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Dating the Anthropocene: Towards an empirical global history of human transformation of the terrestrial biosphere

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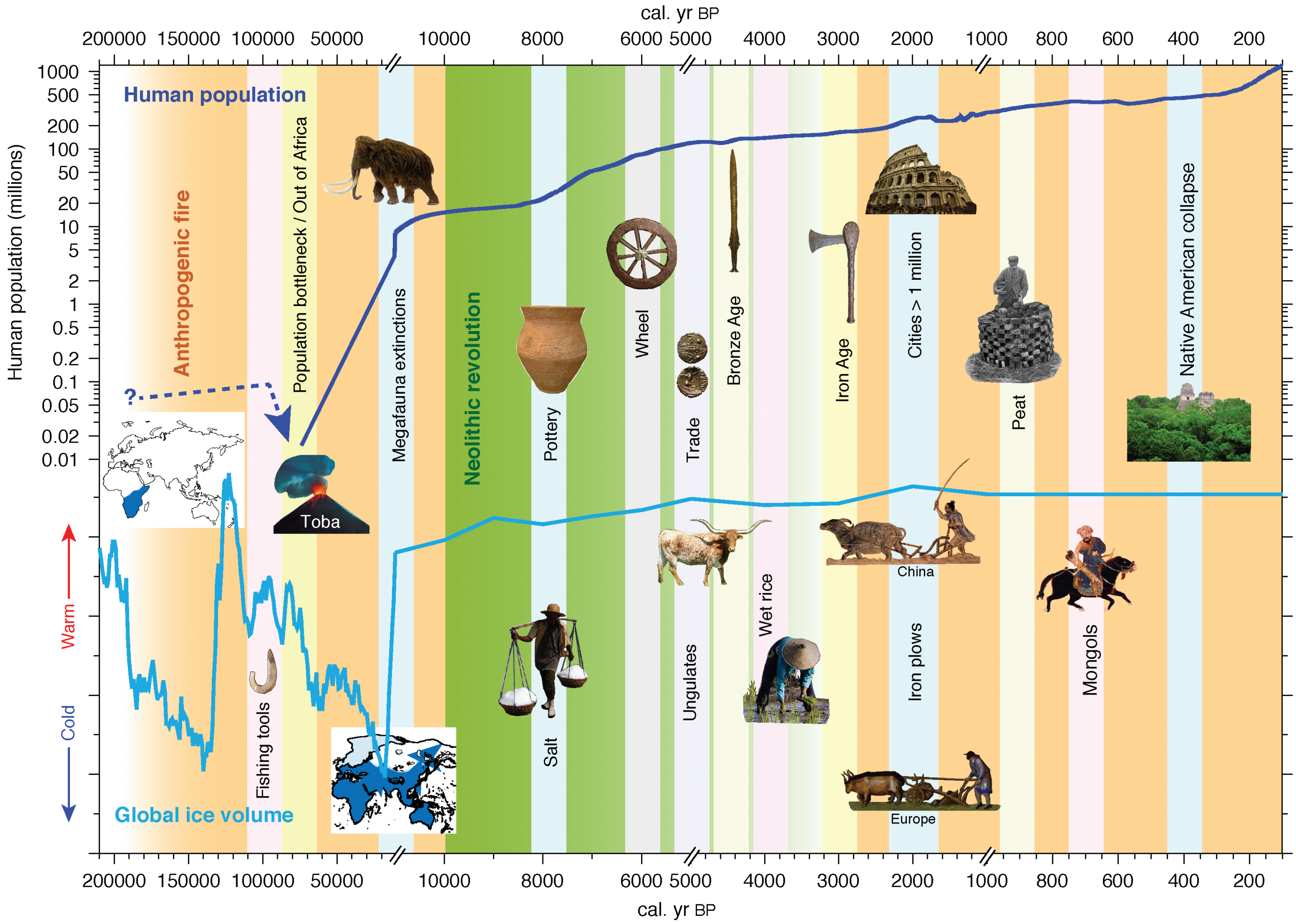
Abstract

Human use of land is a major cause of the global environmental changes that define the Anthropocene. Archaeological and paleoecological evidence confirm that human populations and their use of land transformed ecosystems at sites around the world by the late Pleistocene and historical models indicate this transformation may have reached globally significant levels more than 3000 years ago. Yet these data in themselves remain insufficient to conclusively date the emergence of land use as a global force transforming the biosphere, with plausible dates ranging from the late Pleistocene to AD 1800. Conclusive empirical dating of human transformation of the terrestrial biosphere will require unprecedented levels of investment in sustained interdisciplinary collaboration and the development of a geospatial cyberinfrastructure to collate and integrate the field observations of archaeologists, paleoecologists, paleoenvironmental scientists, environmental historians, geoscientists, geographers and other human and environmental scientists globally from the Pleistocene to the present. Existing field observations may yet prove insufficient in terms of their spatial and temporal coverage, but by assessing these observations within a spatially explicit statistically robust global framework, major observational gaps can be identified, stimulating data gathering in underrepresented regions and time periods. Like the Anthropocene itself, building scientific understanding of the human role in shaping the biosphere requires both sustained effort and leveraging the most powerful social systems and technologies ever developed on this planet.

Introduction

Human populations and their use of land are leading causes of global changes in biodiversity (Braje and Erlandson, 2013), biogeochemistry (Foley et al., 2005), geomorphic processes (Syvitski and Kettner, 2011) and climate (IPCC, 2013; Ruddiman, 2013). These global changes form the core evidence that supports formal recognition of the Anthropocene (Crutzen, 2002; Steffen et al., 2007; Zalasiewicz et al., 2011; Ellis, 2011; Ruddiman, 2013; Smith and Zeder, 2013). Yet efforts to date the emergence of human use of land as a globally significant force transforming the Earth system remain incomplete and controversial (Seddon et al., accepted). Dates for the beginning of the Anthropocene range from the Pleistocene/Holocene boundary (Smith and Zeder, 2013), to the mid-Holocene rise of agriculture, approximately 7000 years BP (Ruddiman, 2013), to the industrial revolution, circa AD 1800 (Steffen et al., 2011) to the Atomic Age (Zalasiewicz et al., 2011).

Resolving this major question on Anthropocene origins will require rigorous empirical assessment of the global extent and degree of direct human transformation of the terrestrial biosphere from Pleistocene to present (Figure 1). Such study must be based on the field observations of archaeologists, paleoecologists, paleoenvironmental scientists, environmental historians and other scientists concerned with long-term investigation of human-environmental interactions.



Observations from the field

Archaeological and paleoecological evidence already confirm that humans have a long history of altering ecosystems at sites around the world beginning in the late Pleistocene (Smith and Zeder, 2013; Braje and Erlandson, 2013; Ellis et al., 2013). Site data are also being used to reconstruct population and land use histories at increasingly larger scales and levels of detail (Fuller et al., 2011; Johnson and Brook, 2011; Gaillard et al., 2010; Dincauze, 2000; Shennan et al., 2013). Nevertheless, it is clear that land-use histories and impacts of regional environments varied greatly across contemporaneous regions, which calls for more detailed local and regional studies and methods of integrating them across global scales.

Natural vegetation, largely omitting anthropogenic influences, has been reconstructed over two time slices across the continents using standardized paleoecological archives as part of the BIOME6000 project (http://www.bridge.bris.ac.uk/resources/Databases/BIOMES_data; Prentice and Webb III, 1998), though data quality and temporal and spatial coverage is highly variable and very limited in some regions. Interdisciplinary collaborations among paleoecologists, archaeologists, and paleoclimatologists are developing regional histories of human populations, land use, climate and ecosystem change using similar approaches (PAGES project http://www.pages.unibe.ch; IHOPE http://ihopenet.org). Cyberinfrastructure projects by archaeologists (e.g. http://archaeologydataservice.ac.uk/) and paleoecologists (e.g. http://www.neotomadb.org) are enhancing efforts to share field data towards larger scales of synthesis. Yet all of these efforts combined will not be sufficient to date human transformation of the terrestrial biosphere from Pleistocene to present. The vast majority of archaeological and paleoecological data that are collected are still rarely shared online, are rarely described or standardized for broader use, must be scaled appropriately to serve as local components of global change studies, and must be integrated within a global statistical framework.

Figure 1

Global timeline of human transformation of the terrestrial biosphere.

The timeline illustrates a variety of major events and changes in human populations, climate and human-environment relationships from late Pleistocene to present, beginning with anatomically modern humans in Africa ca. 200 ka (map, left). Genetic evidence indicates population dip at 70 ka (Toba eruption), followed by rapid growth and expansion out of Africa and across Eastern Hemisphere by the Last Glacial Maximum (map bottom). Rapid climate change, widespread extinction of megafauna and human colonization of the Western Hemisphere follow.

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Spatially explicit global historical reconstructions

Great progress has been made recently in reconstructing spatially explicit long-term global histories of human populations, land use and ecosystem transformation using model-based approaches (Boyle et al., 2011;

Kaplan et al., 2011; Klein Goldewijk et al., 2010; Klein Goldewijk et al., 2011; Ellis et al., 2013). These efforts combine global patterns of terrain, hydrology, soils and climate with very limited data on regional and global human populations and demographic models of land use to "backcast" historical patterns of human populations and their use of land from the present day to the beginning of the Holocene. Although these model-based reconstructions indicate that human transformation of the terrestrial biosphere was likely globally significant more than 3000 years BP, generally agreeing with existing archaeological evidence, their results have yet to be empirically evaluated with site-based observations (Ellis et al., 2013). Moreover, as these modeling efforts become progressively more sophisticated and detailed, they will increasingly require globally and temporally representative sets of site-based observations for model calibration and evaluation across regions and time periods.

Challenges in dating human transformation of the terrestrial biosphere from Pleistocene to present

Major long-term investments in remote sensing and climate modeling have enabled fundamental advances in scientific understanding of the contemporary dynamics of the biosphere and climate. However, there has been no similar level of sustained investment in collaborative scientific infrastructure capable of assessing the global state of human transformation of the terrestrial biosphere based on local observations either for today or in past time periods. Some progress has been made in supporting, standardizing and synthesizing regional ecological assessments (e.g. Long Term Ecological Research Networks; The US National Ecological Observatory Network). However, at global scale, this form of assessment remains a challenge even for contemporary time periods (Vihervaara et al., 2013), with a variety of current efforts now attempting this using both experimental (Fraser et al., 2013) and observational approaches (Jetz et al., 2012; Ellis, 2012) based on collaborative online geodata cyberinfrastructure (Bernard et al., 2013; Tallis et al., 2012). As noted by those engaging in these efforts, the first and foremost challenge is in gaining and sustaining adequate long-term support, though funding agencies, including the Earth Cube program of the US National Science Foundation now appear to be moving in this direction (Bernard et al., 2013). However, true progress will require more than a patchwork of demonstration projects and *ad hoc* tool development, but rather a long-term international investment in developing a common vision and infrastructure.

Serious challenges remain even if adequate resources are made available to support collaborative efforts and infrastructure capable of assessing the global state of human transformation of the terrestrial biosphere based on local observations. One major issue is the need to develop a culture of reciprocity that encourages data sharing freely online, with archaeologists and paleoecologists especially known for hoarding data for long periods. Systems used to share and organize data require that these be standardized, harmonized, and well described by metadata — a massive challenge even within a discipline and almost overwhelming across disciplines. One useful observation is that simply making the effort to standardize, share, and compare data using online cyberinfrastructure tends to drive fundamental changes in scientific practice, expediting communication and improving data collection and management practices to match global frameworks and stimulating broader research questions and larger scales of research (Newman et al., 2012; Karasti et al., 2006; Ribes and Lee, 2010; Lutters and Winter, 2011).

Another major challenge is the tendency of researchers to select sites that are more accessible or otherwise thought to be more promising for discovery, leading to major geographic biases and global gaps in site selection and observations (Martin et al., 2012). These site selection practices have already been shown to bias the conclusions of archaeological research on human use of land in Amazonia (McMichael et al., 2012) and on the sites of early agricultural domestications (Fuller, 2011). As with the practice of data sharing, it is likely that simply by engaging in assessments of geographic bias in site selection, the utility of more robust and representative site selection practices may be encouraged. However, the ability to make such assessments of geographic and temporal biases at global scale from Pleistocene to present requires that global data representing the global environmental and anthropogenic patterns that would reveal such biases and the statistical tools to use them are available to scientists when selecting sites for field research- which is not the case at present.

Prospects for an Anthropocene collaborative geo-cyberinfrastructure

Recently, a collaborative geo-computation cyberinfrastructure has been developed to enable real-time quantitative global assessment of geographical biases in sets of local case studies. The online system (The GLOBE project: http://globe.umbc.edu; Ellis, 2012) uses spatially explicit global data of a wide range of global environmental and social variables including climates, soils, terrain, population and other key factors relevant to assessing the global representativeness of local land use observations. Enhancing this system with quantitative tools for temporally explicit global assessments would provide a statistically robust empirical framework for evaluating the global significance of human use of land at different time periods from sets of time sequence observations obtained at field sites. A conceptual illustration of such a system is presented in Figure 2. By design, this system would incentivize and facilitate sharing, georeferencing and harmonization of existing empirical data and expertise from archaeological and paleoecological sites around the world within a robust global statistical framework. Although the existing corpus of site-based observations by archaeologists, paleoecologists, and other paleoenvironmental scientists likely incorporates major gaps in observation across world regions and time periods, the act of assessing these globally would likely stimulate further data gathering in underrepresented regions and time periods.

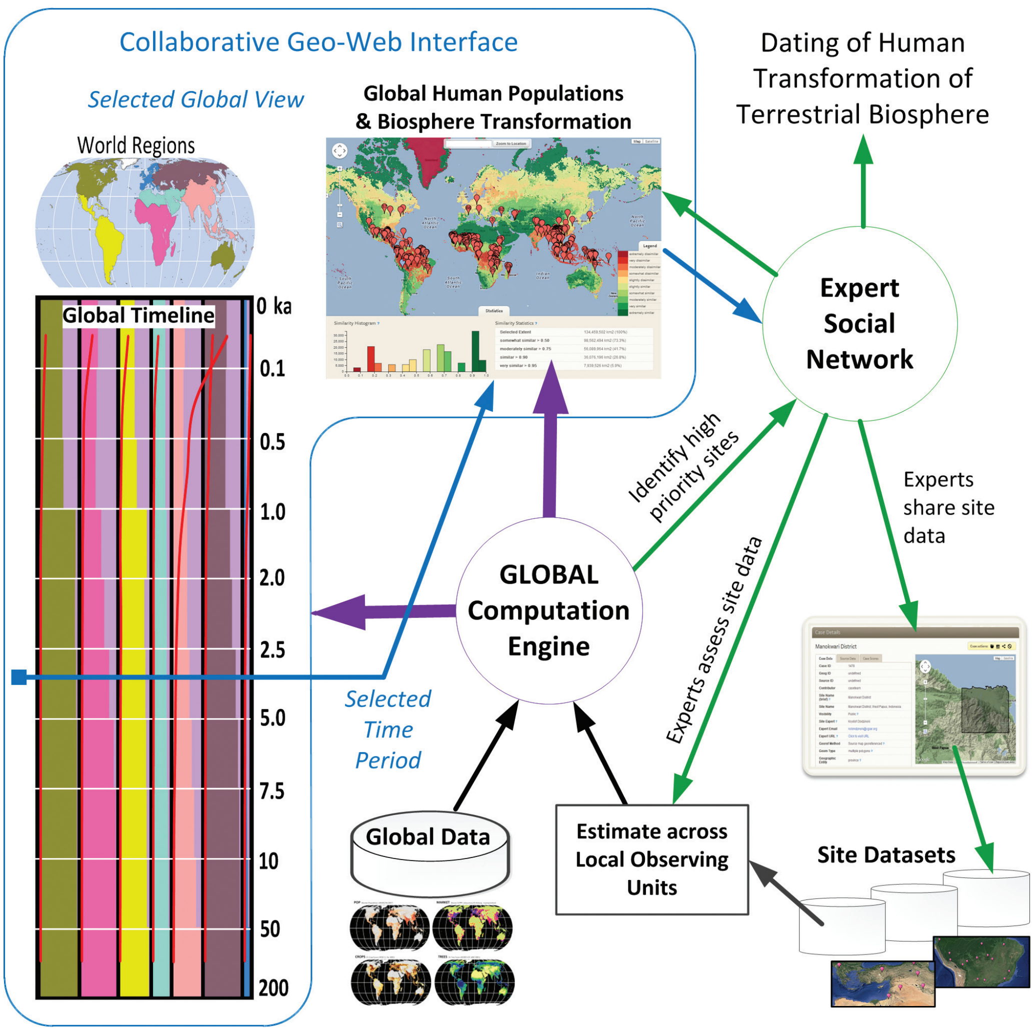

Figure 2

Conceptual design of online Anthropocene collaborative geo-cyberinfrastructure for dating human transformation of the terrestrial biosphere.

Site data are utilized to estimate human populations and ecosystem transformation across local observing units (eg. hexagonal global map tiles) and these are integrated globally to assess human transformation of the terrestrial biosphere using a global geo-temporal computation engine facilitating collaborations across social networks of experts.

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Conclusions

Both Anthropocene science and Earth stewardship will benefit profoundly from a more robust, detailed and quantitative understanding of the long-term trajectory and significance of human transformation of the biosphere. For example, human transformation of the biosphere is often portrayed as the recent disturbance of a pristine nature by industrial society, with many significant contemporary implications for Earth stewardship, including effective strategies for biodiversity conservation (Jackson and Hobbs, 2009) and the geopolitics of carbon sequestration (Pongratz et al., 2011). The general availability of spatially explicit quantitative global data on the dynamics of human populations and their use of land over the long-term would dramatically enhance efforts to manage and mitigate global climate change, global processes of species extinction and invasion, fire regimes, sedimentary processes and other long-term environmental changes of the Anthropocene. The time is ripe and the prospects are good for a major new transdisciplinary Anthropocene community to come together and make unprecedented progress in understanding the human role in shaping and sustaining the terrestrial biosphere over the long term.

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Contributions

All authors contributed to writing this paper.

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Competing interests

The authors declare no competing interests.