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Re-conceptualizing the Anthropocene: A call for collaboration

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ABSTRACT

Since it was first proposed in 2000, the concept of the Anthropocene has evolved in breadth and diversely. The concept encapsulates the new and unprecedented planetary-scale changes resulting from societal transformations and has brought to the fore the social drivers of global change. The concept has revealed tensions between generalized interpretations of humanity's contribution to global change, and interpretations that are historically, politically and culturally situated. It motivates deep ethical questions about the politics and economics of global change, including diverse interpretations of past causes and future possibilities. As such, more than other concepts, the Anthropocene concept has brought front-and-center epistemological divides between and within the natural and social sciences, and the humanities. It has also brought new opportunities for collaboration. Here we explore the potential and challenges of the concept to encourage integrative understandings of global change and sustainability. Based on bibliometric analysis and literature review, we discuss the now wide acceptance of the term, its interpretive flexibility, the emerging narratives as well as the debates the concept has inspired. We argue that without truly collaborative and integrative research, many of the critical exchanges around the concept are likely to perpetuate fragmented research agendas and to reinforce disciplinary boundaries. This means appreciating the strengths and limitations of different knowledge domains, approaches and perspectives, with the concept of the Anthropocene serving as a bridge, which we encourage researchers and others to cross. This calls for institutional arrangements that facilitate collaborative research, training, and action, yet also depends on more robust and sustained funding for such activities. To illustrate, we briefly discuss three overarching global change problems where novel types of collaborative research could make a difference: (1) Emergent properties of socioecological systems; (2) Urbanization and resource nexus; and (3) Systemic risks and tipping points. Creative tensions around the Anthropocene concept can help the research community to move toward new conceptual syntheses and integrative action-oriented approaches that are needed to producing useful knowledge commensurable with the challenges of global change and sustainability.

1. Introduction

The concept of the Anthropocene has evolved in breadth and diversely since it was first proposed in 2000 (Crutzen and Stoermer, 2000; Crutzen, 2002), now ranging from a proposed

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definition of a new geological epoch, a widely-used metaphor for global change, a novel analytical framework, a meme about the relationship of society to nature, and the framing for new and contested cultural narratives. At its core, the concept of the Anthropocene encapsulates the unprecedented planetary-scale changes resulting from societal transformations, at least since the European industrial revolution and particularly over the past 65 years of world development. We have now documented the linked and global scale impacts of these changes including past, present, and anticipated future changes in climate, biodiversity, ocean acidification, atmospheric composition, radioactive and artifacts deposits, soil and water quality and sediment flows (MA, 2005; UNEP, 2012; IPCC, 2014; Steffen et al., 2015a; Waters et al., 2016). It has brought to the fore the social drivers of global change, including changes in technology, resource consumption, population and settlement patterns, mobility, cultures and ideas, communication, and trade, as well as civil and military conflicts. Few global change science concepts have enjoyed such a broad and rapid uptake in technical and public discourses, despite a long history of scholarship exploring human interactions with the global environment.

Worster (1988:6) argued that ' . . . planetary history has been fundamentally environmental history' and that the writing of such history goes back at least to Georges-Louis Leclerc's *Des epochs de la nature* (1779). Since then, geographers, Earth scientists, environmental historians, philosophers, archaeologists and anthropologists have been concerned with how people and nature at the planetary scale have influenced each other (Turner et al., 1990; Bonneuil and Fressoz, 2013; Robin et al., 2013; Hamilton et al., 2015). Over the past 40 years, a rich array of concepts and narratives that encapsulate the imprint of human societies on the global environment have emerged, including the "anthroscene" (Revkin, 1992), "socioscene", "technoscene", "capitaloscene", "econoscene" (Malm and Hornborg, 2014), "anthroposphere" (Baccini and Brunner, 2012), among many others. However, apart from the Club of Rome's World3 model (Meadows et al., 1972) and the Gaia hypothesis (Lovelock, 1972), both foundational to Earth system science, all of these earlier and more recent understandings of human action on the planet differ significantly from the concept of the Anthropocene as it is understood today. As also noted by Hamilton and Grinevalt (2015), the Anthropocene, as proposed by Crutzen in 2000, is based on the concept of the *Earth system*, a single complex system at the planetary level with its own emergent properties, states and modes of functioning. The Anthropocene thus represents *a state change in the Earth system* (Waters et al., 2016), viewed of an interdependent social–ecological system. This differs from earlier ideas of human pressures, arising from a combination of population growth and economic and technical change, having an impact on natural systems, whether local or global.

The concept of the Anthropocene as a state-change of the Earth system has proven to be a powerful bridging concept in the natural sciences, as it requires the full range of relevant disciplines to understand how such a system functions and how it is changing. It has progressively gained importance in the social sciences and humanities, offering an interface for engagement in global change issues (Palsson et al., 2013; Castree et al., 2014). Furthermore, because the Earth system science approach seeks to embrace people and society as embedded in the Earth system, the Anthropocene concept offers the opportunity for bridging across disciplines and approaches in increasingly open systems of knowledge production (Gibbons, 1999). In other words, the Anthropocene concept requires the full inclusion of the analysis of the economic, demographic, ecological, political, symbolic, and cultural aspects of globally interconnected societies just as much as it needs to draw on oceanography, the atmospheric sciences, earth sciences, glaciology and the palaeo-environmental sciences.

And yet, the Anthropocene concept has also brought front and center tensions and epistemological divides between and within the natural and social sciences, and the humanities. The Anthropocene concept calls for a radical recasting of the dualistic ways that researchers, analysts, and commentators think about interactions between two historically distinct worlds: the world of social, economic and political systems and processes, and the biophysical systems of the planet (Chakrabarty, 2009). It motivates deep ethical questions about the politics and economics of global change, including diverse interpretations of past causes and future possibilities. Importantly, it reveals a tension between a generalized interpretation of humanity's contribution to global change, where "humans" are seen as the culprits as a unitary global force, and interpretations that are much more differentiated and more historically, politically and culturally situated (Biermann et al., 2016). If human agency is reduced to a single, undifferentiated force driving change at a global scale, thus downplaying historical, cultural, political, and economic differences within and across regions, the fundamental dynamics which social change brings to the Anthropocene could not be captured (Malm and Hornborg, 2014). This means that the Anthropocene inevitably invites different, in some cases perhaps incommensurable perspectives to examine past changes and future possibilities (Biermann et al., 2012; Bai et al., 2015). As such, the concept has motivated divergent visions for collaborations around research and action in global change and sustainability, with some calling for stronger integration of social sciences and humanities and Earth system science and others cautioning against it (Chakrabarty, 2009; Biermann et al., 2016; Palsson et al., 2013; Ogden et al., 2013; Berkhout, 2014; Malm and Hornborg, 2014; Dalby, 2015; Lövbrand et al., 2015). These divergences in such a conceptual debate are not surprising; however, as we argue in this article, it is now equally important to move forward to fully make use of the potential of an integrative understanding of the Anthropocene.

This article thus explores how the Anthropocene concept can encourage more inclusive understandings of global change and sustainability, as well as the predicaments faced by such understandings. Based on bibliometric analysis and literature review, among others, we discuss the broad acceptance of the term, its interpretive flexibility, the emerging narratives, and the debates it has inspired. While the research communities have made significant advances in integrating the social and environmental dimensions of global change, significant tensions remains, which stand in the way of advances in understandings and potential actions to address global change and sustainability. To get the most out of the Anthropocene concept, these tensions must be addressed in a collaborative manner. This will open-up new ways of resolving some of the conceptual and methodological challenges of studying complex, non-linear, accelerated social–environmental problems that are emblematic of the current new epoch in planetary history.

The analytical challenges revealed through the Anthropocene concept call for the research community to work together in novel ways on research approaches that embrace complexity and reflexivity. We argue that without truly collaborative and integrative research, many of the critical exchanges around the Anthropocene concept are likely to perpetuate fragmented research agendas and to reinforce disciplinary boundaries and stereotypes. At the very least, this means recognizing and appreciating the strengths and limitations of different knowledge domains, approaches and methodologies (Poteete et al., 2010). It also calls for breaking up some of the remaining barriers between knowledge systems (Tengö et al., 2014; Díaz et al., 2015), and across North-South divides,

for which the Anthropocene might serve as a useful bridging concept, framing new analytical problems and offering ways of addressing them. To illustrate, we discuss three overarching global change problems where novel types of collaborative research could make a difference: (1) emergent properties in social–ecological systems; (2) urbanization and resource nexus; and (3) systemic risks and tipping points. We conclude by reflecting on the opportunities created by the Anthropocene concept and its potential to bring together contributions from multiple knowledge branches, and also from wider stakeholder communities, around the complexities of global change and sustainability.

2. The Anthropocene as a bridging concept

2.1. The popularization of the concept across disciplines

A bibliometric survey of the term 'Anthropocene' using Thomson Reuters' *Web of Science* database was conducted for the 16 years (2000–2015 inclusively) since the concept was first introduced by Crutzen and Stoermer in IGBP's Global Change Newsletter (2000). The results (Fig. 1) indicate 1066 publications employing the term in the title, abstract, or text body, which have been cited some 8451 times. Both the number of published items and their citation rates have inflected sharply upward since 2010. For example, the number of items published roughly doubled twice

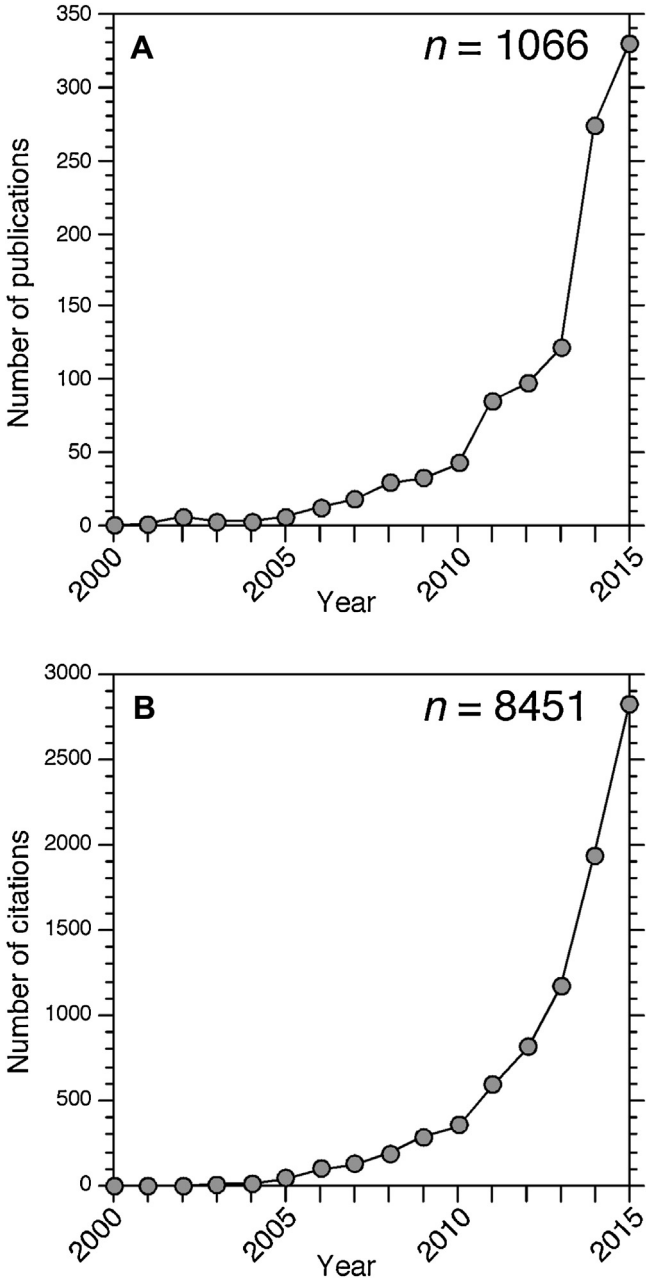

Fig. 1. Bibliometric analysis of the term Anthropocene between 2000 and 2015 inclusively. (A) number of published items with Anthropocene in the title, abstract, or text body; and (B) citation trends for these works collectively.

between successive years, once in 2010–2011 (42–86 items respectively), and again in 2013–2014 (122–274). The average citation rate currently stands at 7.9 citations per item, producing an *h*-index (where *h* equals the number of papers with $\geq h$ citations) of 40. While disciplines grouped under the "earth and environmental sciences" contributed by far the most published items (64%), those under "humanities and social sciences" make up 24% of the contributions. A similar pattern is observed in the Scopus database.

What can be learned from this analysis? First, the term Anthropocene has clearly attracted a great deal of attention and debate. It is clear from the analysis that the concept originated in Earth system science. Yet in recent years, a number of interdisciplinary and dedicated peer-reviewed journals have been established, including *Anthropocene*,*The Anthropocene Review*, *Elementa*: *Science of the Anthropocene*, and *Earth's Future*, all joining an existing array of dedicated scholarly arenas.

Secondly, as a topic of inquiry the Anthropocene is maturing rapidly as evidenced by the h-index and citation rates. In fields such as ecology and conservation science, it is an accepted term, no longer queried by editors and reviewers. Despite claims from some in the geology community that this merely reflects "pop culture" (Autin and Holbrook, 2012), the emerging consensus is that the adoption of a term which emerged in the Earth sciences (Crutzen, 2002) has been adopted by other scientific communities. Notably, as the above data illustrates, the humanities and social sciences are making growing use of the concept, comprising a quarter of the published work, including literature that is critical the concept's use and utility.

Finally, the term Anthropocene has taken on multiple meanings and uses in different scholarly communities. We suggest that the term has become a 'boundary object' (Star and Griesemer, 1989), enabling communication between scholars spanning different branches of the physical, life, social sciences, and humanities, as well as the arts and designing. An inclusive notion of the Anthropocene may be beneficial, not least because it encourages exploration from a wide range of perspectives, including the more subtle and political dimensions of global change. By offering an open and flexible conceptual frame, the Anthropocene serves as a bridging concept.

2.2. Anthropocene narratives in creative tensions?

Along with the broad scope of its interdisciplinary diffusion, the Anthropocene has engendered multiple narratives of global change and futures (Bai et al., 2015). At least in part, the attention to human agency has shifted from the often catastrophist narratives of global environmental change to novel narratives of empowerment and action, through the realization that societies are now globally interdependent in having become a major influence on the Earth system. The notion of the Anthropocene clearly signals that both individuals and societies have become increasingly connected in various ways, even though with highly unequal contributions to and benefits from the transformations of the Earth system. This understanding of the Anthropocene, however, raises important normative questions about how the future should be, inherent and inescapable in both scientific research and political practice (Purdy, 2015; Dalby, 2015; Biermann, 2014; Bai et al., 2016). It also stimulates diverse narratives about the intentionality of changes in social–ecological systems, cultural attitudes and tolerance to such changes, as well as the thorny problem of the prioritization of and the responsibility for such changes among individuals and collectives (Dellink et al., 2009).

Recent publications have proposed a variety of typologies of narratives to represent, and in some cases standardize, the diversity of approaches and voices around the Anthropocene concept as discussed above. Lövbrand et al. (2015), for example, defined three categories of approaches based on the ways they perceive claims arising from the rather diverse international global environmental change research communities and related fields: a post-natural ontology, a post-social ontology, and a post-political ontology.

Similarly, Bonneuil (2015) proposes a typology of four grand narratives that are associated with the mobilization of the term, setting out a more diverse set of perspectives:

1) A *naturalist* narrative that emphasizes the what, how, and when the humans have altered the Earth system with particular attention to the potential of interdisciplinary integration to provide scientific and technological knowledge to society and policy makers regarding adaptation to and mitigation of the impacts of global change;
2) A *post-nature* narrative that deploys the term Anthropocene as a symbol of post-modernity, where the dichotomy between culture and nature is dissolved (Descola, 2013), and where the Anthropocene concept is seen as a useful alternative, even if it conveys multiple and at times unclear meanings to move beyond the disorders of modernity (*e.g.*, Latour, 2015);
3) An *eco-catastrophist* narrative that tends to focus on vulnerabilities of society and the dangers of unknown social and environmental tipping-points, highlighting the historical studies of civilizational collapses (*e.g.*, Diamond, 2005; Tainter, 2006; see also discussion on narratives and interpretations of crisis in Danowski and Viveiros de Castro (2014)); on Limits to Growth (Meadows et al., 1972), and the over-population debate (Erlich and Erlich, 2013);
4) An *eco-Marxist* narrative that focuses on the contradictions of capitalism in promoting growth and inequality and technological advances, while at the same time causing environmental disasters. Not unlike political ecological frameworks, the emphasis is on the role of the history of capital circulation and appropriation within unequal global social relations (*e.g.*, Hornborg et al., 2007).

These narratives contain multiple interpretations of what the Anthropocene represents for society, including its origins, causes and the range of ethical and effective responses (*e.g.*, Shellenberger and Nordhaus, 2011) as well as the possibility of better governance systems to "navigate the Anthropocene" (Biermann et al., 2012; Biermann, 2014; Purdy, 2015), and of charting plausible and desirable futures in the Anthropocene (Bai et al., 2016).

Fundamental historical differences, implicit or explicit in these (and interpretations of) narratives, in concepts and approaches remain a significant challenge for the understanding of global changes and societal issues more broadly (Wallerstein, 2010). The terminologies, typologies, types of questions, levels or scales of analyses, and persistence of dualisms employed in the diverse disciplinary traditions, particularly about theories of social change and human-environment interactions, often imply contrasting ways of interpreting and explaining change. The legacy of analytical dualisms, including strict separations between and within the natural and social sciences, has contributed to reinforcing differences rather than advancing understanding of inter-dependencies of human–environment interactions (Brondizio and Moran, 2011; Tallis et al., 2014). Culture–nature, structure–agency, universal–particular, rational–moral, mind–body, materialist–idealist, positivist–interpretivist, critical–uncritical, quantitative–qualitative, and global-local represent some of the most prominent constructs that also influence the reception, use, critiques, and interpretations of use of the Anthropocene concept.

The epistemologies at play range from positivist and materialist understandings of reality that aim to encompass social processes and cultural phenomena, to more interpretivist, constructivist and

post-structuralist approaches emphasizing meaning, perceptions, and intentionality influencing individual action. Furthermore, more individualistic approaches tend to reduce social structures to the properties and interactions of individual agents (whether emphasizing rationality and maximization choices or subjectivity and consciousness), whereas structural approaches (whether emphasizing political economic or cultural determinants) view individuals as relatively powerless. These extremes generally reinforce dualities for their own sake (implicitly or explicitly demarcating disciplinary, ideological, and political stances), not only as analytical devices (Ellen, 1996). At least implicitly, those holding a more positivist and materialist orientation tend to downplay epistemological differences between the traditional natural and social sciences, while those holding a more constructivist or critical-studies orientation tend to highlight ontological and epistemological differences (Lövbrand et al., 2015). Both "sides" hold quite different views about the potential for integration of approaches. Positivist approaches may aim toward a 'total systems' view of science, while post-structuralist and constructivist approaches tend to argue for a position of pluralism. We want to argue for a 'middle ground' under which complementary approaches can be bridged (see also Turnheim et al., 2015).

The concept of the Anthropocene is as much a materialistic claim about the organization and consequences of global change, as it is an idealistic claim about sense-making and the motivations to act for a sustainable and socially fair future. Arguably, there is a value in sustaining both of these positions, if they remain in 'creative tension' with each other and encourage new ways of thinking and addressing the inherent complexity of global problems. The challenge is not to default to either conflicting epistemological differences or to middle-range theories that may heighten differences between and within disciplines. Rather, as framed by Chakrabarty (2009: 213), the challenge is to " . . . bring together intellectual formations that are somewhat in tension with each other: the planetary and the global; deep and recorded histories; species thinking and critiques of capital." Or, as stated more broadly by Edgar Morin, the challenge is to engender "complex thinking", that is " . . . a thinking that is capable of unifying concepts which repel one another and are otherwise catalogued and isolated in separate compartments" (Morin, 2008: 81). Below we discuss the importance of recognizing and confronting epistemological tensions associated with the concept.

3. From human species to societies in a world system

Evidence behind the Anthropocene concept and the reasoning for recognizing a new geological epoch have brought to the fore attention to various turning points in human history that have contributed to shaping the functioning of the Earth system, from early to recent periods (*e.g.*, Waters et al., 2016; Steffen et al., 2011; Ruddiman, 2013; Ellis et al., 2013; Zalasiewicz et al., 2015). These include, for instance, the expansion of agriculture and fire use, the exploitation of fossil fuels, the onset of the industrial revolution, the advent and use of nuclear bombs, and the current post-1945 "great acceleration" of human activities, urbanization, and unprecedented appropriation of common pool resources.

This perspective has been instrumental in defining key features that warrant a reconceptualization of the Earth system and regional landscapes as shaped by the cumulative history of social transformations (Turner et al., 1990; Balée and Erikson, 2006). The Anthropocene's defining feature is the insight that human societies have and are more than ever contributing to regional and global environmental changes, and now have consciousness and agency to potentially reflect on and solve some of the problems that it creates.

Yet, while there is broad recognition that understanding these trends and their implication for society, and to other species, require collaborative frameworks built jointly by social and natural sciences and the humanities, significant difficulties remain. The research and intellectual trajectories on global change and globalization have evolved in parallel, and in spite of significant advances in bringing natural and social sciences to collaborate on global environmental change (Mooney et al., 2013), and new analytical frames to global studies (Kahn, 2014), they remain loosely related (Chakrabarty, 2009). Debates around the Anthropocene are contributing to advancing collaboration and understanding of global change, while conversely highlighting disciplinary limitations, epistemological tensions, language gaps, and political narratives preventing collaboration toward this goal.

Both political and practical views suggest that it is not very useful to frame the Anthropocene in a way that assumes a role of "humankind" as a global aggregate of the multiple societies, diverse societal sectors, and peoples. As such, the Anthropocene concept has been criticized for being a predominantly 'Northern' frame that overlooks global inequalities and historical disparities, social and cultural differences and perspectives (see Biermann et al., 2016). Criticisms of the Anthropocene concept (*e.g.*, Malm and Hornborg, 2014; Crist, 2013; Moore, 2015, among others) also express a concern about the preponderance of the natural sciences in crafting a narrative of the Anthropocene that overlooks inequalities as paramount to understanding the underlying causes and consequences of global change (Dalby, 2015). Malm and Hornborg (2014) argue that grounding the Anthropocene narrative on the rise of the fossil-driven industrial revolution extends the preponderance of a small European elite to the broader humanity caught within an unequal world system that still persists. The Anthropocene is thus not seen as a human condition, but rather the result of a particular history of global economic and political arrangements.

Criticism of the naturalistic narrative of the Anthropocene has been important in advancing discussions of the social dimensions of global change. It touches on issues at the core of climate change negotiations and the responsibility of different parties regarding mitigation responses (Parks and Roberts, 2010). In contrast, there have been limited advances in analytical frameworks that are able to deal with the complexity of interactions between historical and current political economies. The processes triggered by European colonial expansion and industrial revolutions have continuously transformed and shaped regions and populations around the world (Wolf, 1982). Capitalist expansion continues to shape national structural adjustments policies, to promote resource extraction schemes with unequal and disastrous consequences (Harvey, 2006), and to drive changes in consumption patterns around the world (Wilk, 2002; Schaffartzik et al., 2014). These processes have not been monolithic, but are patterned and specific to different contexts. Inequalities in power and political and resource control have become as significant within as they are across regions, and are connected across scales, from the local to the global. The question then becomes, how to conceptualize and analyze interactions between historically rooted inequalities (within and between societies) and contemporary globalized economic networks influencing regional and global environmental change?

Recent data shows significant changes in the regional distribution of the drivers and environmental impacts associated with global change. While OECD countries show stable or improving trends across many indicators of global change, larger emerging countries show the opposite (Steffen et al., 2015a; see also Steffen et al., 2004). This has been driven in part by economic growth and poverty reduction in these countries, and in part by the displacement of production and pollution through trade and a globalized division of labor. This scenario shows patterns of path

dependency and inertia of global and regional political economies driving global change, global inequalities and unsustainable rates of resource use. The contradictory improvement in environmental indicators in many regions in parallel with the serious deterioration of many global environmental conditions brings to fore questions of the effectiveness and fairness of ongoing international environmental negotiations and mitigation strategies (Parks and Roberts, 2010).

Understanding these trajectories into the future requires a better spatial and temporal differentiation, of how political economies linking local to transnational processes connect extractive systems, production, consumption, industrial transformations, and pollution affecting the biosphere (Biermann et al., 2016). This challenge also requires more sophisticated analytical and modeling approaches of system interactions (Liu et al., 2015; Verburg et al., 2015), and their relationships to regional landscapes (Crumley, 2013). Is it possible to approach the concept of the Anthropocene from the bottom up, beginning with diverse social–ecological realities and working up to a global scale analysis, rather than the other way around? What new conceptual frames could motivate collaborative research on the relationship between narratives, values, cognition, and behavior underlying these changes? In what ways can new conceptual frameworks help to advance models of coupled social–ecological systems that are able to account for intertwined drivers and path dependency, complex networks and emergent phenomena that are all occurring within multiple and increasingly connected biophysical constraints and risks?

The nature of these analytical problems suggests that greater knowledge integration is a necessity rather than a choice. In other words, to advance new ways of analyzing complexity in social–ecological systems we need to go beyond the recognition that actors, processes and structures are connected and systems are multi-scale, and to recognize that global change research frameworks and narratives involve diverse perceptions of, and assumptions about, human-environment relationships and social relationships. This invites a view of global change complexity as a feature of interdependent biophysical and social systems, including networks of various natures among individuals, groups, and entities with history, expectations, limitations, agency, reflexivity and innovations affecting interactions.

To illustrate our analysis, we elaborate on three overarching and interrelated global change problems that call for engaging new frontiers of collaborative research, emblematic of the Anthropocene.

4. Opportunities for collaborative global change research

There is a world of opportunities, and no shortage of societal problems, for collaborative research on global changes and sustainability challenges (see for instance examples in Bai et al., 2016; Biermann et al., 2016; Verburg et al. 2015). As illustrative examples, here we identify three global change phenomena that encapsulate the importance of bringing collaborative research beyond to new levels: (1) emergent properties in social–ecological systems; (2) urbanization and resource nexus; and (3) systemic risks and tipping points. Many advances have been made in understanding these issues in social–ecological systems analysis and sustainability science broadly speaking. In fact, they reflect novel combinations already underway of global change and sustainability research that brings together diverse segments of Earth system sciences, the social and ecological sciences, and the humanities (Weaver et al., 2014; Future Earth, 2013, 2014). These efforts are leading to new conceptual syntheses and forms of analytics that are pushing the boundaries of disciplinary and interdisciplinary training. These issues also require pushing the knowledge production enterprise beyond science to include both concerns with its usability by decision-makers and various sectors of society (Dilling and Lemos 2011), as well as synergies with other knowledge systems (*e.g.* indigenous, traditional, and local) (Kirchhoff et al., 2013; Tengö et al., 2014; Díaz et al., 2015). This calls for institutional arrangements that facilitate collaborative research, training, and knowledge sharing. Progress toward these goals, however, will depend on more robust and sustained funding for collaborative global change and sustainability research.

4.1. Emergent properties in social–ecological systems

The Anthropocene reflects the cumulative history of local and regional social changes operating in various and evolving forms of connections to global processes. These changes have been intertwined with evolving extractive commodity chains, resource use systems, urbanization and industrialization, infrastructure and flows of technological diffusion, all of which exhibit some level of path dependency as well as different types of emergent patterns manifested in regional land- and seascapes. At the same time, the simultaneity and/or synchronicity of an increasingly connected world ensue that new technologies, financial systems, and ideas have the potential to be adopted almost simultaneously around the globe (Homer-Dixon et al., 2015; Galaz et al., 2015). Such synchronicity and simultaneity means seemingly that small actions at local scale can add up to positive or negative impacts at a regional or global scale that affect distant areas in an increasingly rapid pace (Seitzinger et al., 2012; Biermann et al., 2016). In structural terms, new types of connectivity continue to emerge, while pre-existing connections and networks underlying changes continue to operate across regions and transforming landscapes (Lambin and Meyfroidt, 2011; Brondizio et al., 2009). Such structural changes are increasingly shaping the complexity of the Earth system and how we understand it both biophysically and in terms of earth system and regional governance (Young et al., 2008; Ostrom 2010; Folke et al., 2011).

These emergent social–ecological arrangements and their manifestations across landscapes can be observed from different perspectives. Some are concerned with mismatches between ecosystems, institutions, and expanding resource economies, and their implications for conflicting property rights and governance of common pool resources (Brondizio et al., 2009; Cole and Ostrom, 2012; Duraiappah et al., 2014). Others are concerned with how increasing mobility and communications interact with global economic and political processes, spurring increasingly larger networks operating across geopolitical boundaries and functioning in disaggregated ways (*e.g.*, Sassen, 2011; Ogden et al., 2013). Independently, accelerated and interconnected changes are creating new and emergent arrangements with varying implications and opportunities for different social groups and their ability to adapt to climate and other types of change, and to find innovative solutions (Westley et al., 2011). Within these complex landscapes and networks, for example, a significant portion of biodiversity-, water-, and carbon-rich areas considered key to climate change mitigation are managed by indigenous peoples and local communities. They are at the forefront of confronting accelerated social–ecological changes and increasing demands for resources (Pressey and Ferraro, 2015). Their voices, predicaments, and the lessons they have to offer on living with and managing our common pool resources are yet to be seriously considered by the global change and other research communities.

The unprecendent adoption of information and communication technology has intensified the circulation of information, ideas and narratives influencing changes to individual and organization behavior in ways that have meaningful, but non-linear aggregate

consequences. These interconnections are barely understood. In all cases, these dynamics contribute to changes in the structures and properties of systems, making assumptions about continuity or stability in system and social behavior, as well the units of analysis used to interpret them, in many assessments and models, invalid (Eitelberg et al., 2015). An important question emerges: when do local-level actions dampen out to have no appreciable effects at larger levels, and when do they amplify to drive significant impacts at larger levels, even the global? Integrating traditional theories and narratives of social organization with new approaches to network, spatial and multi-level analyses and analysis of landscape complexity offer exciting new opportunities for interdisciplinary collaboration. It also offers meaningful analysis to society, particularly to social groups directly affected and displaced by these changes.

4.2. Urbanization and resource nexus

Rapid urbanization is a key indicator of the accelerating human endeavor in the Anthropocene (Steffen et al., 2004; Grimm et al., 2008; Seto et al., 2010; Bai et al., 2014). The speed and scale of urbanization worldwide represent a multi-dimensional process of economic, land use, demographic, political-social, and behavioral change that are among the major drivers of global change (Bai et al., 2010). From dietary changes to energy use, urban areas are driving demands for expanding infrastructure, mining, resource extraction, land use, and water. Although these processes are accumulated effects of decisions by individuals and households in response to differing opportunities in rural and urban areas, the high and indeed causal correlation between urbanization and economic growth has resulted in the high-level policy interventions in countries to promote urbanization for economic growth (Bai et al., 2014; Bloom et al., 2008). The outcomes of these interactions in mobility, social re-organization, economic networks, and policy are yet to be fully understood, calling for holistic and integrated approaches to the analysis of regional landscapes.

The functional relationship between urban and rural has also shifted from the traditional consumer and producer model to a more complex picture (Friis et al., 2015). Such changes in human settlement not only mean increasing in the number of urban dwellers in fast growing and infrastructure poor urban centers, but also profound transformations into the rural areas, with the shift from unidirectional migration to bidirectional circulation (*e.g.*, Liang and Ma, 2004; Eloy et al., 2014). These evolving interactions and telecoupling across resource systems call for better understandings of connections between distant drivers affecting demand for agricultural land, terrestrial, mineral, marine, water, energy resources, and how their nexuses place burdens on different regions and sectors of society (Adger et al., 2009; Seto et al., 2012; Seitzinger et al., 2012; Fairhead, 2013; Liu et al., 2013).

These interactions imply that sectorial analysis is no longer sufficient to understanding the nexuses and trade-offs between socio-technical systems regarding food and energy production, water security and biodiversity resilience, their interdependencies and vulnerabilities (Liu et al., 2015; Cudennec et al., 2015). This implies the need for new ways of modeling the social and environmental trade-offs of policy choices, institutional arrangements, and economic incentives, and their local and distant outcomes; including novel approaches to data collection, integration, and dissemination (Poteete et al., 2010; Alessa et al., 2015; Verburg et al., 2015). This also implies attention to the role of different lifestyles and worldviews in decision-making models. A new generation of models may contribute to bring together current advances in modeling human behavior and agency and Earth System dynamics, as well as how visions and narratives of urban and rural sustainability consider trade-offs of various choices and their potentially contrasting outcomes.

4.3. Systemic risks and tipping points

In an increasingly networked world, as the complexity and strength of interactions grows, there is a growing risk that human-made systems become unstable and uncontrollable (Helbing, 2013). Not only is human action modifying natural cycles and systems, it is also adding completely new elements and increasingly extensive human-made systems and organisms (Waters et al., 2016). The wide and synchronous dissemination of new anthropogenic manufactured or used elements (including synthetic chemicals, radionuclides, and nanomaterials), artifacts (including plastic, metals), and organisms (diseases, invading species, new selected, adapted or created species), either through natural processes and vectors (meteorology or hydrology, atmospheric composition or ocean acidity) or new circulation patterns and processes (movement, migration, and exchanges) conspire to defy geopolitical boundaries. The emergent functioning and trajectory of the dynamic Earth system now opens to new progressive, chronicle and accidental dangers through new components, processes and connections, and new magnitude-intensity relationships (Rocha et al., 2015; Steffen et al., 2015b).

These changes have been conceptualized in terms of regional (Dearing et al., 2014), socioecological systems (Renaud et al., 2013), and planetary tipping points (Lenton et al., 2008; Rockström et al., 2009; Steffen et al., 2015b). While some of these conditions are real and defined by biophysical limits, many are subject to current knowledge and interpretation (Eitelberg et al., 2015). Some current conditions may in reality be tipping points of system change. The extent to which global changes are reaching or surpassing potential biophysical boundaries at regional and planetary scales remains a question, at least in terms of selecting the right indicators (Erb et al., 2012). What is relevant in this case is that the notion of the Anthropocene has extended the idea of such boundaries as being significant only to the extent that they are linked with social, economic or cultural processes (Cote and Nightingale, 2012; Scheffer et al., 2012). For instance, how might potential biophysical tipping points interact with fluctuations in the financial system and what are the potential cascading effects these interactions may create (including how they affect social resilience to chronic and extreme events)? What are possible alternatives to prevent and respond to the cascading effects of social–ecological regime shifts at different scales?

Developing prognostic models and early-warnings of such cascading risks and discontinuities for human systems is already a great analytical challenge that many groups are pursuing. The scale of these challenges, however, requires further stepping up in collaborative research. In fact, the explosion in the capacity to collect, manipulate and disseminate data has not been matched by conceptual and methodological advances in linking multiple forms of evidence, historically segmented by disciplinary specialties. The opportunities are significant across a wide array of questions (Butt, 2009; ICSU, 2014; Moran et al., 2014), including for collaborating on new analytics for integrating traditional forms of social science data with earth observation and 'Big Data'. New indicators of chronic and critical global change are needed, especially capturing linkages between systems and their implications to different sectors of society and ecosystems (Rocha et al., 2015). Early warning systems are needed to reduce impacts of crises, respectively before and after their occurrence (Galaz et al., 2014). These early warning systems should increasingly compensate for accelerated changes, from market shifts, to disease outbreaks, to climate events. This includes widening their detection range to capture connections, emergences and weak

signals, and their cascading consequences. Advancing collaborative and integrative research on these issues could make a difference to a significant portion of the population in many regions confronting environmental stresses and risks at unprecedented scales.

5. Concluding remarks

The global change research community, broadly defined, has made significant advancements in understanding different components of local, regional, and global environmental problems and possible solutions toward more sustainable and desirables futures. The last 40 years have seen the mainstreaming of interdisciplinary collaborations, the rise of sustainability science, coupled social–ecological systems frameworks, improved modeling of Earth system processes, and a broader engagement of the social sciences and humanities in global change research. It has also seen the immediate dissemination of increasingly voluminous data and information, and a better understanding of the social and economic drivers of greenhouse gas emissions, and of other grand cycles like nitrogen. As we move forward, however, these advances need to be matched by a deeper understanding of the complex functioning of the nexus between regional and global political economic processes that underlie global change and pathways of development within the Anthropocene.

The Anthropocene concept is not neutral about evidence of where the primary driver lies: the values, behaviors, and political economic structures that entangle people and societies operating within a world system. That is, we have an *a priori* view about the connections and interactions intrinsic to the social–ecological systems being described. Looking forward, the question arises about how different conceptualizations and analytical frames can create opportunities or barriers for change. Or, is it a feature of the Anthropocene that the dynamic of the complex system become independent of the reflection about it? How do new types of knowledge and images of global change affect societies' relationship with each other and with the rest of the nature, and thus influence how societies behave/operate as part of an interdependent system?

These questions call for new syntheses efforts and integrative approaches between the natural and social sciences and the humanities around complexity and co-evolution in the Anthropocene. Debates around the Anthropocene concept, as presented above, have brought forward both deep epistemological rifts between disciplines and an exciting collaborative research agenda for global change and sustainability. Arguably, in hindsight, the Anthropocene debate has served as a point of departure for potential ways of integrating the Earth system and the social sciences and the humanities, and the knowledge and needs of a wide variety of social groups. Since the 1980s, numerous efforts under the auspices of the international Global Environmental Change research programs, such as IGBP, IHDP, DIVERSITAS, and the WCRP, and other international research networks have contributed to advance initiatives grounded on complementarity in expertise and shared interest on common questions. These international collaborative networks have given rise to how we understand and predict global change in general and climate change in particular (*e.g.*, MA, 2005; IPCC, 2014). They have contributed to our understanding of paleo and historical environmental changes, the great global acceleration, and the human dimensions of environmental change today. But there is now a need to push-on by extending and deepening our understanding of complex change in the Anthropocene, and to connect this with action toward transformations to sustainability (Hackmann et al., 2014). Building upon the legacy of global environmental change programs as mentioned above, the Future Earth program is one example of an international collaborative network supporting such a development. It proposes research agendas and a collaborative framework focused on addressing societal issues and explicitly linking the social and natural sciences and humanities with a broader community of stakeholders (Future Earth, 2013, 2014). In addition to many regional efforts and programs, new global efforts of various natures and foundations are also emerging around the new post-2015 Sustainable Development Goals (Griggs et al., 2013; ICSU-ISSC, 2015) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2015), among many others. In different ways, these efforts call for forward-looking collaborative learning and understanding.

Debates surrounding the Anthropocene concept have already proven fertile in opening a conversation around fundamental issues underlying global change and pathways to sustainability. Instead of remaking historical bifurcations between and within the social and biophysical sciences and the humanities, it is more productive to concentrate on ideas and approaches that make collaboration successful and meaningful to the broader society. Creative (and constructive) tensions around the concept can help the research community to move toward new conceptual syntheses and integrative methodologies that are needed to understand the complexities of the Earth system, and which are commensurable with the social and environmental challenges in front of us.

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