent the opponents' arguments, followed by attempts to 'set the record straight', when it would be more useful to focus on finding common ground [78]. Moreover, it has so far taken place largely within the USA, where much of the controversy reflects the hold that the new conservation philosophy has on the Nature Conservancy, which calls itself the world's largest conservation nongovernmental organization [80]. Arguably, however, the more anthropocentric focus of the new conservation is most relevant in parts of the world, such as much of Africa, where conservation is chronically underfunded and undereffective, and human population growth and poverty are highest [81].

of a recent book of essays: *Keeping the Wild: Against the Domestication of Earth* [48]. Although some of this reflects traditional conservation concerns for preserving minimally modified natural ecosystems [41], others accept that there is no going back, but still wish to give free rein to natural processes wherever possible, arguing that that it is still possible to value 'naturalness' and 'wildness' in a world where nowhere is pristine [31]. An example of how this can work in practice comes from Europe, where the recovery of a number of large mammal and bird species after decades of conservation effort has spurred ambitious plans for 'rewilding' large areas in a landscape that is far from pristine [49].

The Anthropocene in social sciences

Social scientists have been quick to point out that the current focus on the biophysical aspects of global environmental change makes little sense when the problems being studied are caused by humans, harm humans, and can only be solved by humans [50]. There is clearly an urgent need to understand the links between biophysical and social processes of change, and to integrate contributions from across the social sciences: economists, geographers, demographers, sociologists, anthropologists, psychologists, and others [51]. Many authors have expressed a hope that conceptualizing the challenges that face us under the umbrella of the Anthropocene would allow different disciplines to collaborate and develop strategies for dealing with global change [52]. Calls for planetary stewardship and global environmental governance are common to all disciplines that use the term 'Anthropocene', suggesting that such a collaboration, perhaps based initially around a global spatial database of Anthropocene impacts, is not an impossible dream. The need for environmental scientists to communicate increasingly more effectively with political and business leaders, as well as the general public, is another shared theme of the Anthropocene literature, reflecting the recognition that humans are at the core of both the problems and solutions [53]. Finally, it has been pointed out that the Anthropocene concept necessarily has a moral component, because it acknowledges the role of human activity [30]. We can choose which Anthropocene will actually happen.

Concluding remarks

The Anthropocene concept has proved a useful shorthand for anthropogenic global change and has made it impossible to treat the present period as 'business as usual', with consequences for how ecological research and conservation management are conceptualized and conducted. A decision to formalize the Anthropocene with a start date sometime in the industrial era would be consistent with most current usage, with a post-1945 date likely to most acceptable in both ecology and conservation. Preindustrial human impacts were patchy and diachronistic, while a definition based on the start of the industrial revolution in Europe makes little global sense. An agreed start date would surely aid communication, within both the biophysical sciences and the social sciences. Hopefully, this would lead to increased collaboration. Biophysical scientists are going to need allies from the social sciences if they are going to influence policy and practice, and these alliances are likely to be most effective if they have deep roots in shared research and teaching. If the concept is eventually going to be formalized, the earlier this decision is made the better.

The Anthropocene concept has already been disruptive in conservation biology, which from its inception during the late 1970s had an essentially biocentric focus [54]. The new fault lines are not far from several older ones, but they are unusually deep, probably because they involve money and power, as well as deeply held differences in philosophies, and it is important that the field does not fragment at a time when we need broader alliances. Formalization is also likely to catch the public imagination, so conservationists must be ready with positive messages and practicable ways forward to minimize the risk of a 'nothing is natural so anything goes' philosophy reducing support for biological conservation. Although a focus on ecosystem services is useful in certain circumstances, biotic impoverishment will eventually threaten these [55], so species extinctions have practical consequences as well as being morally repugnant [56].

The disappointing results of the two biggest attempts at global environmental governance, the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) [57], do not encourage optimism about humanity's capacity for planetary stewardship, but some problems, such as greenhouse gases, can only be tackled on a global scale, and many others,

including biodiversity loss, need to be tackled simultaneously at local, regional, and global scales. If there are two general lessons that ecologists and conservationists most need to learn from, and for, the Anthropocene, it is the need to develop broad and deep collaborations, and to cultivate public support for their work. In a rapidly changing, human-dominated world, someone must speak for Nature.

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