Pivotal 20th century contributions to the development of the Anthropocene concept: overview and implications

Ricardo A. Correia, Zeynep C. H. Correia, Ana C. M. Malhado and Richard J. Ladle*

Humans have become such dominant drivers of planetary changes that scientists are now debating the establishment of a new epoch: the Anthropocene. The concept of the Anthropocene has gained rapid visibility, quickly becoming a trademark of 21st century scientific literature. Interestingly, some studies claim that this idea can be traced back to the 19th and 20th centuries, others suggest that this concept is strongly associated with emerging multidisciplinary views of humans as drivers of global environmental change. In this article, we analyse bibliographical data to trace the key 20th century contributions towards the development of this concept in scientific literature. Using data from Web of Science, we identify five historical citation peaks and show that their associated key publications stem both from natural and social sciences, clearly highlighting the multidisciplinary nature of Anthropocene science. With the ongoing debate for a formal definition of the Anthropocene epoch, we argue that a geological definition aligned with the interdisciplinary development of the concept may be the best way to ensure that it remains relevant to the wider scientific community.

Keywords: Bibliometrics, citations, multidisciplinary science, reference publication year spectroscopy, scientometrics.

HUMAN actions have deeply transformed the Earth's surface[1–5] and pushed the crucial Earth System processes beyond their safe operating space[6,7]. The realization that human actions have produced a fundamental shift in our relationship with the environment has led to the origin of a new concept: the Anthropocene.

First proposed by Paul Crutzen and Eugene Stoermer in a publication aptly entitled 'The Anthropocene'[8], the concept gained rapid acceptance by the scientific community[2,9]. Not only the number of scientific articles using the term 'Anthropocene' has exponentially increased since it was first proposed[10,11], several newly established academic journals have also been dedicated to its study. Examples include *Anthropocene*[12], *Earth's Future*[13], *Elementa*[14] and *The Anthropocene Review*[15]. These facts suggest that the Anthropocene is quickly becoming a key concept of 21st century science.

Ricardo A. Correia, Ana C. M. Malhado and Richard J. Ladle are in the Institute of Biological and Health Sciences, Federal University of Alagoas, Praça Afrânio Jorge, s/n, Prado, Maceió, AL, Brazil; Ricardo A. Correia and Richard J. Ladle are also in the School of Geography and the Environment, University of Oxford, Oxford OX1 3QY, United Kingdom; Zeynep C. H. Correia is in the Department of Urban and Environmental Sciences, Ankara University, Cemal Gürsel Cad., Cebeci, Ankara, Turkey and Department of Political Science and Public Administration, Kırıkkale University, Yenişehir Mh. 71450, Kırıkkale, Turkey.
*For correspondence. (e-mail: rahc85@gmail.com)

Despite its recent popularity, many studies suggest that Anthropocene has several 'precursors' and deep roots in 19th and 20th century science[2,16,17]. Others, however, question this interpretation and argue that the present concept emerges from the more recent interdisciplinary understanding of the Earth System[18]. This discussion about the origin and meanings of the concept may be particularly relevant at a time when the debate for a formal geological definition of the Anthropocene epoch is ongoing[19,20].

In this paper, we aim to add to this debate by exploring 20th century publications that contributed to the development of the Anthropocene concept in scientific literature using reference publication year spectroscopy (RPYS). This quantitative method can be used to identify seminal contributions towards the development of research topics[21], and has already provided some fascinating insights on the emergence of specific concepts in scientific literature[22–25]. By analysing the temporal frequency distribution of references cited by a set of publications, RPYS allows the identification of years where particularly important studies were published.

Methods

We carried out a search on Thomson Reuters' Web of Science (WoS) to obtain a representative sample of scientific publications addressing the 'Anthropocene'. A topic

search of Web of Science's core collection was carried out on 14 February 2017 using the term 'Anthropocene' as search string. Results were filtered to include only research articles (i.e. excluding reviews, conference proceedings, etc.) published until December 2016. The complete record of identified references, including references cited by each publication, was extracted and used for analysis.

Data were analysed using RPYS method introduced by Marx *et al.*[21]. This method is based on the temporal frequency analysis of references cited in a set of publications and can be used to explore the historical roots of a research field and identify seminal contributions that shaped its development[23–25].

The purpose of this analysis was to identify original studies that contributed to the development of the field, which only recently gained widespread visibility, so we restricted our analysis to publications from the 20th century (1901–2000). The software used to extract cited references is described by Bornmann *et al.*[22] and freely available at http://www.leydesdorff.net/software/rpys/. After extraction, we plotted the distribution of cited references between 1901 and 2000, and selected relevant peaks in cited reference years by identifying the top 5% (95% quantile) most cited years. All figures and numerical analyses were carried out using R software[26].

Results

We identified a total of 867 scientific publications indexed by WoS using the term 'Anthropocene'. The first indexed publication matching these criteria dates back to 2002 and, since then, there has been an exponential increase in the number of publications using the term (Figure 1). Analysis of cited references yielded over 10,000 unique citations published between 1901 and 2000, and there were five distinct peaks corresponding to the years 1973, 1983, 1987, 1995 and 2000 (Figure 2).

We recorded a total of 126 citations to manuscripts published in 1973. Of these, 19 citations referred to a single article by Crawford S. Holling, a Canadian ecologist and Emeritus Eminent Scholar and Professor in Ecological Sciences at the University of Florida. The article in question, entitled 'Resilience and stability of ecological systems', was published in the journal *Annual Review of Ecology and Systematic*. This paper discusses the differences between resilience and stability focused viewpoints of ecological systems and argues that a management approach of ecosystems based on resilience can better accommodate the uncertain nature of ecological systems[27].

Publications from 1983 received 224 citations and, interestingly, no single publication stood out in terms of citations. The remarkably homogenous distribution of citations among publications suggests that this year's citation peak does not stem from a single publication, but rather a larger set of potentially relevant ones. Still, it is worth highlighting that the most cited publication from 1983, with eight citations, is the book *Anti-Oedipus: Capitalism and Schizophrenia* by Gilles Deleuze, a philosopher and Felix Guattari, a psychoanalyst[28]. This is a complex text, where the authors critically address modern micropolitics of desire through the lenses of human psychology, economics, society and history[29]. An interesting fact is that all citations to the book in our database refer to the English language translation, published in 1983 by the University of Minnesota Press, and not the original French version published in 1972.

The next peak was in 1987, with a total of 350 citations. The key publication this year was a report by the United Nations World Commission on Environment and Development entitled 'Our Common Future'[30]. Also known as the Brundtland Report, this publication was cited 31 times. The report aimed to stimulate an integrated discussion of environmental and development issues, focusing on multilateralism and the interdependence of nations in search of a sustainable development path. It is credited with, and often remembered for, introducing the most commonly used definition of 'sustainable development'[31].

A total of 784 citations were registered for manuscripts published in 1995. Much like the second peak in 1983, the number of citations per publication is remarkably even, which suggests it might arise from a higher than average number of potentially relevant references. The largest share of this year's citations, 18 in total, referred to the book by William Cronon entitled *Uncommon Ground: Toward Reinventing Nature*. The author is an environmental historian at the University of Wisconsin–Madison. In this text, Cronon traces the concept of wilderness throughout American history, claims that the notion of an untouched, pristine wilderness is unreal and

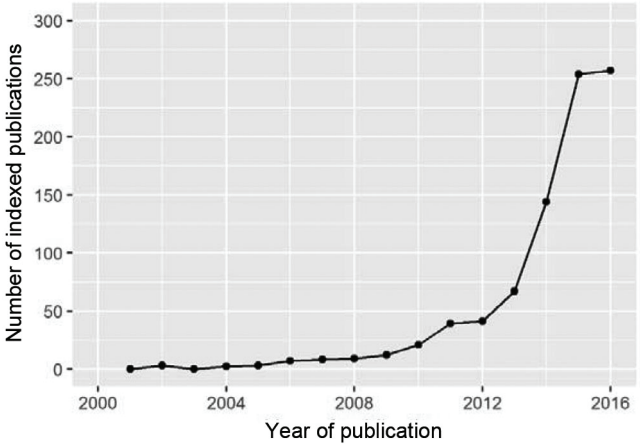

Figure 1. Temporal distribution of the number of scientific articles returned by Web of Science core collection based on the search term 'Anthropocene'.

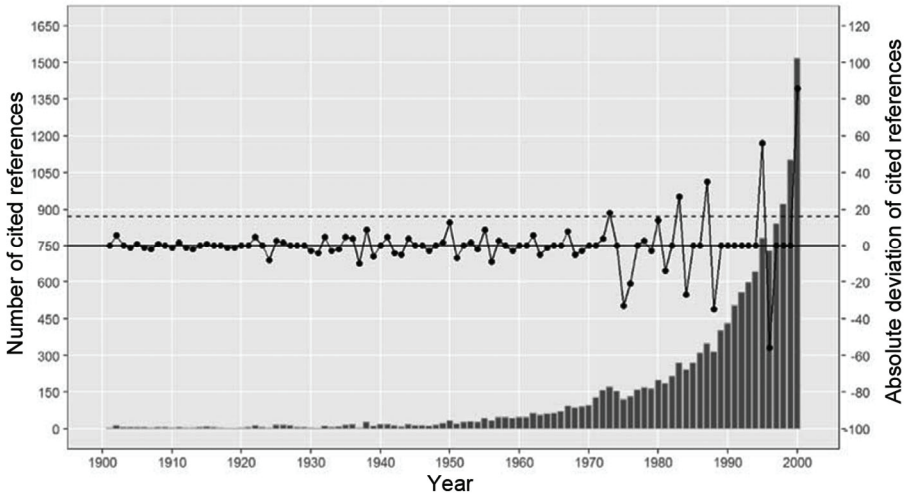

Figure 2. Distribution of cited references between 1901 and 2000 is shown in dark gray columns. The black dotted-line shows the absolute deviation of cited references for a given year from the 5-year median. The dashed line delimits the top 5% most cited years accentuating years with a higher than expected number of citations.

argues that humans should strive for a more critical self-conscious use of nature[32].

The final peak was observed in 2000, with a total of 1077 citations, making it the highest number of citations observed in a single year. Inevitably, this peak was driven by a single publication receiving 179 citations and entitled 'The Anthropocene'[8]. Co-authored by Paul Crutzen, a Nobel prize winner for his work in atmospheric chemistry, and Eugene Stoermer, leading biologist at the University of Michigan, this publication is often credited with introducing and popularizing the term 'Anthropocene'[2,15]. Our results reinforce this idea: this publication has been cited more than four times the number of the second most cited reference (Table 1) and might become a 'champion work'[33–35] in due time.

Finally, it is interesting to note that apart from Deleuze and Guatarri's book, the remaining key publications are among the 10 most cited references in our database (Table 1), which includes over 10,000 individually referenced publications. Other highly cited publications include Latour's[36] book *We Have Never Been Modern*, *Human Domination of Earth's Ecosystems* by Vitousek *et al.*[37], a second book by Deleuze and Guattari[38] entitled *A Thousand Plateaus*, *The Limits to Growth* by Meadows *et al.*[39], *Simians, Cyborgs, and Women: The Reinvention of Nature* by Haraway[40] and a Hooke's[41] article 'On the history of humans as geomorphic agents'.

Discussion

The present analysis provides a clear picture of the multidisciplinary nature of Anthropocene study. Our sample of scientific literature certainly does not cover every single publication addressing the Anthropocene. However, we believe it provides a robust sample of the existing literature and highlights how the concept has been adopted by – and draws inspiration from – both natural and social sciences[10,11].

Identified key publications stem from a wide range of scientific disciplines such as geology, ecology, philosophy, history of sociology, sustainability and environmental science. Furthermore, important contributions from anthropology, economy, psychology and gender studies can also be found among the top cited references (Table 1). These findings support the idea that the representation of the Anthropocene in current scientific literature has been shaped by an increasingly interdisciplinary understanding of Earth Systems[10,18]. Inter- and multidisciplinary efforts are a hallmark of 21st century science[42] and the recent establishment of the Anthropocene concept in the scientific literature also bears this mark.

Why is this important? Going forward, any future representation of the concept within the scientific literature will inevitably be tied to its formal definition as a geological epoch[43], if such a decision is reached. As shown here, the role of social sciences in the evolution of the Anthropocene concept and study is indisputable[9,44,45], but ongoing discussions to conceptualize the geological description of the Anthropocene epoch have been aptly criticized for not including social scientists[19].

Reification of the Anthropocene will have enormous symbolic significance, with the potential of providing a convenient and powerful concept that will endure and unite diverse fields interested in the study of environmental and planetary change[46]. Any formal definition of the Anthropocene epoch must fall under the scope of geological sciences and their authorities[47], but failing to align it

Table 1. Summary table of 10 most cited references in Anthropocene literature

Authors	Year	Title	Citations
P. Crutzen and E. Stoermer	2000	The Anthropocene	179
B. Latour	1993	We have never been modern	42
P. M. Vitousek *et al.*	1997	Human domination of Earth's ecosystems	32
World Commission on Environment and Development	1987	Our common future	31
G. Deleuze and F. Guattari	1987	A thousand plateaus	25
D. Meadows *et al.*	1972	The limits to growth	25
D. Haraway	1991	Simians, cyborgs and women: the reinvention of nature	21
R. L. Hooke	2000	On the history of humans as geomorphic agents	20
C. S. Holling	1973	Resilience and stability of ecological systems	19
W. Cronon	1995	Uncommon ground: toward reinventing nature	18

to the broader meaning of the concept can limit some of its potential rhetorical and symbolic power, and even result in a division of the concept into multiple 'Anthropocenes'[20].

Hence, we concur that a future definition of the Anthropocene should consider criteria that encompass (as best as possible) the multiple dimensions of the concept as it came to be shaped and perceived by the wider scientific community[48]. Ongoing discussions represent a unique opportunity to re-conceptualize the Anthropocene[11] in a manner that can ensure, and even reinforce, its status as a multidisciplinary concept that is relevant for a large number of natural and social sciences dedicated to the study of global environmental change. Perhaps more importantly, it will guarantee the significance of Anthropocene message in the wider societal debate about the interaction between humans and the environment[49,50].

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