2 Contextual Changes in Earth History: From the Holocene to the Anthropocene — Implications for Sustainable Development and for Strategies of Sustainable Transition

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Abstract

Human activities have changed many of the key parameters of the Holocene geological epoch of the recent past so much that we now live in the Anthropocene. New perspectives in earth system science suggest that sustainable development and plans for transitions to a sustainable peace now have to consider the possibilities of rapid phase shifts in the biosphere. Constraining human activities to within a safe operating space defined by key ecological boundaries in the earth system is key to sustainability but planning has to recognize that rapid shifts may be coming. The implications of this suggest that sustainability planning has to think beyond notions of national security and recognize that human actions are shaping the future configuration of the planet and hence changing the geopolitical context. Adopting a perspective of geopolitical ecology with a focus on global economic production rather than only on traditional ideas of environmental protection is key to the future if planetary stewardship of the Anthropocene is to be successful.

Keywords: Anthropocene, Earth System Science, ecological phase shift, Holocene, sustainable development, Planetary Boundaries, Planetary Stewardship, political geoecology, safe operating space.

2.1 Earth History and Sustainable Development

Discussions about peaceful transitions to a sustainable society are driven by an often-implicit understanding that humanity ought to live in a planetary system that is at least broadly similar to the geological circumstances of the last ten thousand years.[2] Geologists and Earth system scientists usually call this period the Holocene. It provided the ecological conditions that facilitated the emergence of human civilization. Now recent research into the earth system, and a growing recognition of the sheer scale of human transformation of many environments, suggests that the assumption of a relatively stable geological context for humanity is at best misleading, and at worst a dangerous failure to think carefully about the new context that humanity is creating for itself in the new epoch driven by human actions, this new epoch of the Anthropocene.

If rapid ecological change accelerates in the next few decades, as all indications are that it will, then rapid adaptations to new circumstances have to be part of the planning for transitions to more sustainable modes of life. Sustainable peace strategies must consider the possibility of rapid and unexpected ecological phase shifts. If peace is to prevail these will have to be lived through without major powers resorting to military action in attempts to deal with at least some of the consequences of environmental and social disruptions. This is the key implication that arises from juxtaposing discussions of peace, transitions and sustainable development with the new insights into geological and ecological sciences.

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2.1.1 Formulating Sustainable Development

The *World Commission on Environment and Development* (WCED), chaired by Gro Harlem Brundtland, popularized the phrase 'sustainable development' in its widely cited report *Our Common Future*. The famous definition at the beginning of the second chapter of the report reads: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: 43). This has become the standard definition of one of the most widely used terms in contemporary international politics.

The authors of *Our Common Future* went on to elaborate on the definition, stating that it involved two key concepts. The first is "the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given" (WCED 1987: 43). The second concept is "the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs" (WCED 1987: 43). But the authors went on to emphasize that the social and the physical are inextricably interconnected. "Even the narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation" (WCED 1987: 43). How to do this is not exactly easy; claims to inter-generational and intra-generational equity persist in discussions of sustainable development, but the dramatic trajectory of economic change since the Brundtland Report was published a generation ago has apparently not operated on the report's principles despite the repeated invocation of the term 'sustainable development'.

Bluntly put, the term was at best a compromise. It was an attempt to incorporate Northern concerns with environment with Southern concerns about development. Fifteen years after Indira Gandhi called poverty the worst kind of pollution at the United Nations Conference on the Human Environment in Stockholm, the necessity of dealing with rapid environmental change and with impoverishment in many parts of the world required that some compromise between development and environmental protection be articulated in international forums. At the time, alarm about the depletion of stratospheric ozone and concerns about industrial accidents–with Chernobyl and Bhopal very much on people's minds–was coupled with worries about deforestation and the limited possibilities of expanding agricultural production. Ozone depletion in particular made it clear that some environmental vulnerabilities were in fact widely shared and some sense of global cooperation was necessary to deal with these matters.

Southern leaders were adamant that Northern environmental issues should not be used as a method for constraining what they saw as essential Southern economic growth (Kjellen 2008). Given that most of the big environmental problems of the time were caused by Northern activities, simple matters of justice required that those who had caused the problems be the ones to pay for the solution. Where ozone depleting substances were a problem, Southern leaders insisted that Northern economies help provide technological alternatives to compensate for what they portrayed as foregone development opportunities. Such principles linking environment to development have subsequently been key to much of the diplomatic discussions about aid and development. More recently, these themes have been key to international discussions of climate change where technology transfer and development aid are part of the negotiations under the rubric of common but differentiated responsibilities (Brunee/Streck 2013). This terminology has become the taken-for-granted language for discussing many international political matters, not just obviously and immediately 'environmental' matters.

This has more recently been complemented by attempts to reconfigure economies and societies in ways that are more obviously 'sustainable' in that they reduce energy and resource use and hence put less pressure on ecological systems. They remain key themes in the more recent scholarly discussions of sustainable transitions (Grin/Rotmans/Schot 2010) and policy-oriented documents focusing on innovations necessary for global governance (WGBU 2011). The growing recognition in at least some states, and European ones in particular, that de-carbonizing energy supplies is key to dealing with climate change is linked to a recognition that development cannot be equated with economic growth as traditionally understood. Ever larger appropriation of resources to feed increased material production is anathema to serious attempts to think about sustainability and further disrupts the livelihoods of many of earth's poorer peoples (Nixon 2011). Coupled with new measurement metrics, only most obviously the notion of an ecological footprint that calculates the amount of land surface needed for each economic or social entity to be at least carbon-neutral, such strategies attempt to dramatically increase efficiencies and recycle materials. They also attempt to limit the extraction of new resources from fields, forests and mines while simultaneously trying to deal with questions of global justice (Sachs/Santarius 2007).

2.1.2 Sustainability in the Anthropocene

Given the scale of the changes already caused by humanity, earth system scientists are now suggesting that we live in a new geological epoch, one commonly called the Anthropocene following Paul Crutzen's (2002) popularization of the term. There are complicated technical discussions about when the Anthropocene might have started, related to which ecological functions of the system are defined as the most important (Ruddiman 2005), and scepticism on the part of at least some geologists as to whether this is a useful formulation for solving scientific questions in stratigraphy (Autin/ Holbrook 2012). The most commonly accepted view is that the Anthropocene began with the industrial revolution and the growth of the use of fossil fuels, first coal and subsequently petroleum and natural gas (Steffen/Crutzen/McNeill 2007). Steam power was key to the industrial revolution period, both as a source of industrial power and as a mode of locomotion that rapidly connected parts of the global economy and greatly facilitated the extraction of resources and the spread of commercial agriculture.

While this changed many aspects of the global system, starting in the aftermath of the Second World War the global economy began what is now called a period of "great acceleration" (Steffen/Grinewald/Crutzen/McNeill 2011). Powered by an increasing use of petroleum in addition to the coal use, mass consumption economies grew rapidly, first in the United States, Europe and Japan. Subsequently, the rise of Asian economies–in Korea, Singapore and elsewhere–extended this pattern, with China in particular adopting a capitalist-driven consumption model of 'development' in the 1980s. India too has joined the race to consume. Carbon dioxide in the atmosphere has risen rapidly so that it is now present in quantities unknown in the geological history not only of the Holocene, since the last ice age, but back through previous ice ages and interglacial periods stretching back at least 800,000 years.

In earth system science terms, what comes next is a matter for humanity to decide. A 'planetary stewardship' would seem to be the desirable next phase of the Anthropocene. But if the earth system is to be sustained in something roughly approximating Holocene conditions, many things will have to change, not least the understandings at beginning of environment' and humanity's place 'in it'. In the terms of international relations, what should be secured to facilitate a sustainable earth is rather different from what has been seen as essential until very recently; geopolitics can no longer operate on the assumption that the 'playing field' of international politics is a given (Hommel/Murphy 2013). The key point about the Anthropocene perspective is that climate change and other ecological changes are remaking the context of international politics (Dalby 2014).

2.1.3 Recontextualizing Peace and Sustainability

To fill in some of the details for recontextualizing geopolitics in these terms, this chapter first looks to the discussions of earth system science and how the current geological situation is understood. Considerable caution is needed in invoking this particular scientific view of present circumstances; science is not unrelated to attempts to govern human affairs, and the political implications of attempting to see the earth as a whole are not trivial (Lovbrand/Stripple/Wiman 2009). Nonetheless, insofar as environmental contexts are part of the larger considerations of peace and sustainability in coming decades, the earth system science perspective provides a contextualization that distances analysis from an undue focus on states and demands an engagement with the specific material contexts of vulnerability in an innovative way that makes it difficult to avoid the key issues of the politics of security (Dalby 2009). The larger engagement between humanities, social and natural sciences that has often been bypassed by disciplinary foci on one or the other is in urgent need of engagement, and earth sciences provide an especially productive way to link environmental change to history (Hornborg/McNeill/Martinez-Alier 2007) as well as to a wider range of humanities scholarship (Palsson/Szerszynski/Sörlin et al. 2012). Insofar as peace is to be linked to sustainability, such intellectual conversations are simply essential; these frameworks are increasingly being used to discuss innovative development policies as well as climate adaptations (Pisano/Berger 2013; Raworth 2012).

While earth system science cannot provide a blueprint for a sustainable future, it has developed a loose framework for what is called a 'safe operating space' for humanity in light of key ecological functions of the biosphere. The chapter reviews these prior to returning to the questions of what is needed in terms of transitional strategies and how international security needs to be rethought if a sustainable earth is to be produced in coming generations. In the words of the unofficial report to the United Nations Conference on the Human Environment in Stockholm in 1972, there is “Only One Earth” (Ward/Dubos 1972). How we think about it is now rather different from that early environmental view of what needs to be done, not least because we have recently come to understand humanity as a geological-scale actor in the earth system. While earth system science does not provide answers to the key political questions facing humanity, it does provide a framing of the options that is increasingly influential (Dalby 2013a).

The rest of this chapter argues that, whatever the finer points of transition and peace strategies engaging sustainability, they all now have to be considered in light of these new insights into the new geological circumstances that humanity is creating for future generations. The chapter first turns to earth system science and the discussion of phase shifts, tipping points and the key question of the boundaries of a safe operating space for humanity in the earth system. These boundaries involve more than climate change that gets most contemporary attention; it is important to consider other ecological changes that humanity is making if the context for sustainability is to be adequately formulated. Later sections of the chapter emphasize that notions of stewardship and transitions have to be understood in light of these new global ecological understandings. The final section suggests that any consideration of peaceful transitions or sustainability now has to include both a recognition that any proposed transition involves decisions about what kind of ecology its strategies imply and, crucially, that rapid ecological change may be the context in which the transitions happen. Any plans for a transition to a new less rapacious mode of economy will also have to include thinking about how to peacefully cope with rapid and sometimes unanticipated ecological change. Earth system science has profound implications for how social sciences now understand their task (Schellnhuber/Crutzen/Clark et al. 2004); taking these seriously is essential for all strategies for economic sustainability.

2.2 Earth System Science

> Human actions are often viewed as external drivers of ecosystem dynamics; examples include fishing, water extracting, and polluting. Through such a lens the manager is an external intervener in ecosystem resilience. However, many of the serious, recurring problems in natural resource use and environmental management stem precisely from the lack of recognition that ecosystems and the social systems that use and depend on them are inextricably linked. It is the feedback loops among them, as interdependent social–ecological systems, that determine their overall dynamics and sustainability (Folke/Jansson/Rockström et al. 2011: 722).

With much more attention now placed on the question of sustainability, and given increasing concerns regarding a wide range of large-scale ecological changes and climate change in particular—well beyond the concerns in *Our Common Future*—the possibilities of transitioning to a sustainable mode of economic life on the part of developed economies extend the conceptual framework of sustainable development further. Earth system sciences have emphasized how difficult it is to clearly define the parameters of ‘physical sustainability’ while also confirming the necessity of understanding social considerations as an essential part of the biosphere. The planet is ‘under pressure’ from widespread human activities (Steffen/Sanderson/Tyson et al. 2004). While in the 1970s environmentalists had often looked to the discussion of “the limits to growth” in terms of pollution and resource availability (Meadows/Meadows/Randers/Behrens 1972, 1974), now the earth system science literature nuances these matters by looking to a more wide-ranging series of boundaries to what has been called the “safe operating space” for humanity (Rockström/Steffen/Noone et al. 2009a, 2009b). Climate change in particular has raised questions about how we might now understand ‘physical sustainability’ given that human actions are already changing some of the key parameters of the biosphere.

This is a profound shift in understanding of humanity’s place in the larger cosmological ordering of things. Just as astronomy’s proofs that the earth orbited the sun rather than the other way round shook human conceptions profoundly as modern science began its investigations, now earth system sciences are making clear that the planet is not a given stable context into which humanity was recently added, but rather a dynamic system that humanity is now profoundly and rapidly changing. ‘Physical sustainability’ is not a stable given context for humanity; human systems are actively shaping the future geology of the planet, directly altering terrestrial ecosystems and indirectly changing many other aspects of the biosphere, and need to be contextualized that way in any serious thinking about how to address the needs of future generations (Ellis 2011). We are in this new epoch of the Anthropocene, one where human actions are leaving traces in the sedimentary record in many remote places, a geomorphological footprint as it were of the age of humanity (Brown/Tooth/Chiverrell et al. 2013). These actions may yet leave a distinctive geological footprint on the history of the planet (Clark 2012). Even if the geological legacy we leave may not be this epochal when viewed from millions of years in the future, the rapidly changing context is more than enough to raise profound questions for societal stability and with it human security in coming decades (Scheffran/Brzoska/Brauch et al. 2012).

2.2.1 Ecological Phase Shifts

> As a result of the enormous complexity of the system as a whole, it is not possible to predict the outcomes of rapidly increasing human pressures on the Earth System, but it is clear that thresholds have been or are being reached, beyond which abrupt and irreversible changes occur. These changes will affect the basic life-support functions of the planet (UNEP 2012: 210).

In earth system science terms, the current transformations that humanity has set in motion amount in some accounts to an approaching phase shift in how the biosphere functions (Barnosky/Hadly/Bascompte et al. 2012). Ecological thresholds have either already been crossed or are in danger of being crossed with the consequence that ecosystems will likely operate in new and potentially unpredictable ways (Huggett 2005).

> The shift from one state to another can be caused by either a 'threshold' or 'sledgehammer' effect. State shifts resulting from threshold effects can be difficult to anticipate, because the critical threshold is reached as incremental changes accumulate and the threshold value generally is not known in advance. By contrast, a state shift caused by a sledgehammer effect–for example the clearing of a forest using a bulldozer–comes as no surprise. In both cases, the state shift is relatively abrupt and leads to new mean conditions outside the range of fluctuation evident in the previous state (Barnosky/Hadly/Bascompte et al. 2012: 52).

These shifts can occur at various scales, and while the overall effect may be global, it is important to emphasize that the cumulative effects of many small changes may cross thresholds at larger scales.

> In the context of forecasting biological change, the realization that critical transitions and state shifts can occur on the global scale, as well as on smaller scales, is of great importance. One key question is how to recognize a global-scale state shift. Another is whether global-scale state shifts are the cumulative result of many smaller-scale events that originate in local systems or instead require global-level forcings that emerge on the planetary scale and then percolate downwards to cause changes in local systems. Examining past global-scale state shifts provides useful insights into both of these issues (Barnosky/Hadly/Bascompte et al. 2012: 53).

Those past events suggest that the current transition is more rapid than previous dramatic changes in the earth system, the most recent of which was the transition from the last ice age.

While transitions happen very quickly relative to the fairly stable states that precede them, the pace of human adaptation of numerous aspects of the biosphere may be unprecedented. "Global-scale forcing mechanisms today are human population growth with attendant resource consumption, habitat transformation and fragmentation, energy production and consumption, and climate change. All of these far exceed, in both rate and magnitude, the forcings evident at the most recent global-scale state shift, the last glacial–interglacial transition" (Barnosky/Hadly/Bascompte et al. 2012: 53) which gave rise to the geological period of the Holocene. This is one of the worrisome factors in our present circumstances: there are few clear geological analogies to draw upon to anticipate how the earth system will respond to the new forcing mechanisms humanity has created.

However, the question of whether there are global tipping points that will mean the earth system in total will rapidly tip into some new format is disputed, and much remains to be studied on potential linkages between different drivers of system change (Hughes/Carpenter/Rockström et al. 2013). Brook, Ellis, Perring et al. (2013) suggest that for at least four of the main drivers a phase shift in the immediate future is unlikely at least for terrestrial ecosystems.

> Our examination of the evidence suggests that four principal drivers of terrestrial ecosystem change–climate change, land use change, habitat fragmentation, and biodiversity loss–are unlikely to induce planetary-scale biospheric tipping points in the terrestrial realm. Criteria that would increase the likelihood of such a global-scale tipping point–homogeneity of response over space at a short timescale, interconnectivity, and homogeneity of a causative agent across space–are not met for any of these drivers. Instead, terrestrial ecosystems are likely to respond heterogeneously to these variable forcings and, with a few exceptions, show limited interconnectivity" (Brook, Ellis, Perring, et al. 2013: 399–400).

In part this is because humanity has already transformed so much of the terrestrial ecosystem that there is not a natural state that might tip in terms of land use. All of which makes the case for great caution in predicting global ecological consequences of further changes. It also emphasizes the key point that ecological change is highly geographically variable in the earth system and human vulnerabilities are dependent on this and the increasingly artificial circumstances in which most of us live (Dalby 2009).

The most worrisome dimension to all this is not that the world will gradually change as a result of human activities, but that the earth system will be rapidly changed in ways that are not conducive to human flourishing. This may happen if the whole earth system enters a rapid phase of non-linear change that results in a new relatively stable configuration, but one very different from that so far familiar to human societies. While this may be unlikely in the immediate future, and some of the earlier concerns about rapid change may have been exaggerated (Committee on Understanding and Monitoring Abrupt Climate Change and its Impacts 2013), exactly how many ecosystems will respond to accelerating climate change is a crucial unknown (Hughes/Carpenter/Rockström et al. 2013). The Anthropocene presents us with a new set of questions concerning the cumulative consequences of human actions, and possible interactions among them, that are key to any discussion of what kind of future we may be creating. The question of the Anthropocene as posed by Rockström, Steffen, Noone et al. (2009a) is nothing less than "What are the non-negotiable planetary preconditions that humanity needs to respect in order to avoid the risk of deleterious or even catastrophic environmental change at continental to global scales?"

2.2.2 Boundaries, Thresholds and Tipping Points

Such 'planetary preconditions' are not easy to establish, not least because ecological matters rarely work in simple linear processes. They often have very considerable abilities to function while key drivers of important facets vary considerably. Many are resilient too, being able to bounce back after serious disruptions. Not all ecosystems function in patterns that are immediately obvious and they are sometimes interconnected over distances in ways that are hard to clearly analyse. Many have threshold values that, once surpassed, lead to systems changing dramatically as they cross a "tipping point" (Lenton/Held/Kriegler et al. 2008). In the case of the global ecosystem, human and ecological systems are so interconnected and enmeshed that they now have to be considered together if any discussion of sustainability is to make sense. "Because ecosystems are variable, one must focus on the risk, not the certainty, of exceeding an objectively defined target or threshold" (Bennett/Carpenter/Cardille 2008: 132). Calculating such things is rarely easy, but clearly many earth scientists are convinced that some boundaries have already been crossed, and others may well be in the next few decades, with consequences that are potentially disastrous to the contemporary modes of human existence.

More specifically, ecological change has to be understood in terms of potential non-linearities, thresholds, and tipping point responses to stresses that drive systems in particular ways.

> Ecosystem attributes such as species abundance or biological carbon sequestration can respond in three (stylized) ways to biotic and abiotic drivers. The first type of response is characterized by being consistently proportional to the magnitude of the driver, thus exhibiting a 'smooth response' pattern, where no single critical point can be determined. In the second class of ecosystem change, the response, at some critical level of forcing, is amplified by internal synergistic feedbacks and thus becomes nonlinear in relation to the driver, changing the slope of the response curve. The third class similarly involves nonlinearity, but exhibits hysteresis, in which at least two stable states exist, implying limited reversibility. The term tipping point applies to the second and third class of ecosystem change and refers specifically to the inflection point or threshold at which the ecosystem response becomes nonlinear or the rate of change alters steeply (Brook/Ellis/Perring et al. 2013: 397).

Rapid and unpredictable change is what worries most political decision-makers: the potential for drastic disruptions to increasingly artificial social-ecological systems is what has stimulated seemingly endless invocations of environmental security since the Brundtland Commission explicitly raised concerns that environmental disruptions could potentially cause military conflict (Floyd/Matthews 2013). Such considerations have become all the more urgent because scientific evaluations of current transformations are identifying thresholds in many systems.

> Theoretical or empirical evidence of tipping points, manifesting on decadal to centennial time scales, exists at local and regional scales for many subsystems of the Earth system, including the cryosphere, ocean thermohaline circulation, atmospheric circulation, and marine ecosystems. In the terrestrial biosphere, tipping points involve ecosystem attributes such as species abundance or carbon sequestration responding nonlinearly and potentially irreversibly to proximate drivers like habitat loss or climate change (Brook/Ellis/Perring et al. 2013: 396).

The interconnected nature of these suggests very clearly that any attempt to think carefully about sustainability, and strategies for transitions towards more sustainable human systems, will face fraught interpretive tasks in terms of the science. These will be just as fraught as potential governance arrangements if in the next few decades humanity seriously tries to shape a functional biosphere for future generations.

2.2.3 Multiple System Stressors

All of this is made more complicated by the simple but unavoidable point that multiple stressors are working simultaneously on most systems.

> In a related area of concern, we are struggling conceptually with how to propose robust boundaries for issues that are spatially distributed heterogeneously around the world. Part of the answer relates to the potential geographic specificity of process and function—the primary concern is not the physical intervention in the structure itself. Thus for instance, deforesting the equatorial/tropical Amazon basin really might be more of a planetary cause for concern than land use change over an equivalent area elsewhere, not because of what it materially consists of nor the area involved, but because of the interplay of that particular patch of vegetation with the processes influencing global water and energy balance (Cornell 2012: 2).

Thus, while global boundaries are suggestive, specific ecosystems in particular places matter and trying to ascertain which of these are most important in terms of ecological function is not easy, although it is essential for earth system governance (Bierman 2012).

To even think in such terms requires a conceptual shift from modern notions of a nature external to humanity that provides the environmental context for humanity, to formulations that understand at least the affluent fossil-fuel-powered part of humanity as a key ecological actor in what effectively are geological processes. Such considerations suggest that humanity itself be understood in geological terms given the scale of its actions, a discussion that has given rise to various prior formulations of present times in geological terms before science settled on the informal use of 'the Anthropocene' in the last decade (Davis 2011). What is also clear is the relative novelty of major human interventions in the biosphere, although on closer examination the question of when humanity started to have a noticeable impact on the biosphere and which impact is most important turns out to be very complicated (Ruddiman 2005). Nonetheless, what is clear is that human actions are now transforming the biosphere and the concern is that unless great care is taken not to cross crucial thresholds, we may change it in ways that threaten human civilization profoundly. Not crossing key thresholds in the biosphere is a key part of any strategy that aims to transition from current economic practices to ones that remain safely within the planetary operating space (Rockström/Steffen/Noone et al. 2009a).

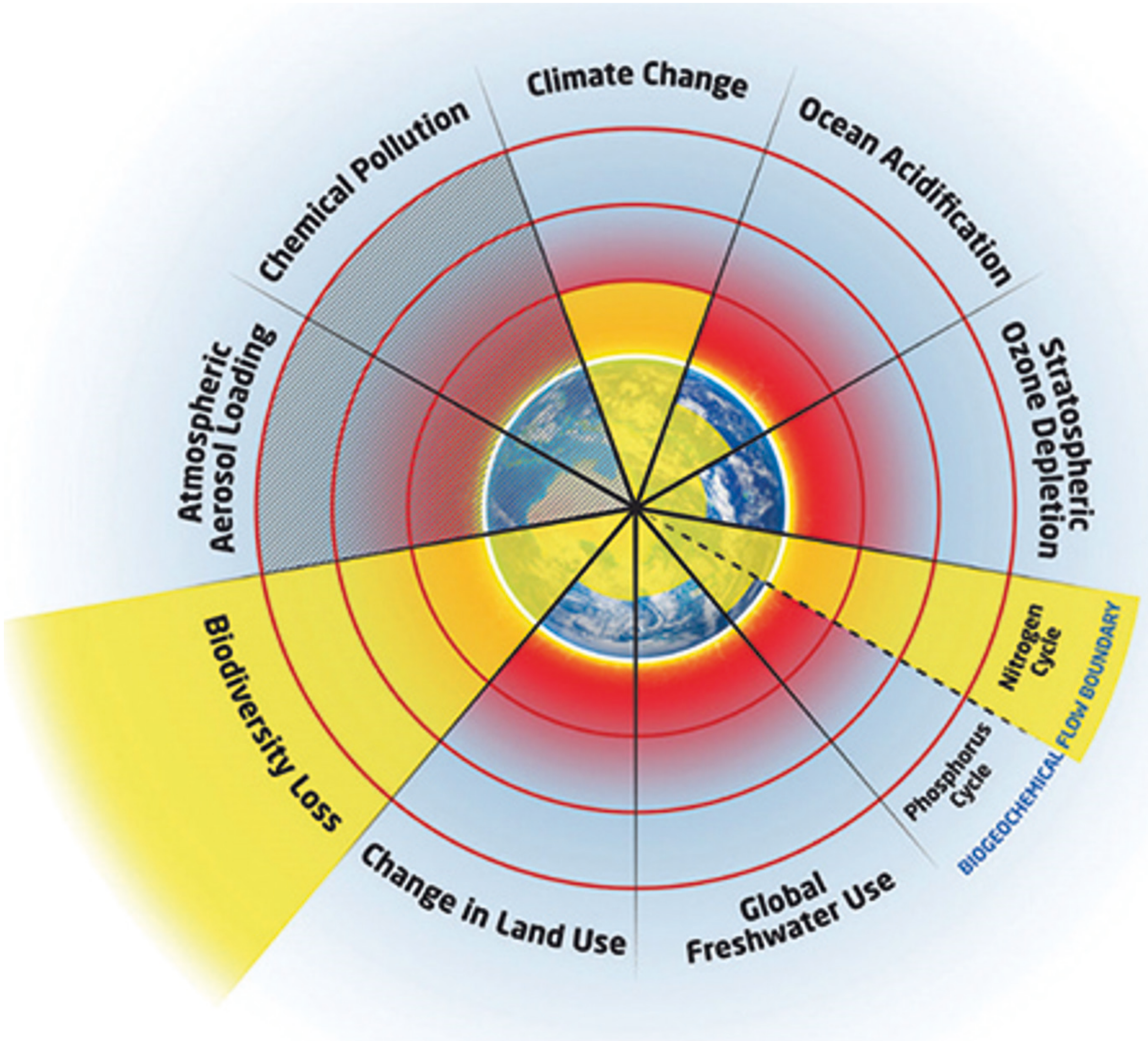
2.3 Planetary Boundaries

> Industrial human systems, in just two centuries, have already introduced at least three clearly novel biospheric processes: the use of fossil energy to replace biomass fuel and human and animal labour, revolutionizing human capacity for ecosystem engineering, transport and other activities; the industrial synthesis of reactive nitrogen to boost agro-ecosystem productivity; and, most recently, genetic engineering across species (Ellis 2011: 1013).

In attempting to provide at least a preliminary answer to questions about how far such transformations can be taken while keeping essential biospheric processes working in more or less the conditions humanity is familiar with, Rockström, Steffen, Noone et al.'s (2009a) formulations of a safe operating space for humanity suggest that nine planetary boundaries need to be especially carefully monitored (see figure 3.1). While these are obviously not precisely definable technical measures, they are postulated as conditions short of those that might plausibly be thresholds that, if crossed, might shift ecological conditions from the present desirable state into one much less desirable from the human point of view. Thresholds are defined in terms of coupled human natural systems and nonlinear transitions, and the example given is the recent unanticipated retreat of Arctic ice caused by anthropogenic global warming (2007 was a year of especially dramatic reduction in the Arctic Ocean ice cover).

Given the complexity of earth system processes, such simple definitions are very difficult to operationalize in terms of practical metrics. "Some Earth System processes, such as land use change, are not associated with known thresholds at the continental to global scale, but may, through continuous decline of key ecological functions (such as carbon sequestration), cause functional collapses, generating feedbacks that trigger or increase the likelihood of a global threshold in other processes (such as climate change)" (Rockström/Steffen/Noone et al. 2009b). While these may occur at smaller scales (in particular biomes), they may become a matter of global concern when aggregated if their occurrence is widespread. Determining the boundaries prior to such thresholds is not easy and depends on judgments in the face of numerous uncertainties.

Figure 2.1: Planetary Boundaries for a Safe Operating Space for Humanity. **Source:** Stockholm Resilience Centre: "Azote Images"; at: <http://www.stockholmresilience.org/21/research/research-programmes/planetary-boundaries.html>.



With such caveats carefully noted, the Rockström team identified nine boundaries to a safe operating space for humanity about which they are especially concerned. Three of these are systemic processes at the planetary scale, namely, climate change, ocean acidification, and stratospheric ozone depletion. While the first two are processes with global-scale thresholds, in the case of stratospheric ozone this is less clear. The other boundaries deal with aggregated processes from local and regional changes. The associated thresholds here are less clear in the case of global phosphorous and nitrogen cycles, atmospheric aerosol loading, freshwater use, and land use change. Biodiversity loss and chemical pollution are also listed: they are clearly slower processes than the others and lack obvious global-scale thresholds. From such categorizations, climate change and ocean acidification, both of which are predominately caused by the accumulation of carbon dioxide due to human use of fossil fuels, as well as deforestation, are the immediate cause for concern, being both planetary processes and ones that are happening quickly. All the others listed matter as well, as they are important parts of the life support systems for humanity even if there is no way to establish precise thresholds yet. Even more complicated is that these processes interplay and connect in numerous ways; changes in one may cause other processes to cross boundaries.

The initial planetary boundaries framework was updated and extended in 2015 (Steffen/ Richardson/ Rockström et.al 2015). The new version added updates to the initial scientific estimates, and added an additional discussion of what they termed "novel entities" a category that encompasses the new products of industrial civilization which has added numerous new things to the biosphere, the consequences of which are at least so far less than clear. The revised formulation also emphasized the geographical diversity of boundaries, noting that some boundaries are transcended in some regions, but not elsewhere, a matter that makes the framework more precise, but adds difficulty to the task of aggregating the local boundaries into global calculations. Johan Rockström (Rockström and Klum 2015) at least argues that it is still possible to have a civilization based on abundance within these revised planetary boundaries; but critics are doubtful whether there is the necessary clarity concerning what needs to be done to stay within the climate change boundary in particular (Anderson 2015).

2.3.1 Climate Change

The most high-profile theme in the discussion of the Anthropocene is climate change: the body of science related to this topic is now huge. The consensus, widely adopted at the Copenhagen climate negotiations in 2009, is that any warming above 2 degrees Celsius is to be avoided as it will be dangerously disruptive. What is less clear is the long-term level of carbon dioxide in the atmosphere that will keep the climate below this threshold. Concentrations reached 400ppm briefly in 2013, and while environmental activists suggest that perhaps 350ppm is the maximum level that should be maintained in the long run—approximately the level when *Our Common Future* was written—there are as yet few serious suggestions as to how the atmosphere can be brought back to such a level, one already reached after the first few decades of the great acceleration. With the Arctic Ocean ice cap already melting and warming the northern hemisphere as a result of increased albedo, one of the positive feedbacks that concerns climate science is clearly already in operation. Enhanced methane emissions from melting northern permafrost also suggest accelerated warming in this region. The trend to ever-greater emissions of carbon dioxide from combustion and further destruction of forests suggests rapid climate change. Considerations of rapid climate change are now part of the scenario planning exercises for the future (Anderson/Bows 2011) and increasingly a matter of concern to financial planners who have belatedly begun to consider the consequences of climate system disruptions (Potsdam Institute 2012; see the chapter by Schellnhuber et al. in this volume).

In terms of the boundary debate, climate is one of the key potential drivers that might cross significant tipping points this century with potentially serious disruptions to human systems. Lenton, Held, Kriegler et al.'s (2008) summary suggested that Arctic Sea Ice, the Greenland Ice Sheet, the Atlantic Thermohaline Circulation, the West Antarctic Ice Sheet, the El Nino–Southern Oscillation, Indian Summer Monsoon, Sahara/Sahel and West African Monsoon, Amazon forest dieback, and possible Boreal forest dieback were all contenders for major changes as a consequence of accelerating climate change. While this is far from encompassing the whole earth system, these components are substantial parts of it and they raise the alarm about potential climate security risks very clearly, especially as the monsoons are key to feeding much of Asia and Africa. But as Lenton's (2013) subsequent investigation of environmental shocks makes clear, all this change also matters in human terms: as a matter of how vulnerable people are in particular places and, related to that, a matter of institutional preparedness—or the lack thereof—in particular societies. All this is especially important because, despite repeated warnings that this boundary is one that humanity is on track to transcend, some key scientists are warning that scientific projections of what is needed to prevent global heating, are still not being taken anything like seriously enough by politicians (Anderson 2015).

2.3.2 Ocean Acidification

One of the so-called 'carbon sinks' that removes carbon dioxide from the atmosphere is the ocean where the gas is absorbed in surface waters. But this process is itself a matter with profound ecological consequences.

> Nearly one third of the carbon dioxide released by anthropogenic activity is absorbed by the oceans. But for this fact, current atmospheric CO_2 concentrations would be higher than they already are. However, CO uptake lowers the pH and alters the chemical balance of the oceans, in particular the solubility of calcium salts. This phenomenon is called ocean acidification, and is occurring at a rate faster than at any time in the last 300 million years (Gillings/Hagan-Lawson 2014: 3).

The solubility of calcium salts is a key factor in the success of coral reefs and other marine creatures dependent on shells; if the water is too acidic, coral skeletons or shells may dissolve and cause reefs to stop functioning and shellfish to die. The ecosystem consequences of this phenomenon and other disruptions of marine life may be crucial to the future of the biosphere:

> In the final analysis, protection of the ocean may be more important than protection of atmosphere or land because it stores more carbon, mediates climate variability and provides essential ecosystem services (Gillings/Hagan-Lawson 2014: 4).

This point is especially important given the obviously global dimensions to the oceans. Despite the large-scale implications of shifts in oceanic functions, they frequently remain a low priority for environmentalists whose focus is on terrestrial systems, which are perceived as more immediately a matter of human experience. Indeed, the focus on 'greening' things in environmental politics and the formulation of 'green' policies suggests a focus on chlorophyll that is key to growing plants. But the earth system perspective and a focus on Anthropocene life suggests that, given the importance of the atmosphere, oceans, and ozone layer, a focus on blue formulations, following from oxygen in ozone and in water in particular, might be more appropriate. Correcting this inherent 'terrestrial bias' is one of the key implications of earth system thinking.

2.3.3 Stratospheric Ozone Depletion

If there is a success story in global environmental management and international cooperation, it is clearly the Montreal Protocol and its subsequent additional amendments and extensions (Benedick 1991). These mandated the end to the production of *chlorofluorocarbons* (CFCs) and the gradual reduction of the use of other halocarbons. While they remain in the atmosphere and will for decades more as they gradually decay, the annual ozone holes over the poles are not increasing, although in 2014 detection of new chemicals in the atmosphere in small quantities raised concern about the efficacy of this regime (Laube/Newland/Hogan et al. 2014). Coincidentally, the reduction in CFCs in the atmosphere has been a useful climate change measure given their potency as greenhouse gases. While other chemicals such as nitrous oxides will still have some detrimental effects on ozone levels in the stratosphere, the immediate danger of removing the essential ultraviolet filter from the upper atmosphere, something essential to terrestrial life, has been removed.

However, while this success is worth emphasizing, so too is the point that the combination of easily identifiable dangers, the availability of technical replacements for the outlawed gases, and the relative simplicity of the technical issues allowed for a relatively rapid evolution of policy. Likewise, financial compensation to Southern states for difficulties they might have encountered in making the transition was forthcoming and was not a prohibitive cost to signatories to the agreements. But this regime, frequently invoked as a model for dealing with other 'global' environmental matters, and a prominent part of the discussions about climate change in particular, may not be a good fit for more complicated issues where numerous technologies operate and where substitutions are much more difficult to identify and implement (Hoffman 2005).

2.3.4 Phosphorous and Nitrogen Cycles

One of the keys to the rapid transformation of rural landscapes has been the availability of artificial fertilizers that have, when coupled with tractors and other farm machinery, facilitated industrial-scale monoculture farming. While the fossil fuel 'subsidy' to natural systems has boosted productivity dramatically in the so-called 'green revolution', it has done so by disrupting rural social systems and ecologies and by dramatically increasing the circulation of nitrogen and phosphorous through the biosphere. "Nitrogen flux through the biosphere is primarily a biological process, while phosphorus availability arises slowly through geological weathering. Humans sidestep the phosphorus bottleneck by mining and distribution of fertilizer onto agricultural lands, thus inadvertently increasing the flow of phosphorus into the oceans" (Gillings/Hagan-Lawson 2014: 5). Eutrophication and other ecological disruptions result from the addition of artificial fertilizers into aqueous environments; ocean anoxic events that have caused large-scale die-offs may have been caused by phosphorous being washed into the ocean.

However, the boundary on this ecological change is distant when considered at a global scale despite the fact that phosphorous run-off rates may be significant for some coastal waters. An important consideration with managing phosphorous is that it is geographically heterogeneous: while the application of fertilizers in some places may have eutrophication effects on terrestrial waterways, phosphorous deficiencies elsewhere limit ecosystem productivity. This means that a global boundary for phosphorous is very difficult to calculate even if specific ecosystems have transcended boundary conditions (Carpenter/Bennett 2011). Nitrogen pollution also has regional effects but as yet does not seem to be close to any global threshold (Vries/Kros/Kroeze/Seitzinger 2013). The nitrogen cycle is more complicated to assess as, in the form of nitrous oxide, it is an important greenhouse gas and hence also counts as part of the climate change calculations.

2.3.5 Atmospheric Aerosols

Combustion of fossil fuels, and in particular their inefficient combustion, leads to particulate matter and various chemicals in the atmosphere that have numerous effects (Tsigaridis/Krol/Dentener et al. 2006). These have been of particular concern recently in terms of their immediate pollution effects in Asia and the possible effects global warming may have on disrupting the Asian monsoon, the key rainfall pattern that supplies agricultural systems in the region with water, thus helping feed a large portion of the human population (Kitoh/Endo/Kumar et al. 2013). Ironically, aerosols also act as cooling agents in the atmosphere, shading the ground from sunlight. This effect is clearly visible in studies of the consequences of volcanic eruptions and has become one of the proposed ideas for geoengineering to artificially cool the planet in coming decades if climate change becomes an immediately hazardous phenomenon. As such, aerosols are both pollution and a health hazard but also potentially an artificial sunshade, if practical attempts to cool the planet are undertaken. Hence the great difficulty in assessing the total impact of aerosols on global heating as well as other related human effects.

2.3.6 Freshwater Use

Human activities divert large quantities of surface and ground water for farming, industrial use, as well as for basic human needs such as drinking, bathing, cooking, and household use, making discussions of water security for humanity very complicated indeed (Grey/Garrick/Blackmore et al. 2013). Potable water is key to basic hygiene and disease prevention and, as such, a key dimension to human functioning in many increasingly artificial ecosystems. Water supplies are both a matter of 'natural' supply (as in rain and snow), but also, given the extensive plumbing systems that now supply cities in particular, very much a matter of artificial hydrology. Many rivers no longer flow all the way to their estuaries due to the volume of water diverted en route. Groundwater aquifers are also being pumped dry in many places. While this may not have many direct ecological effects beyond the locations where aquifers feed water springs and hence provide water for ecosystems and human use, the effects matter once the water is depleted and the unsustainable activities dependent on that water source have to be discontinued.

Climate change may alter rain and snow patterns, causing droughts and forcing ecosystems and farming arrangements into new configurations. The California drought emergency of 2014 suggests difficult political choices concerning the allocation of remaining water supplies. Such decisions regarding prioritization have practical, social and philosophical implications for the communities and actors affected. Water is an essential part of human politics, contested and used in numerous ways that defy easy categorization, but an unavoidable necessity in all human activities no matter how humans try to govern its use (Linton 2010). It is clear that human use of fresh water is rapidly increasing due to food cultivation requirements in particular. As such, governance issues will be an important part of sustainability transitions. "This indicates that the remaining safe operating space for water may be largely committed already to cover necessary human water demands in the future" (Rockström/Steffen/Noone et al. 2009b: 16).

2.3.7 Land Use Change

Humanity cleared land for agricultural purposes throughout much of the Holocene period. Indeed, part of the argument that the Anthropocene started long before the industrial revolution is related to the release of methane from agricultural activities (Ruddiman/ Vavrus/Kutzbach/He 2014). The scale of the transformations that have already taken place are such that ecologists have suggested that traditional classifications of the world's large geographical designations of natural areas in terms of biomes now needs to be updated with the addition of various "anthromes" (Ellis/Goldewijk/Siebert et al. 2010). Deforestation reduces carbon sink capabilities at least in forests where trees do not decay quickly and return their carbon to the atmosphere. The albedo of bare land is very different from that of a tree canopy. Forests' water retention functions also affect other hydrological functions. Clearly terrestrial land cover is key to many ecological matters and it is very hard to aggregate these into any one meaningful global threshold.

That said, humanity is already using much of the most fertile parts of the planet's land surface and we will need to implement many changes in how land is used if the ecological footprint of agriculture is to be reduced while its efficiency is simultaneously increased to feed a still-growing population (Foley/Ramankutty/Brauman et al. 2011). Part of the concern about land use change is the question, "Can a threshold for habitat clearance effects on biodiversity be defined on a global scale?" (Brook/Ellis/Perring et al. 2013: 399). The answer would seem to be negative not least because "thresholds are deeply context dependent" and "tipping points might differ between scales" (Brook/Ellis/Perring et al. 2013: 399). Beyond that, it is also worth emphasizing again that, given the diversity of terrestrial land cover, it is unlikely that terrestrial ecosystems will universally respond to a global tipping point crossing some other boundary; they are more likely to react heterogeneously in the event of major disruptions.

2.3.8 Biodiversity Loss

The huge changes to landscapes, including deliberate land clearing as well as inadvertent habitat disruption, in combination with hunting and fishing, has already led to the extinction of many species. The rates of extinction are much greater than the normal background rates of species disappearance in the geological record, suggesting that we are living through the sixth global extinction event in the planet's history (Kolbert 2014). While many species have disappeared, other artificial species, such as farm animals, have expanded greatly. These, however, are dependent on human systems and not a replacement for the diverse species that make up 'natural' ecosystems. The rate of extinction is the key consideration: the alarming pace of extirpation has been driven by most of the other ecological processes in addition to direct human predation on particular species. Given the diversity of species in tropical rainforests, many of them with very limited geographical ranges, forest clearing is an especially damaging human activity in terms of reducing species diversity. Further complicating efforts to stem biodiversity loss, conservationists warn that assuming that these ecosystems have already been radically disrupted may undercut important conservation efforts that can still protect many species, especially in tropical areas less immediately susceptible to climate change playing out more intensely in polar regions (Caro/Darwin/Forrester et al. 2012).

While possible food and pharmaceutical derivatives may be being destroyed, the large concern is that unknown future possibilities for life are being precluded. In the very long run, the planet will no doubt replenish life forms, but humanity faces an impoverished range of life forms in the centuries ahead. It is important to note that not all species are equally important in ecosystem function: removing "top predators and structurally important species such as corals and kelp, results in disproportionately large impacts on ecosystem dynamics" (Rockström/Steffen/Noone et al. 2009b: 15). As such, while an overall reduction in the rate of extinction by several orders of magnitude is needed to push biodiversity loss to a level within the safe operating space, specific species may have a disproportionate effect on particular ecosystems and their functioning. It consequently becomes clear that managing the global scale must be balanced with micro-scale interventions.

The overall pattern of biodiversity loss in comparison to previous mass extinction events is not clear (Condamine/Rolland/Morlon 2013), even if the trend in particular places due to 'sledgehammer' clearing effects frequently is observable and better understood. This remains the case in the updated version of the planetary boundaries framework where matters of biodiversity loss are nuanced by dealing with them in terms of biosphere integrity, and focusing on functional and genetic diversity in specific biomes (Steffen/ Richardson/Rockström et.al 2015). The lack of clarity about baselines in terms of species numbers and extinction rates remains a measurement problem in terms of the precise location of the boundary even if the trajectory of rapid extinction is clear.

2.3.9 Chemical Pollution

While pesticides were a central driver in the rise of environmentalism in the United States in particular, inspired by Rachel Carson's book *Silent Spring*, other forms of industrial pollution have long been a problem both for ecosystems and as a direct cause of human health issues. Recent smog events in China are reminiscent of the situation in London sixty years earlier when the death of thousands as a result of smog caused by coal fires finally led to comprehensive efforts to reduce smoke. Many of the environmental campaigns of the 1960s and 1970s in the developed world led to technological innovations that removed pollutants from smokestacks and effluent pipes. Ecological modernization provided numerous technical fixes to pollution problems but only rarely led to more fundamental social change. With the rise of globalization, industrial production frequently moves to states with less rigorous regulations, effectively outsourcing pollution rather than permanently and directly addressing the problem. Of great concern are the very low-level toxic substances that may have effects on particular species and thus alter whole ecosystems indirectly. These include such substances as endocrine-disrupting chemicals. Where the thresholds on such activities might be is not yet clearly known.

2.3.10 Boundary Priorities

The most immediate concerns are with atmospheric greenhouse gases. Nonetheless, as Rockström and colleagues emphasize, the nine factors identified as safe operating space boundaries interact and interconnect in complicated ways. It is worth remembering that chlorofluorocarbons, the most obvious cause of stratospheric ozone depletion, are also powerful greenhouse gases. The regime to curtail their production is effectively also an agreement to deal with climate change even if it is not designed explicitly to do this! Crossing one boundary may have many serious and unpredictable consequences for others: this simple but difficult point is key to any serious consideration of how to facilitate transitions to sustainability. Sustainability usually implies a fairly stable context for humanity but, as the earth system science analyses briefly summarized here suggest, in the present context sustainability of societies has to be considered in terms of the rapidly changing context for humanity and the simple fact that societies have been changing rapidly as rural transformations and urbanization interact.

Viewed as a totality, the planetary boundaries perspective suggests that humanity has effectively taken its own fate into its hands in terms of the future configuration of the planetary system. However, while we have clearly crossed the boundaries in terms of biodiversity loss, the artificial production of nitrogen in the atmosphere, and climate change, it appears that human action has at least halted the dangerous trend of ozone depletion and limited it to the areas within the high-altitude polar vortex wind systems. Although depletion will remain a problem until at least the middle of the current century, given the existing inventory of ozone depleting substances already released, it is important to remember that the boundary has not been crossed nor does it seem likely that this will happen given the widespread agreement that chlorofluorocarbons and related chemicals are too dangerous for more than very limited use. Dealing with this boundary has been relatively easy given that the components necessary for a solution were practical and political opposition to agreements was relatively weak. Other boundaries are much more difficult to deal with, even if it is clear where they might be and how close we are coming to some of the thresholds.

2.4 Planetary Stewardship for a Sustainable Earth?

Implied but rarely spelled out in the discussion of sustainable development is the assumption that the planetary conditions inherited from the Holocene are essential for future generations to meet their needs. The discussion presupposes that the baseline condition of the planet is one given by the Holocene parameters that facilitated the emergence of human civilization and that the planetary boundaries are effectively guard-rails beyond which humanity should not venture. Sustainable development is about economic change while effectively maintaining Holocene conditions, ones that are presumably the optimal state for humanity. The extraordinary growth in human numbers and associated increase in economic activity over the last half-century of the great acceleration have been powered by the extraction and combustion of fossil fuels. This process has reversed the long-term ecological pattern of life sequestering carbon from the atmosphere, and effectively made industrial humanity a new geological force in the planetary system. Constraining the further expansion of these activities and planning to reduce the carbon dioxide levels in the atmosphere to something approaching pre-industrial levels is key to most policies of transition to a sustainable future. However, the very awkward assumption about this formulation is that it presupposes precisely what current processes of unsustainable development have started to fundamentally change:

> Environmentalist traditions have long called for a halt to human interference in ecology and the Earth system. In the Anthropocene, the anthropogenic biosphere is permanent, the legacy of our ancestors, and our actions as human systems a force of nature, making the call to avoid human interference with the biosphere irrelevant. The implication is clear; the current and future state of the terrestrial biosphere is up to us, and will be determined by human systems of one form or another, whether it is the momentum of our past or new pathways we are able to achieve in the future (Ellis 2011: 1027).

It is abundantly clear that decisions about human economic activities are now central to constructing the future of the planet and instrumental in determining whether key boundaries will be crossed. Preventing these transgressions while simultaneously working back to levels within the boundaries in terms of nitrogen and climate change, as well as drastically reducing the rate of loss of biodiversity, is key to any transition to a human condition that lives within the safe operating space. The alternative requires a transition to a very different configuration of the biosphere, one impossible to predict precisely but, given the phase shifts already looming, one very different from the conditions that have given rise to human civilization. The implicit assumption in juxtaposing transitions and a peace that can be sustained is that ecological changes will not be so drastic or so quick that major powers resort to military force in attempts to control the human consequences of the disruptions.

In Steffen, Persson, Deutsch et al.'s (2011) terms, the next phase of the Anthropocene requires planetary stewardship, a complex matter of global governance that will require numerous social innovations if the earth is to be kept within a safe operating space loosely analogous to Holocene conditions. While production of chlorofluorocarbons and other ozone-depleting substances has largely ceased due to international cooperation, this has occurred despite a remarkable amount of foot-dragging on the part of specific sectors of some economies, notably strawberry producers in California, reluctant to give up their particular mode of soil sterilization (Gareau 2013). The larger lesson of this case is the necessity of thinking in terms of how humanity produces things, and how these processes are governed. Phasing out the use of ozone-depleting substances emphasizes that merely regulating the use of substances is not enough for at least some of the planetary boundaries; prohibition of certain activities may be required, and that, in turn, is a matter of global governance where industrial corporations as well as state governments must be involved in determining production priorities.

Looking further ahead, it is clear that decisions about such things as the continued production of coal-powered electricity generation stations are matters of industrial policy that have global consequences. If climate boundaries are not to be yet further transcended, then thinking in terms of the political economy of energy systems is essential to future planetary governance. But this is more than a matter of governments regulating some detrimental environmental consequences of economic activity; it is about production decisions and, quite literally, *who* decides *what* gets made. While there is a wide diversity of economic decision-making authorities currently operating, the neo-liberal modes of letting markets make such decisions seem unlikely to constrain the use of fossil fuels quickly enough to begin reducing carbon dioxide emissions any time soon, even if they do focus attention on how markets might work as governance mechanisms (Newell/ Paterson 2010). The climate boundary has been breached and the larger patterns of the great acceleration suggest that this trajectory is not likely to change quickly despite repeated, although as yet limited, efforts to restrict emissions under the *United Nations Framework Convention on Climate Change* (UNFCCC).

This has in turn raised the question of geoengineering, attempting to artificially manipulate the global climate to at least temporarily mask the effects of elevated levels of greenhouse gases (Hamilton 2013). However, as the discussion of the other planetary boundaries emphasizes, dealing with just one facet of boundary crossing, such as the failure to cope with rapidly rising greenhouse gases, needs to take into consideration other facets of the earth system. As one of the leading proponents of experimenting with climate engineering technologies is keen to emphasize, while artificial sulphate aerosol use may be feasible as a method of "solar radiation management", it will not address the major issue of ocean acidification—hence, reducing emissions of carbon dioxide must remain the priority for global environmental politics (Keith 2013).

The implications of such considerations are profound. While arguments for a transition to a sustainable future suggest that rapidly reducing the disruptions to the natural arrangements that humanity has known since the end of the last ice age approximately ten millennia ago are essential, it is no longer the case that this future will occur in the given circumstances implied by the invocation of physical sustainability. The assumption built into environmental concerns through the discussion of the limits to growth in the 1970s, the 1980s discussions of sustainable development, and subsequently through the initial formulations of the UNFCCC in the 1990s is that the planet ought to be kept in more or less the configuration that has so far nurtured civilization. This is implied in the formulation of 'physical sustainability' in *Our Common Future*, and spelled out clearly in the formulation of avoiding dangerous human interference with the climate system that is the key operant phrase in the UNFCCC.

But all this is very new in human affairs. "At the first major global environmental governance conference—the 1972 Stockholm Conference on the Human Environment—none of the major earth system challenges that we discuss today was on the agenda. And this was merely forty years ago. Hardly anybody talked then about ozone depletion, climate change, desertification, or the mass extinction of species" (Biermann 2012: 9). Given these novel circumstances, it is hardly surprising that humanity does not have institutions, much less governance structures, to effectively deal with such issues. However, as other chapters in this book suggest, such structures are now urgently necessary, and need to be formulated so that warfare is precluded as an adaptive mechanism, both because it will make other adaptations more difficult and, in the event of major weapon use, add yet further unpredictable perturbations to the earth system. In the words of the German Advisory Committee on Climate Change, a United Nations 2.0 is needed, a new structure whose purpose "... would be to take the planetary guard rails into account as a guiding principle that governs all UN actions, the pursuit of which would guarantee the protection of climate and environment in order to stabilize the Earth system as much as peace, security and development" (WGBU 2011: 316). While this remains an aspiration, the speed of current ecological changes make thinking about new habits of cooperation to deal with coming transformations a crucial part of any transition strategy.

2.5 Sustainable Transitions in a Rapidly Changing Future

Most of the ideas about mitigating climate change, the predominant emphasis in climate discussions until relatively recently, epitomized by the UNFCCC, have either implicitly or explicitly assumed that the Holocene condition is the optimal biospheric arrangement for humanity. Given the patterns of agricultural activity at the moment, taking advantage of most of the temperate humid biomes to grow crops using petroleum-powered industrial production systems is not surprising, but it is important to note that the assumption that this is how the social organization of food production ought to be, or that extensive monocultures of grain are the only way to feed humanity in the long run, are simply that: assumptions. If these systems are not optimal, then perhaps other ecological possibilities open up and new ways of feeding, fuelling, and housing humanity may be possible. Thinking in these terms makes it clear that sustainable development strategies need to operate in ways that do not foreclose such possibilities for future generations; a flexible interpretation of future needs is a crucial component of such policies.

Many of the ecological ideas that structure thinking about environmental strategies also presume some form of stability, or at least a notion of homoeostasis as the desirable state toward which policy should direct human activity. The last generation of ecological management thinking has drawn heavily on notions of resilience, as well as the frameworks of panarchy and non-linear changes (Gunderson/Holling 2001). Earlier assumptions of stable ecosystems and ecological transitions back to a climax condition following disruptions have not been entirely abandoned, but ecological thinking is now clearly much more complicated than visions built upon simplistic assumptions of a stable nature disrupted by human economic activity. Even in arguments about resilience, however, it is clear that the assumptions of stability are integral to subsequent 'bounce back' strategies after a major disruption. Policies using such thinking usually postulate a given relatively stable situation which, after facing disruption, can return to more or less the situation prior to the disruption.

However, as the growing awareness of the sheer scale of the human transformation of the biosphere becomes clear and the failure of humanity to curb the use of fossil fuels in particular ensures at least some climate change is inevitable, policy is frequently turning to questions of how to adapt to these new circumstances. In Bangladesh, where poor people are especially vulnerable to flooding and storms moving up from the Bay of Bengal, adaptation is the order of the day. Flood shelters and rebuilding coastal mangrove forests are necessary tools for dealing with rising sea levels and inundations. In such states there is limited choice in terms of policy; they have done little to cause climate change and can do little to change the global energy mix that is accelerating the process. What sustainability and the transition to it might mean in such changing circumstances suggests that the most important aspect of sustainability is the flexibility to adapt to new circumstances as they arise. How to make social systems that can change quickly without disruptions, social breakdown, or the use of organized coercion is not easy but it is key to any serious attempt to link peace with sustainability.

The clear implication to be drawn from earth system science is that such questions are in need of immediate scholarly attention. "These are admittedly huge tasks, but are vital if the goal of science and society is to steer the biosphere towards conditions we desire, rather than those that are thrust upon us unwittingly" (Barnosky/Hadly/Bascompte et al. 2012: 57). Sustainable development implies that economic transitions to modes of industrial activity that do not exceed the parameters of the conditions inherited from the Holocene are key to maintaining a relatively stable biosphere, the *sine qua non* for future generations being able to supply their own needs.

But if some of those key parameters have already been exceeded, as the discussion of planetary boundaries suggests, then what kind of transition is needed to peacefully move to what kind of future must be much more carefully deliberated. Nature can no longer be taken for granted as some sort of given context for humanity; the Anthropocene discussion makes it clear that the future of humanity and whether that future is peaceful or not depends on much more than traditional discussions of the causes of war. Now humanity it shaping its context in novel ways, and that too has to be a key part of any discussion of transitions to new modes of economy and life.

2.6 Implications for Contextualizing Sustainable Peace

Focusing on the insights of earth system science and the clear understanding that humanity is shaping the future in ways that are much more profound than has been understood until very recently requires that social scientists and policymakers interested in thinking through both strategies of sustainable development and peaceful modes of transition to more ecologically benign economic modes of human life now have to incorporate at least four key themes in their work. These are: a notion of security very different from cold war versions; a recognition that geopolitical contexts are changing; a perspective on political geoecology; and, crucially, a focus on economic production rather than just on environmental protection as key to the next phase of the Anthropocene.

2.6.1 Beyond National Security

We are currently on track for a much warmer world, one where ecological disruptions are inevitable (Anderson/Bows 2011). The potential for human conflict caused by these disruptions to undo the economic progress and improvements in human welfare made in recent generations is a key part of the logic of sustainable development spelled out in *Our Common Future*. Indeed, this is the logic that underpins the whole discussion of environmental security even if the empirical evidence on the small scale repeatedly suggests that environmental change does not directly cause violence (Theisen/Holtermann/Buhaug 2011; O'Loughlin/Witmer/Linke et al. 2012). But larger-scale ecological phase shifts might present the world system with much greater disruptions than small-scale rural displacements and agricultural failure in specific regions. Transitions to sustainability that focus on the complexity of social change in particular parts of the world are important, but how particular places play a part in shaping the overall configuration of the future matters greatly (Grin/Rotmans/Schot 2010). Planning for these in advance rather than relying on force to try to deal with some of the disruptions is now key; it requires a move towards policies for global human security.

Nonetheless, much of the recent literature that links climate change to security persists with traditional American formulations wherein instabilities in distant parts of the world are understood as potential threats, whether through terrorism or violence spilling over from conflict zones. More specifically, climate change has been formulated as a threat enhancer or 'multiplier' implying that related policies are essential in preventing future conflicts (CNA 2007; Campbell/Gulledge/McNeill et al. 2007; UN 2009). The necessity of dealing with climate change is specified as key in these formulations but what is threatening in terms of security is defined in terms of political instabilities in peripheral areas, not the disruptions caused by the global economy. Recent attempts to think through the practicalities of environmental insecurity by focusing on water and climate change suggest that structural inequalities in the global economy and political discrimination are more important immediate drivers of conflict if not interstate war (Zografos/Goulden/Kallis 2014). This key finding links back to the initial WCED (1987) formulations of sustainable development that insist that matters of equity are key to sustainable development that is peaceful.

More recently, as numerous institutions and governments start to come to terms with the fact that some climate change is inevitable, policy questions about how to adapt to changing circumstances are coming to the fore (Dalby 2013b). But now adaptations themselves are causing further environmental transformations. States are buying or leasing land in other states to ensure supplies of food in future, leading to further displacements of peoples to make way for plantations and commercial farming arrangements. These trends add to land use transformations and, in some cases, chemical pollution that put stress on existing ecosystems. Extending the modern agricultural development model that has already caused dramatic disruptions to many ecosystems may just accelerate environmental change; these systems need innovations as part of a larger effort to rethink global governance in terms of planetary boundaries (Galaz/Biermann/Crona et al. 2011). Such policies have 'back-draught' effects that need to be considered in terms of unanticipated consequences of trying to deal with climate change while ignoring other aspects of environmental change (Dabelko/Herzer/Null et al. 2013). Attempts to adapt to climate change have consequences in terms of how landscapes are remade: such changes need to be thought of in those terms if earth system analysis is to be worked into policy considerations.

2.6.2 Changing Geopolitical Contexts

This has international repercussions in terms of trade and the international flows of investment that shape how one state impacts another's ecology. All of this emphasizes decisions about what is being made, and how, rather than discussions of protecting an environment that has already been transformed many times over: this is the context for twenty-first century geopolitics. A further extension of this point is that the geopolitical rivalries of the present are frequently being played out in the arcane details of trade negotiations (Wang/Gu/Li 2012). Who will write the rules on technological standards related to new generations of energy technologies now matters, and here the mostly neglected dimension of geopolitics in discussions of sustainable transitions needs to be engaged directly (Markand/Raven/Truffer 2012). How what gets produced in future will also quite literally shape the planetary ecology of the future.

Understanding that geopolitics is no longer a simple matter of military rivalry but a matter of shaping the technological future to the short-term advantage of the rule-writers–with long term implications for how the biosphere is shaped–is crucial to linking earth system thinking to matters of geopolitics. This becomes even more important where discussions of possible geoengineering experiments enter the discussion (Galaz 2012; Luke 2010; Humphreys 2011) as a contribution to attempts to keep the planet's climate within a safe operating space. The related point is that environmental changes have already transformed the terrain of great power rivalry; nineteenth-century assumptions about the given context of politics are no longer tenable premises for serious political discussion (Hommel/Murphy 2013).

2.6.3 The Perspective of Political Geoecology

Thinking about the point that nature is no longer the given context for humanity in terms of international peace and security requires a very different approach from that of traditional geopolitics, with its attendant focus on territorial states and their rivalries as key to war and peace. Thinking in terms of a 'political geoecology' of human actions at the global scale shaping the future global context, rather than taking it for granted, is now key to any notion of a sustainable peace if serious consideration is to be given to ensuring that climate and other ecological disruptions do not trigger violent policy responses (Brauch/Dalby/Oswald Spring 2011). A geopolitical imagination of competing territorial states as what is most important in human affairs is simply out of date as the premise for either policy prescription or academic analysis. While states may still write many of the rules for international trade, and as such are still a key institution in shaping the future, understanding geopolitics in these terms is now much more important than traditional discussions of elite military rivalries and struggles to dominate the planet.

While technical details of trade arrangements may be important in the shaping of the future, so too are the cities and towns in which the majority of us now live. The Anthropocene has also been about the urbanization of humanity and the construction of increasingly large artificial environments of concrete and asphalt. The commodities and resources that are extracted often at great distance in rural hinterlands supply these consumption spaces, spaces that also function as centres of political innovation in many ways (Magnusson 2011). How cities are rebuilt and governed to simultaneously reduce their carbon footprint and make them less vulnerable to extreme events will matter greatly in coming decades. But as Naomi Klein (2014) has ruefully noted, thinking about practical ways to green cities and building sensible public transit systems, communal green spaces, and local food systems has not been a priority among many political movements. If members of such movements and communities were thinking seriously about the artificial landscapes of the present, these considerations should certainly be prioritized.

Even more important is to think about how suburban sprawl, which is so dependent on automobiles and uses large amounts of energy very inefficiently, can be reworked with ecological principles in mind. Likewise, informal solutions to the huge challenges of urbanization in the global South that take ecological issues seriously also present possibilities for adaptation that improve the lot of residents of the new cities there (Robertson 2012). All of this urbanization is dependent on the integration of the global economy which is in turn shaping the life chances of people in the new cities of our time, and hence producing new geopolitical circumstances that make old imperial struggles to gain colonies or zero sum games to directly control agricultural territories increasingly anachronistic. Struggles over economic activity are now shaping national policies as well as city strategies; the task for a political geoecology is think through these interconnections as they shape the increasingly artificial habitats of the future.

2.6.4 Producing the Anthropocene

Thinking in these terms makes it clear that production—quite literally *what* humanity is making—is a key consideration in understanding and constructing our future; getting that clearly in focus is integral to a sustainable transition (Harris 2012). The Anthropocene will be shaped by decisions taken both by community planners and executives in boardrooms who decide which commodities will be made and how they will be produced. It makes a big difference if new electrical systems are powered by solar panels or coal-burning power stations. If automobile manufacturers stop making gasoline-powered cars in favour of other propulsion systems, this too will have all sorts of ramifications for climate and other ecological changes. Global cooperation on such matters is a key component for transitions to sustainability.

In part, this point also relates to where they are produced. Territorial strategies to 'green' some societies by outsourcing the production of energy- and pollution-intensive industries to less regulated societies, an accusation frequently levelled at European states, do not solve problems when viewed in earth system terms. Authority over ecological processes necessitates deeper action than state territorial strategies of rule, especially when territorial arrangements for such policies as emissions trading quotas and ecological offsets are involved. Outsourcing pollution may satisfy some limited state-based counting methods, but it is not an ecologically sensible strategy if more than short term geographically-specific spaces are considered. This new geography of connection in the increasingly globalized economy, and the possibilities of commodity chain governance also suggest that the traditional assumptions of state-based national security are insufficient frameworks for governance in the next phase of the Anthropocene.

All of which becomes ever more pressingly urgent if the earth system discussion is engaged precisely because assumptions of a stable ecological context for humanity can no longer be taken for granted. Peace is a condition to be struggled for but the struggle will be carried out in future in ecological and social conditions that are rapidly changing. Any strategy of transition from present consumption-based extractive modes of economy to ones that can be sustained in the long run have to recognize that this transition will happen against the backdrop of dramatic ecological change. Strategies that link development and sustainability now have to factor in the possibilities of ecological phase shifts if the earth system boundaries are further transgressed in the next few decades. This makes planning more difficult, but also emphasizes the fact that humanity is making the future of the planetary system as well as its own economic and social future. They are but two sides of the same coin, a matter requiring a transition to new ways of thinking about economics and politics if peaceful human societies are to be created as the next phase of the Anthropocene.

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