Available online at www.sciencedirect.com

SciVerse ScienceDirect

Current Opinion in Environmental Sustainability

Planetary boundaries, equity and global sustainability: why wealthy countries could benefit from more equity

Will Steffen[1,2] and Mark Stafford Smith[3]

The planetary boundaries concept, which aims to define a safe operating space for humanity within the dynamics of the Earth System, has often been criticised on the basis of a presumed conflict between global equity and environmental sustainability goals. However, a re-analysis of the equity–environmental sustainability relationship suggests that significant synergies can be developed to build a more unified approach for working towards global sustainability. The synergies are especially strong for those planetary boundaries based on processes that are aggregated from very heterogeneous distributions at sub-global levels. It is possible to address the biophysical aspects of these boundaries from an Earth System perspective in ways that often may be, and sometimes must be, compatible with enhancing many aspects of social equity. Furthermore, it may well be in the self-interest of wealthy nations to achieve a more spatially equitable world in terms of access to resources and ecosystem services. Combining social equity considerations with the biophysical planetary boundaries approach may therefore constitute a necessary, and perhaps even sufficient, condition for achieving global sustainability.

Addresses
[1] Stockholm Resilience Centre, Stockholm University, Sweden
[2] Fenner School of Environment and Society, The Australian National University, Canberra, Australia
[3] CSIRO Climate Adaptation Flagship, Canberra, Australia

Corresponding author: Steffen, Will (will.steffen@anu.edu.au)

Current Opinion in Environmental Sustainability 2013, **5**:403–408

This review comes from a themed issue on **Open issue**

Edited by **Rik Leemans** and **William Solecki**

For a complete overview see the Issue and the Editorial

Available online 7th May 2013

1877-3435/$ – see front matter,

http://dx.doi.org/10.1016/j.cosust.2013.04.007

Introduction

The quest for sustainability at the global level [1] is often undermined politically by a presumed conflict between global equity and environmental sustainability goals. This presumption triggers negative reactions from both developing and developed countries, for different reasons. Developing countries perceive that global-level environmental goals proposed by developed countries may constrain development designed to reduce poverty [2]. Meanwhile, developed countries suspect that more equity in resource access in a world with finite resources means that they must give up some of the material wealth that they enjoy today [e.g. 3].

This tension over equity has plagued climate change negotiations for many years [4]. The concept of planetary boundaries [5,6•], introduced as a necessary condition for humanity to achieve global sustainability more generally, has met a similar reaction in the international policy community, as witnessed by one of us (MSS) in international forums.[4] However, here we argue that it is *in the self-interest of the wealthy nations* to take steps to reduce the difference in per capita resource use between themselves and developing countries as a critical step towards global sustainability that would enhance human well-being in both types of countries. However, we also note that there are many institutional and governance challenges in taking these steps.

To make this case, it is important to be clear about an understanding of 'human well-being'. We use the term here in a broad sense, to encompass both individual and societal levels, and both material and non-material aspects of well-being; such a definition has been well-canvassed [e.g. 7,8,9••] and is potentially measurable [10]. It is widely accepted that aspects of well-being do not have a simple linear relationship to income and consumption [e.g. 11]. An inclusive approach thus contrasts with narrower conceptualisations based on Gross Domestic Product (a measure of flow rather than capital), consumption or even the Human Development Index [12]. Importantly, a more inclusive approach provides an opportunity to view the debate over equity and planetary boundaries in a different light, from which, we suggest, new solutions may arise. When we are talking of narrower elements of human well-being, we will name them as such (e.g. material or social well-being).

Planetary boundaries and social equity

Our proposal is derived from a convergence of two lines of argument, one based on the global environmental approach of the planetary boundaries concept and the

[4] For example, at the meeting of the Global Sustainability Panel's sherpas in Madrid, April 2011, African and Caribbean delegates expressed the strong view that planetary boundaries might limit basic development, while developed countries such as Australia were wary that they might limit economic growth.

other based on the socio-economic imperative to improve human well-being in developing countries. That is, we posit that the coupling of social equity considerations (SE) regarding access to resources and ecosystem services to the biophysically oriented planetary boundaries (PB) builds a synergistic, powerful basis for working towards global sustainability (GS):

$$PB + SE \rightarrow GS$$

The planetary boundaries concept is based on the normative judgement that a Holocene-like state of the Earth System should be preserved because it is the only one that we know for certain can support complex human societies. The boundaries are based on the intrinsic, biophysical characteristics of the Earth System, and are designed to keep the Earth System within a Holocene-like state, that is, to provide a 'safe operating space' for humanity [5,6•]. Raworth [13••] has argued that integrating social equity considerations with the planetary boundaries approach would create a 'safe *and just* (operating) space for humanity'. Integrated approaches of this nature are required to create truly comprehensive Sustainable Development Goals [14,15].

Dealing with spatially heterogeneous planetary boundaries

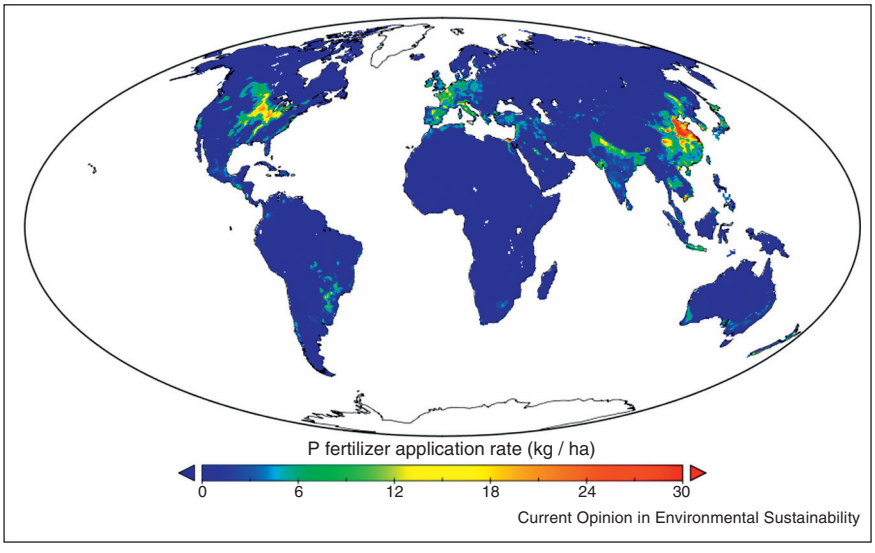
Some of the planetary boundaries, such as that for climate change, are based on globally well-mixed characteristics of the Earth System like greenhouse gases in the atmosphere. Many other boundaries, on the other hand, are linked to Earth System processes or characteristics that are not globally well-mixed but instead aggregated from very heterogeneous distributions at sub-global levels (Figure 4 in [6•]). These aggregated processes have triggered questions about the policy relevance of the planetary boundaries concept [e.g. 16]. Examples include land system change, the nitrogen and phosphorus cycles, aerosol loading and biodiversity.

It matters for Earth System functioning whether changes to processes associated with aggregated boundaries are concentrated in just a few areas or spread more evenly around the globe [e.g. 17•,18–20]. For example, significant deforestation of the Amazon Basin or a shift in the South Asian monsoon caused by a change in regional aerosol loading would affect climate elsewhere around the planet via atmospheric teleconnections. Thus, specifying the boundary for aggregated processes depends both on the spatial distribution of resource use and on the global total, the latter having been the focus of the initial analysis [5,6•].

This distributional dimension of aggregated planetary boundaries has evident implications for the socio-economic imperative to improve human well-being in developing countries. Carpenter and Bennett's analysis of the proposed phosphorus (P) cycle boundary provides a good example [17•]. A redistribution of phosphorus from high-P to low-P regions (Figure 1, [21,22]) would not only lower the risk of a major anoxic event in coastal seas adjacent to high-P regions and thus address the P planetary boundary but could also reduce eutrophication of freshwater systems, a local and regional pollution problem [17•].

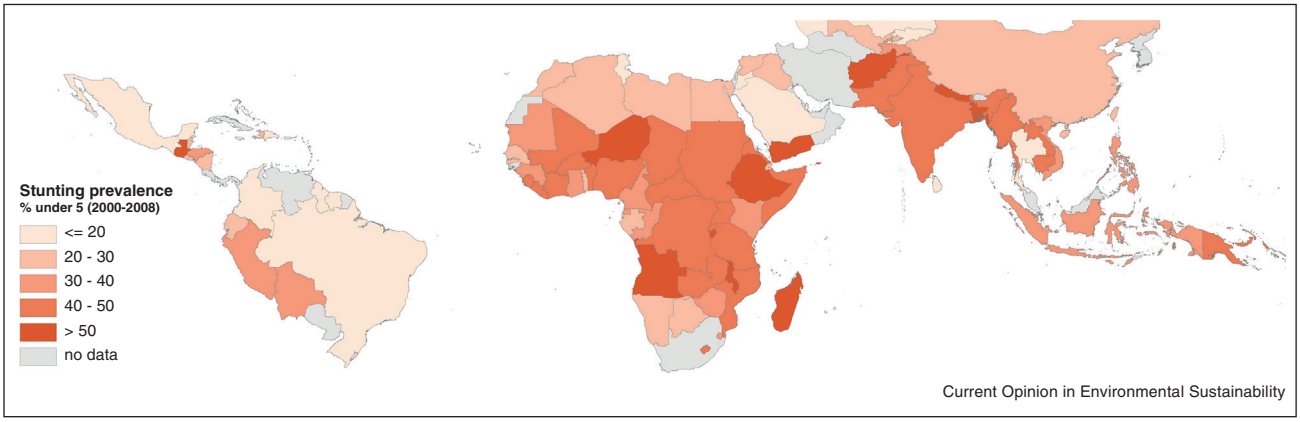
From a socioeconomic perspective, such a redistribution of phosphorus could help to improve agricultural productivity and food security in low-P areas of the world (Figure 2, [23]). Thus, there are spatial redistributions of global phosphorus use that would simultaneously address

Figure 1



Global map of P fertiliser application rates (kg ha^{-1} over grid cell area). Values represent average over all crops across each 0.5° resolution in latitude × longitude grid cell [21].

Figure 2



Countries experiencing chronic food insecurity, estimated using the prevalence of stunting in children under five years of age as an indicator. Note the general relationship to areas of low-P application in Figure 1, with some exceptions (e.g. India) since P application per unit area is also affected by population. Other factors in addition to food production such as institutional, economic and political constraints, contribute to food insecurity. Adapted from [23]. Prevalence of child malnutrition is the percentage of children under 5 whose height for age is more than two standard deviations below the median for the international reference population — known as stunting (ages 0–59 months). For children up to two years old height is measured by recumbent length, and for older children height is measured by stature while standing. The data are based on the World Health Organization's new child growth standards released in 2006 and downloaded from the World Development Indicators database.

the P planetary boundary and enhance human well-being in the developing world by requiring the transfer of critical resources from areas where they are in excess to those where they are most needed. This planetary boundary could be addressed without considering equity, but combining both purposes permits a synergistic ('win-win') outcome.

Table 1 shows a preliminary analysis of some similar issues for other aggregated planetary boundaries. In each case, a strong regional–global biophysical linkage is likely, implying that dealing with the regional-level, distributional aspects of each of these planetary boundaries is necessary to stay within the global boundary. In the case of aerosols and chemical pollution, the distributional aspect relates to the earlier relocation of polluting industries to countries or regions with less stringent environmental controls. As the table shows, addressing the biophysical aspects of aggregated planetary boundaries at sub-global levels can be compatible with enhancing various aspects of social equity such as improved access to resources and ecosystem services in the developing world. Of course, there are many equity issues with achieving the well-mixed boundaries too, but our focus here is on the necessity for the aggregated boundaries to take account of spatial distributions, so that humanity can choose to do this in ways that enhance equity, or not. In addition, many of these proposed actions to achieve more equity in the distribution of resources and ecosystem services are consistent with a wide range of proposals under the broad umbrella of 'green growth', 'green development' or a 'green economy' [9••,24–25].

Achieving greater equity in income and resource distribution

However, achieving such a redistribution of resources or ecosystem services in today's globalised, market-based economy is not easy. It would require greater equity in income distribution between the developed and developing countries, a transformation that is often resisted by developed countries concerned for economic growth, as noted above. Underlying this resistance is the general conflation of human well-being with economic activity (and consumption) as measured by GDP [9••]. Given this assumption, greater equity in income distribution and, by implication, resource consumption in a world with finite resources would necessarily require that the developed world must accept lower levels of *material* well-being [9••]. In the past, the case for greater equity has rested largely on the moral argument of the right to development by poorer countries, but we suggest there are new, additional reasons.

There is a growing body of empirical research at national and sub-national levels showing that greater equality in income can lead to the enhancement of many aspects of individual and social well-being [e.g. 26••,27], including life expectancy, homicide rates, obesity, education outcomes, teenage births, imprisonment rates, mental illness and levels of trust. Wilkinson and Pickett [26••] show that these relationships are generally stronger at national than at sub-national than at local levels, and are likely to be based on deep human responses to social stratification and status competition, underpinned by societal differences in material inequality. Although much of the research is based on developed countries, there is also increasing

Table 1

A preliminary analysis of how spatial social equity considerations might be included in the management strategy for various planetary boundaries. For each boundary (column 1) that has a regional expression with global significance (column 2) we identify at least one aspect of its management which *requires* a consideration of spatial distribution (column 3) and note how this could also contribute to social equity (column 4)

Planetary boundary	Regional impacts with global implications if boundary is transgressed	Managing the boundary's control variable through distribution of technology, resources and ecosystem services	Synergistic effects that can reduce social inequities between and within countries
Phosphorus/ nitrogen cycles	Widespread eutrophication of freshwater and coastal seas → freshwater PB → changes in global hydrological cycle [17•,37]	Redistribution of P and N application around the world to reduce eutrophication while maintaining or enhancing total agricultural productivity	Increase in regional food security, especially in nutrient-poor regions
Land system change	Deforestation of the Amazon basin, with teleconnections to global climate [18,19]	International community paying fully for global-scale ecosystem services	Increased income flows into regional economies dependent on natural resources
Aerosols	Aerosol loading over Indian sub-continent that triggers flip of Indian monsoon and influences Asian monsoon circulation [20,38]	Technology transfer to reduce aerosol emissions from industry, transport and cooking (e.g. deliver universal local energy sources for cooking)	New industries and economic development; improved health; more time for education and social participation by women
Freshwater	Human diversion of water vapour (green water) flows, disrupting climate regulation [39,40] and liquid (blue) water flows, inducing collapse of aquatic ecosystems [41]	Transfer of water management expertise and technology to reduce water demand and improve water quality; globalised economy paying fully for ecosystem services (e.g. reduced deforestation)	Improved health outcomes from better water quality; increase in regional food security via more reliable water resources; increased income flows into regional economies
Chemical pollution	Levels of pollutants (especially POPs) that damage health or disrupt ecosystem functioning over large areas [42,43]	Technology transfer to reduce chemical pollution	Increased health and social equity; enhanced provision of ecosystem services
Biodiversity	Loss of diversity at continental/ocean basin scales at levels that disrupt important ecosystem services (e.g. N/P cycling) or reduce resilience of major ecosystems (e.g. tropical forests) towards disturbance [44]. There is also evidence for a single, global-scale tipping point for biodiversity [45]	Globalised economy to pay fully for ecosystem services; direct actions that enhance biodiversity conservation	Increased income flows into developing countries; new industries built around tourism and conservation

evidence for the same patterns in developing countries [27]. Importantly, this work shows that greater income equality is not only beneficial to society as a whole but is *also in the self-interest of the wealthy themselves*; that is, the wealthy in more unequal nations have poorer social outcomes than the wealthy in more equal nations [26••], even though the latter may possess less absolute wealth than the former.

Is this true also among nations at the global level? We suggest that there may be two reasons to think that a similar conclusion can be drawn at the global scale, one more speculative than the other. First, there are strong reasons to expect that failing to stay within the 'safe operating space' of the planetary boundaries will be at least as deleterious for developed as for developing nations; populations in developing nations may well be more vulnerable to the direct effects of climate change than those of developed countries, but the total economic, institutional and social disruption wrought by events such as Hurricane Sandy on New York may well highlight the loss of resilience in very complex, contemporary societies [28]. Similarly, reductions in regional tensions over scarce resources could benefit developed as much as developing nations.

Second, and more speculatively, we suggest that the relationship between the extent of income inequality and individual and societal well-being that has been observed at the sub-national and national levels may well be an emerging property at the global level too, as economic, financial, social and cultural integration continues to increase, and as globalised media allow the same human responses to social stratification to play out more universally. This hypothesis implies that reducing income inequality between countries, not only within countries, would produce enhanced social well-being in both the wealthy and the developing countries, for

both biophysical and social reasons. That is, *it would be in the social self-interest of wealthy countries to reduce the income inequality between themselves and developing countries*.

Towards global sustainability

By contrast, the dominant paradigm at present to reduce economic inequality is to raise incomes, consumption patterns and technological development of all people in all countries towards levels currently enjoyed by most people in North America, Europe or Australasia. Such an approach, using existing technologies, would clearly transgress most or all of the planetary boundaries and push the Earth System well outside the Holocene state [29]. This would move humanity away from global environmental sustainability and social well-being even if it achieves an increase in incomes in developing countries; and this increase is likely to be transient if the result is to transgress critical planetary boundaries.

We emphasise that we are not suggesting that respecting the planetary boundaries must *necessarily* improve human well-being (nor vice versa); rather, that there are significant synergies to be had between these goals if both are tackled simultaneously, particularly with regard to those planetary boundaries that are not well-mixed (i.e. most of them). Of course, whether these goals can be achieved simultaneously depends on several other critical factors, including the effectiveness of governance systems from local to global levels, the fairness of market mechanisms in the globalised economy and appropriate formulation of local property rights [e.g. 30–32]. The economic and political mechanisms used to implement redistribution of resources or protection of critical biomes are also very important. These could include technology transfer approaches [e.g. 33], taxes on resource use in wealthy countries coupled with appropriate investments in developing countries [e.g. 34], payments for ecosystem services such as forest protection [e.g. 35], or global trust funds [e.g. 36]. Whatever mechanisms are adopted, the fundamental point we make here is that it is likely to be in the self-interest of the wealthy nations to achieve a more spatially equitable world in terms of incomes and resource use.

Thus, while the original planetary boundary analysis [5,6•] did not consider how inequitable the world might be while humanity sought to maintain the Earth System in a Holocene-like state, our hypothesis suggests that combining social equity considerations with the management of the biophysical planetary boundaries may constitute a necessary — and perhaps even sufficient — condition for achieving global sustainability, and is thus crucial for the development of new, truly integrated and universal Sustainable Development Goals [14,15].

Acknowledgements

The authors are grateful to Kate Raworth, Sarah Cornell and Victor Galaz for helpful comments on earlier versions of the manuscript, and to three insightful journal reviewers for their constructive critique.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Reid W, Chen VC, Goldfarb L, Hackmann H, Lee YT, Mokhele K, Ostrom E, Raivio K *et al.*: **Earth system science for global sustainability: grand challenges**. *Science* 2010, **330**:916-917.

2. Najam A: **The view from the South: developing countries in global environmental politics**. In *The Global Environment: Institutions, Law and Policy*. Edited by Axelrod RS, Downie DL, Vig NJ. Washington, DC: CQ Press; 2004:225-243.

3. Grundig F: **Patterns of international cooperation and the explanatory power of relative gains: an analysis of cooperation on global climate change, ozone depletion, and international trade**. *Int Stud Q* 2006, **50**:781-801.

4. Richardson K, Steffen W, Liverman D, Barker T, Jotzo F, Kammen D, Leemans R, Lenton T, Munasinghe M, Osman-Elasha B *et al.*: *Climate Change: Global Risks, Challenges and Decisions*. Cambridge: Cambridge University Press; 2011, 502:. (see Chapter 9: The equity challenge and climate policy: responsibilities, vulnerabilities and inequality in the response to climate change, 229–259).

5. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, Lambin EF, Lenton TM, Scheffer M, Folke C *et al.*: **A safe operating space for humanity**. *Nature* 2009, **461**:472-475.

6. • Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, Lambin EF, Lenton TM, Scheffer M, Folke C *et al.*: **Planetary boundaries: exploring the safe operating space for humanity**. *Ecol Soc* 2009, **14**:32. (online) *http://www.ecologyandsociety.org/vol14/iss2/art32/*.
This paper provides the detailed, fundamental conceptual framework for the planetary boundaries approach and makes an initial quantification for seven of the nine boundaries.

7. Rogers DS, Duraiappah AK, Antons DC, Munoz P, Bai X, Fragkias M, Gutscher H: **A vision for human well-being: transition to social sustainability**. *Curr Opin Environ Sustain* 2012, **4**:61-73.

8. Nussbaum MC: *Creating Capabilities: The Human Development Approach*. Cambridge, MA, USA: Harvard University Press; 2011, .

9. •• Kosoy N, Brown PG, Bosselmann K, Duraiappah A, Mackey B, Martinez-Alier J, Rogers D, Thomson R: **Pillars for a flourishing Earth: planetary boundaries, economic growth delusion and green economy**. *Curr Opin Environ Sustain* 2012, **4**:74-79.
This paper challenges the usefulness of GDP and simple economic growth as an adequate indicator of human well-being in the context of planetary boundaries.

10. Arrow KJ, Dasgupta P, Goulder LH, Mumford KJ, Oleson K: **Sustainability and the measurement of wealth**. *Environ Dev Econ* 2012, **17**:317-353.

11. Kahneman D, Deaton A: **High income improves evaluation of life but not emotional well-being**. *Proc Natl Acad Sci U S A* 2010, **107**:16489-16493.

12. Duraiappah AK, Munoz P: **Inclusive wealth: a tool for the United Nations**. *Environ Dev Econ* 2012, **17**:362-367.

13. •• Raworth K: **A safe and just space for humanity. Can we live within the doughnut?** Oxfam Discussion Paper. Oxford, UK: Oxfam; 2012
This paper provides an overarching framework for global sustainability by combining the planetary boundaries framework with a set of social justice goals required to ensure an adequate level of well-being for all humans, hence framing a safe and just operating space.

14. United Nations: *The Future We Want: Outcome Document from Rio+20 United Nations Conference on Sustainable Development*. New York: United Nations; 2012, http://www.un.org/en/sustainablefuture/.

15. Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I: **Sustainable development goals for people and planet**. *Nature* 2013, **495**:305-307.

16. Lewis SL: **We must set planetary boundaries wisely**. *Nature* 2012, **485**:417.

17. • Carpenter SR, Bennett EM: **Reconsideration of the planetary boundary for phosphorus**. *Environ Res Lett* 2011, **6** http://dx.doi.org/10.1088/1748-9326/6/1/014009.
This analysis introduces the idea that a regional-level redistribution of a resource such as phosphorus can address both local and regional pollution problems and re-define the planetary boundary for phosphorus in a synergistic way.

18. Snyder PK, Delire C, Foley JA: **Evaluating the influence of different vegetation biomes on the global climate**. *Clim Dyn* 2004, **23**:279-302.

19. Snyder PK, Foley JA, Hitchman MH, Delire C: **Analyzing the effects of complete tropical forest removal on the regional climate using a detailed three-dimensional energy budget: an application to Africa**. *J Geophys Res Atmos* 2004, **109**:D21.

20. Zickfeld K, Knopf B, Petoukhov V, Schellnhuber HJ: **Is the Indian summer monsoon stable against global change?** *Geophys Res Lett* 2005, **32**:L15707.

21. Potter P, Ramankutty N, Bennett E, Donner SD: **Characterizing the spatial patterns of global fertilizer application and manure production**. *Earth Interact* 2010, **14** http://dx.doi.org/10.1175/2009EI288.1 (online).

22. MacDonald GK, Bennett EM, Potter PA, Ramankutty N: **Agronomic phosphorus imbalances across the world's croplands**. *Proc Natl Acad Sci U S A* 2011 www.pnas.org/cgi/doi/10.1073/pnas.1010808108.

23. Ericksen P, Thornton P, Notenbaert A, Cramer L, Jones P, Herrero M: **Mapping hotspots of climate change and food insecurity in the global tropics**. Climate Change, Agriculture and Food Security (CCAFS) Report No. 5 (http://2011ccafs.cgiar.org/resources/climate_hotspots).

24. OECD (Organization for Economic Cooperation Development): *Towards Green Growth*. Paris: OECD; 2011, 142.

25. Bowen A, Fankhauser S: **The green growth narrative: paradigm shift or just spin?** *Global Environ Change* 2011, **21**:1157-1159 In: *http://www.sciencedirect.com/science/article/pii/S0959378011001129*.

26. •• Wilkinson RG, Pickett KE: **Income inequality and social dysfunction**. *Annu Rev Sociol* 2009, **35**:493-511.
This paper describes the ground-breaking empirical research that links income inequality to social outcomes at the national level. Note that there is a rapidly expanding literature that is testing these findings, and generally supporting but elaborating them.

27. de Maio F: **Advancing the income inequality — health hypothesis**. *Crit Public Health* 2012, **22**:39-46.

28. Tainter J: *The Collapse of Complex Societies*. Cambridge: Cambridge University Press; 1998, .

29. Steffen W, Persson Å, Deutsch L, Zalasiewicz J, Williams M, Richardson K, Crumley C, Crutzen P, Folke C, Gordon L *et al.*: **The Anthropocene: from global change to planetary stewardship**. *Ambio* 2011 http://dx.doi.org/10.1007/s13280-011-0185-x.

30. Biermann F, Abbott K, Andresen S, Backstrand K, Bernstein S, Betsill MM, Bulkeley H, Cashore B, Clapp J, Folke C *et al.*: **Transforming governance and institutions for global sustainability: key insights from the Earth System Governance Project**. *Curr Opin Environ Sustain* 2012, **4**:51-60.

31. Kinzig AP, Perrings C, Chapin FS, Polasky S, Smith VK, Tilman D, Turner BL: **Paying for ecosystem services: promise and peril**. *Science* 2011, **334**:603-604.

32. Ostrom E: **Polycentric systems for coping with collective action and global environmental change**. *Global Environ Change Hum Policy Dimens* 2010, **20**:550-557.

33. Dixon RK: **Global Environment Facility investments in the phase-out of ozone-depleting substances**. *Mitig Adapt Strateg Global Change* 2011, **16**:567-584.

34. Hof AF, den Elzen MGJ, Beltran AM: **Predictability, equitability and adequacy of post-2012 international climate financing proposals**. *Environ Sci Policy* 2011, **14**:615-627.

35. Seymour F: **REDD (Reducing Emissions from Deforestation and Forest Degradation) and equity: realising synergies and managing trade-offs**. In *Climate Change: Global Risks, Challenges and Decisions.* Edited by Richardson K, Steffen W, Liverman D. Cambridge: Cambridge University Press; 2011238-239.

36. Barnes P, Costanza R, Hawken P, Orr D, Ostrom E, Umaña A, Young O: **Creating an earth atmospheric trust**. *Science* 2008, **319**:724.

37. Seitzinger SP, Mayorga E, Bouwman AF, Kroeze C, Beusen AHW, Billen G, Van Drecht G, Dumont E, Fekete BM, Garnier J, Harrison JA: **Global river nutrient export: a scenario analysis of past and future trends**. *Global Biogeochem Cycles* 2010, **24**:GB0A08 http://dx.doi.org/10.1029/2009GB003587.

38. Lau KM, Ramanathan V, Wu G-X, Li Z, Tsay SC, Hsu C, Sikka R, Holben B, Lu D, Tartari G *et al.*: **The joint aerosol-monsoon experiment: a new challenge for monsoon climate research**. *Bull Am Met Soc* 2008, **89**:369 http://dx.doi.org/10.1175/BAMS-89-3-369.

39. Oyama MD, Nobre CA: **A new climate–vegetation equilibrium state for tropical South America**. *Geophy Res Lett* 2003, **30**:2199 http://dx.doi.org/10.1029/2003GL018600.

40. Rockström J, Gordon L, Falkenmark M, Folke C, Engvall M: **Linkages among water vapor flows, food production, and terrestrial ecosystem services**. *Conserv Ecol* 1999, **3**:5 In: *http://www.consecol.org/vol3/iss2/art5*.

41. Smakhtin V: **Basin closure and environmental flow requirements**. *Int J Water Res Dev* 2008, **24**:227-233.

42. Jenssen BM: **Endocrine-disrupting chemicals and climate change: a worst-case combination for Arctic marine mammals and seabirds?** *Environ Health Perspect* 2006, **114**:76-80.

43. Noyes PD, McElwee MK, Miller HD, Clark BW, Van Tiem LA, Walcott KC, Erwin KN, Levin ED: **The toxicology of climate change: environmental contaminants in a warming world**. *Environ Int* 2009, **35**:971-986 http://dx.doi.org/10.1016/j.envint.2009.02.006.

44. Leadley P, Pereira HM, Alkemade R, Fernandez-Manjarrés JF, Proença V, Scharlemann JPW, Walpole MJ: **Biodiversity scenarios: projections of 21st century change in biodiversity and associated ecosystem services**. Technical Report for the Global Biodiversity Outlook 3 (CBD Technical Series No. 50). Montreal: Secretariat of the Convention on Biological Diversity; 2011 (http://www.cbd.int/ts/).

45. Barnosky AD, Hadly EA, Bascompte J, Berlow EL, Brown JH, Fortelius M, Getz WM, Harte J, Hastings A, Marquet PA *et al.*: **Approaching a state shift in Earth's biosphere**. *Nature* 2012, **486**:52-58.